Avian Predation Annotated Bibliography

Aarestrup, K., Nielsen, C., & Madsen, S. S. (2000). Relationship between gill Na+,K+-ATPase activity and downstream movement in domesticated and first-generation offspring of wild anadromous brown trout (Salmo trutta). *Canadian Journal of Fisheries and Aquatic Sciences*, *57*(10), 2086–2095. https://doi.org/10.1139/f00-164

The relationship between smolt status and downstream movement following release was investigated in two stocks of hatchery-reared anadromous brown trout (Salmo trutta). Yearlings from a domesticated stock (DS) and first-generation offspring (F1) of wild anadromous trout were held under identical conditions from August 1997 until the following spring, where they developed smolt characteristics as judged from increasing gill Na+,K+-ATPase activity. Presmolts (low Na+,K+-ATPase activity), smolts (high Na+,K+-ATPase activity), and desmolts (regressed Na+,K+-ATPase activity) were released on three occasions into the River Salten. Using both dye-marked and radiotagged fish, downstream movement was monitored by either trapping 3 km downstream (dye-marked fish) or radiotracking on a daily basis. The experiments showed a positive correlation between smolt status (gill Na+,K+-ATPase activity) and downstream movement. Gill Na+,K+-ATPase activity may therefore be used as an indicator of migratory readiness in brown trout. F1 and DS trout had the highest migration frequency when released as presmolts and smolts, respectively. Despite smaller size, F1 trout had similar or better survival than DS trout after release. Our data suggest that initiation of downstream movement is influenced by an interaction between the previous physiological development of the fish and a discrete level of water discharge or water temperature.

Ackerman, S. M. (1997). Update: American white pelican colony. *WOS News*, *51*. http://www.wos.org/documents/wosnws/issue51.pdf

In late April 1997, a pelican colony was in full swing on Badger Island. On August 1, 65 immatures were seen along its shoreline.

Adkins, J. Y., Lyons, D. E., Loschl, P. J., Roby, D. D., Collis, K., Evans, A. F., & Hostetter, N. J. (2014). Demographics of Piscivorous Colonial Waterbirds and Management Implications for ESA-listed Salmonids on the Columbia Plateau. *Northwest Science*, *88*(4), 344–359. https://doi.org/10.3955/046.088.0408

We investigated colony size, productivity, and limiting factors for five piscivorous waterbird species nesting at 18 locations on the Columbia Plateau (Washington) during 2004–2010 with emphasis on species with a history of salmonid (Oncorhynchus spp.) depredation. Numbers of nesting Caspian terns (Hydroprogne caspia) and double-crested cormorants (Phalacrocorax auritus) were stable at about 700–1,000 breeding pairs at five colonies and about 1,200–1,500 breeding pairs at four colonies, respectively. Numbers of American white pelicans (Pelecanus erythrorhynchos) increased at Badger Island, the sole breeding colony for the species on the Columbia Plateau, from about 900 individuals in 2007 to over 2,000 individuals in 2010. Overall numbers of breeding California gulls (Larus californicus) and ring-billed gulls (L. delawarensis) declined during the study, mostly because of the abandonment of a large colony in the mid-Columbia River. Three gull colonies below the confluence of the Snake and Columbia rivers increased substantially, however. Factors that may limit colony size and productivity for piscivorous waterbirds nesting on the Columbia Plateau included availability of suitable nesting habitat, interspecific competition for nest sites, predation, gull kleptoparasitism, food availability, and human disturbance. Based on observed population trends alone, there is little reason to project increased impacts to juvenile salmonid survival from tern and cormorant populations. Additional monitoring and evaluation may be warranted to assess future impacts of the growing Badger Island American white pelican colony and those gull colonies located near mainstem dams or associated with Caspian tern colonies where kleptoparasitism is common.

Adkins, J. Y., & Roby, D. D. (2010). *A status assessment of the double-crested cormorant (Phalacrocorax auritus) in western North America: 1998-2009* (p. 69). http://www.birdresearchnw.org/Final_Report_Adkins_et_al_2010_DCCO_StatusAssessment.pdf

The first assessment of population size for double-crested cormorants (Phalacrocorax auritus) along the Pacific coast of North America summarized data collected prior to 1993 in British Columbia, Washington, Oregon, California, and northwestern Mexico, as well as examining historical trends and conservation issues (Carter et al. 1995). More recent status assessments have been completed for sub-populations in California (Capitolo et al. 2004, Shuford 2010) and in British Columbia (Moul and Gebauer 2002). The breeding distribution of this population has changed dramatically over the past 50 years, with increases at some known colonies and formation of many new colonies; the largest increase has been in the Columbia River estuary, where the number of breeding pairs grew from 6,620 in 1992 to 14,032 in 2007. Fisheries managers have raised concerns over the impact of predation by cormorants from this large breeding assemblage on survival of out-migrating juvenile salmonids (Oncorhynchus spp.) from throughout the Columbia Basin, especially those evolutionarily significant units (ESUs) of salmonids that are listed under the U.S. Endangered Species Act. The geographic area included in this updated status assessment of the Western Population of double-crested cormorants extends from the Pacific Coast east to the Continental Divide, north into southern British Columbia (following the breeding range of the species), and south to the international border with Mexico. The current size of the entire western breeding population is estimated to be about 29,240 breeding pairs. The estimate for the current breeding population in British Columbia, Washington, Oregon, and California, which support the great majority of the Western Population, is approximately 26,390 breeding pairs. This represents an increase of nearly 10,000 breeding pairs (ca. 60% increase) since 1987-1992 (Carter et al. 1995, Moul and Gebauer 2002). Based on the best available data for the three Pacific coastal states and British Columbia during the periods ca. 1992 (Carter et al. 1995, Moul and Gebauer 2002) and ca. 2009, our best estimate of the average annual population growth rate (λ) for this population is 1.03, indicating that the population has grown at an average annual rate of about 3% per year over the last two decades. This overall trend apparently reflects continued recovery of the Western Population due to various statutory and ecological factors during the latter half of the 20th Century, including inclusion of the species in the Migratory Bird Treaty Act, the banning of DDT, and the shift by the species toward increased use of artificial nesting habitats. Most of this population increase, however, can be attributed to increases in the numbers of breeding pairs in the Columbia River estuary and at a few inland sites, which currently account for approximately 41% and 29% of breeding pairs in the Western Population, respectively. Concurrently, numbers of breeding pairs in coastal British Columbia, northern Washington, and southern California have declined since 1987-1992. The size of the Western Population of double-crested cormorants is still more than an order of magnitude less than the population that inhabits central and eastern North America. Increasing bald eagle (Haliateeus leucocephalus) populations, episodic human disturbance, and long-term impacts of certain organochlorine and hydrocarbon pollutants may be important factors causing declines in some portions of the range of the Western Population. Parallel studies on the genetic structure of the Western Population and the post-breeding dispersal of double-crested cormorants nesting in the Columbia River estuary suggest a high degree of population connectivity from southeastern California to southern British Columbia. Alaska, extreme southern California, and areas east of the Continental Divide have more limited connectivity to the Western Population of double-crested cormorants.

Adkins, J. Y., Roby, D. D., Lyons, D. E., Courtot, K. N., Collis, K., Carter, H. R., Shuford, W. D., & Capitolo, P. J. (2014). Recent population size, trends, and limiting factors for the double-crested cormorant in western North America: Double-Crested Cormorant Population Trends. *The Journal of Wildlife Management*, *78*(7), 1131–1142. https://doi.org/10.1002/jwmg.737

The status of the double-crested cormorant (Phalacrocorax auritus) in western North America was last evaluated during 1987–2003. In the interim, concern has grown over the potential impact of predation by double-crested cormorants on juvenile salmonids (Oncorhynchus spp.), particularly in the Columbia Basin and along the Pacific coast where some salmonids are listed for protection under the United States Endangered Species Act. Recent re-evaluations of double-crested cormorant management at the local, flyway, and federal level warrant further examination of the current population size and trends in western North America. We collected colony size data for the western population (British Columbia, Washington, Oregon, Idaho, California, Nevada, Utah, Arizona, and the portions of Montana, Wyoming, Colorado and New Mexico west of the Continental Divide) by conducting aircraft-, boat-, or ground-based surveys and by cooperating with government agencies, universities, and non-profit organizations. In 2009, we estimated approximately 31,200 breeding pairs in the western population. We estimated that cormorant numbers in the Pacific Region (British Columbia, Washington, Oregon, and California) increased 72% from 1987–1992 to circa 2009. Based on the best available data for this period, the average annual growth rate (l) of the number of breeding birds in the Pacific Region was 1.03, versus 1.07 for the population east of the Continental Divide during recent decades. Most of the increase in the Pacific Region can be attributed to an increase in the size of the nesting colony on East Sand Island in the Columbia River estuary, which accounts for about 39% of all breeding pairs in the western population and is the largest known breeding colony for the species (12,087 breeding pairs estimated in 2009). In contrast, numbers of breeding pairs estimated in coastal British Columbia and Washington have declined by approximately 66% during this same period. Disturbance at breeding colonies by bald eagles (Haliaeetus leucocephalus) and humans are likely limiting factors on the growth of the western population at present. Because of differences in biology and management, the western population of double-crested cormorants warrants consideration as a separate management unit from the population east of the Continental Divide.

Adrean, L. J. (2011). *Caspian Tern (Hydroprogne caspia) Foraging Ecology and Predation on Juvenile Salmonids in San Francisco Bay, California* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/jw827d95p

Brooks Island, located in central San Francisco Bay, California, currently supports the largest breeding colony of Caspian terns (Hydroprogne caspia) in the Bay Area, and is one of several proposed relocation sites for some Caspian terns from the world's largest colony in the Columbia River estuary of Oregon. Juvenile salmonids have been identified in the diet of Caspian terns nesting at Brooks Island, so I investigated whether the colony, at its current or an enhanced size, poses a threat to the recovery of several runs of salmonids (Oncorhynchus spp.) in San Francisco

Bay that are listed under the U.S. Endangered Species Act (ESA). I also examined the foraging ecology of Brooks Island Caspian terns to 1) determine whether the colony is suitable for expansion based on availability of forage fish resources, a factor potentially limiting the size and productivity of the colony, and 2) investigate how Caspian terns nesting at this colony exploit forage fish resources. I used a bioenergetics modeling approach, employing estimates of tern energy requirements and proportions of energy supplied by various prey types, to estimate consumption of juvenile salmonids by Caspian terns nesting on Brooks Island during 2008 and 2009. Estimated salmonid consumption was 205,000 smolts (95% CI: 175,000 – 245,000 smolts) in 2008 and 167,000 smolts (95% CI: 144,000 – 191,000 smolts) in 2009. Predation rates on ESA-listed Central Valley spring-run Chinook salmon (O. tshawytscha; 0.08%) were lower than those on unlisted fall-run Chinook salmon (1.0%). Average per capita predation rates on juvenile salmonids by Brooks Island Caspian terns (2008: 126 fish; 2009: 123 fish) were less than half those of Caspian terns nesting in the Columbia River estuary. If the current downward trend in the number of Caspian terns nesting on Brooks Island continues until the colony is no longer extant, the resulting declines in predation on salmonids would lead to increases in annual population growth rates ($\Delta\lambda$) of salmonid runs of just small fractions of one percentage point. The proposed enhancement of the Brooks Island Caspian tern colony to 3,000 individuals would at most cause declines in annual population growth rates of 0.3% for fall-run Chinook salmon and 0.02% for threatened spring-run Chinook salmon, assuming that smolt mortality from tern predation is 100% additive. This level of impact to the ESA-listed spring-run Chinook salmon stock is less than the level considered acceptable by the National Marine Fisheries Service ($\Delta\lambda$ = 0.05%). Radio-tracking of Caspian terns nesting on Brooks Island revealed that the maximum foraging distance from the colony was 80 km. The median foraging distance from the colony was greater in 2009 compared to 2008 (20.6 km vs. 14.0 km), average number of foraging trips per day was higher (4.4 vs. 3.4 foraging trips), and average adult colony attendance was lower (43% vs. 52% of daylight hours). These results indicate that the colony was more food-limited during the 2009 breeding season, concurrent with anomalous downwelling along the coast of northern California and reduced availability and size of marine forage fishes, such as herring, sardines, and anchovies. Caspian terns used a number of core foraging areas within 30 km of the Brooks Island colony, both inside and just outside the Bay. Two large core foraging areas were close to or overlapped with the release site for juvenile salmonids in eastern San Pablo Bay, where > 10 million hatchery-raised smolts were released from net pens during both the 2008 and 2009 tern nesting seasons. This finding supports the hypothesis that most juvenile salmonids consumed by terns nesting at the Brooks Island colony were captured at or near the release site. Individual Caspian terns displayed foraging site fidelity, suggesting that foraging at the release site for hatchery-raised salmonids was a learned behavior by some terns. The Brooks Island colony site is within foraging distance of adequate marine forage fish resources in most years, and Caspian terns nesting there are not dependent on juvenile salmonids as a food resource. Consumption of juvenile salmonids by Brooks Island terns would be largely curtailed by modification of hatchery release practices.

Adrean, L. J., Roby, D. D., Lyons, D. E., Collis, K., & Evans, A. F. (2012). Potential Effects of Management on Caspian Tern Hydroprogne caspia Predation on Juvenile Salmonids at a Colony in San Francisco Bay, California. *Transactions of the American Fisheries Society*, *141*(6), 1682–1696. https://doi.org/10.1080/00028487.2012.713886

San Francisco Bay is a proposed relocation site for some of the Caspian terns Hydroprogne caspia currently nesting at the world's largest colony for the species in the Columbia River estuary and consuming salmonids listed under the U.S. Endangered Species Act (ESA). However, several runs of salmonids listed under the ESA occur in San Francisco Bay and managers are concerned that increased Caspian tern predation may pose a threat to the recovery of these fish. We used a bioenergetics modeling approach, employing estimates of tern energy requirements and proportions of energy supplied by various prey types, to estimate the consumption of juvenile salmonids by Caspian terns nesting on Brooks Island in central San Francisco Bay during 2008 and 2009. Estimated salmonid consumption was ~205,000 smolts (95% confidence interval, 175,000–245,000 smolts) in 2008 and ~167,000 smolts (144,000–191,000 smolts) in 2009. The interannual difference in smolt consumption was due to the smaller size of the tern colony and lower nesting success in 2009. Estimated predation rates on ESA-listed Central Valley spring-run Chinook salmon Oncorhynchus tshawytscha (0.1%) were lower than those on unlisted fall-run Chinook salmon (1.0%). Continuation of the current downward trend in the number of Caspian terns nesting on Brooks Island and the resulting reductions in salmonid predation would not be sufficient to reverse salmonid declines in San Francisco Bay. The proposed enhancement of the Brooks Island Caspian tern colony to 3,000 individuals would at most cause declines in annual population growth rates of 0.28% for fall-run Chinook salmon and 0.02% for threatened spring-run Chinook salmon, assuming that the mortality from tern predation is 100% additive.

Ainley, D. G., Anderson, D. W., & Kelly, P. R. (1981). Feeding Ecology of Marine Cormorants in Southwestern North America. *The Condor*, *83*(2), 120–131. https://doi.org/10.2307/1367418

The diets of Pelagic, Brandt's and Double-crested cormorants (Phalacrocorax pelagicus, P. penicillatus and P. auritus) were compared. Data were based on 1,695 pellets and 71 chick regurgitations analyzed by us and information on 34 stomach samples published in the literature. A total of 19 sites between Kodiak, Alaska and central Mexico is represented. The three cormorants often fed in the same areas at the same time using the same technique. They exploited different microhabitats as defined by prey behavior; the prey species overlapped substantially between Brandt's and Pelagic cormorants, but those of the Double-crested Cormorant were quite different. Double-crested Cormorants fed on schooling fish usually occurring well above flat bottoms; Pelagic Cormorants fed on solitary prey on or concealed in rocky substrates; and Brandt's Cormorants fed on prey on or just above the bottom in rocky areas and in areas of flat sand or mud. The latter species fed over flat bottoms more in the northern part of their range than in the southern part where they fed almost exclusively in or near rocky habitat. Double-crested and Pelagic cormorants showed no geographic shift in their feeding habits.

Anchor QEA. (2017). *Double-crested Cormorant (DCCO) Monitoring Report: Avian Predation Program Monitoring* (p. 83). https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll3/id/788

The U.S. Army Corps of Engineers (Corps), Portland District, is evaluating the status of the double-crested cormorant (Phalacrocorax auritus; DCCO) impacts on juvenile salmonids in the Lower Columbia River Estuary (LCRE) per the Corps' Record of Decision to adopt the Final Environmental Impact Statement for Double-crested Cormorant Management Plan to Reduce Predation of Juvenile Salmonids in the Lower Columbia River Estuary (Management Plan; USACE 2015a). The 2014 Supplemental Biological Opinion and Reasonable and Prudent

Alternative for the Federal Columbia River Power System specifically calls for management of DCCO in the LCRE and minimizing impacts to communally nesting Brandt's cormorant (P. penicillatus; BRAC). A portion of the DCCO and BRAC breeding season (April through July) overlaps with the outmigration of millions of juvenile salmon smolts, which are a prey source for DCCOs. The primary goal of the 2015 Management Plan is to reduce the DCCO colony on East Sand Island (ESI) to approximately 5,600 (between 5,380 and 5,939) nesting pairs by the end of 2018 by culling and egg oiling (Phase I) and habitat modification with hazing (Phase II) in order to achieve a 3.5% survival increase for juvenile steelhead (USACE 2015b). Year 2 of implementation of Phase I of the Management Plan is 2016. Because DCCOs and BRACs communally nest, it is important to identify the location of each species during the nesting season to minimize management impacts to non-target species. To maintain the colony size, it is estimated in the Management Plan that the amount of available nesting habitat should be reduced to between 1.04 and 1.15 acres or less, assuming a DCCO nesting density of 1.28 nests per square meter (nests/m2). Objectives In support of the 2015 Management Plan, the objectives of the current (2016) project were to quantify and monitor DCCO nesting activity on ESI and in the LCRE using ground- and aerial-based methods. Methods Prior to the nesting season, the monitoring infrastructure on the ESI DCCO colony was constructed and modified. During the nesting season, weekly aerial and ground surveys of ESI were planned between April 18 and August 10, 2016, coinciding with peak nesting activities, to enumerate nests and cormorants. 2-D and 3-D methods were used to enumerate birds and nests on the colony. Between mid-May and the end of June, the entire cormorant colony left the island. Cormorants returned to the island between June 19 and 21, attempting to re-nest, and were confirmed renesting on the island in all monitoring regions on June 27 (Week 11) with an aerial survey. During the period of cormorant absence, ground surveys at ESI were halted, and the effort was refocused to the Astoria-Megler Bridge where a substantial number of DCCOs had relocated. Due to the disruption of the normal breeding cycle, nesting activities on ESI were protracted. Consequently, ground surveys were extended through the end of September to document nesting chronology during the 2016 season. To monitor colony formation activity in the LCRE at locations other than ESI, aerial flights were conducted by the Corps, and the Anchor QEA team completed boat-based surveys throughout 13 weeks to confirm and verify nest counts. Surveys recorded the following information at ESI and at each colony within the LCRE (other than ESI): • The number of active on-colony DCCO nests and BRAC nests (ESI only) • Acres occupied by DCCO and BRAC (ESI only) • Nest density and distribution (ESI only) • Nesting chronology (ESI only) • The number of loafing DCCOs • Signs of predators or other factors that may impact the colony • Leg band observations (unique alphanumeric colored leg bands) • Photographs to document the colony Results and Discussion East Sand Island DCCO use of ESI differed from previous years; for some unconfirmed reason, cormorants left the colony between Weeks 5 and 11 (from mid-May to late June). The peak DCCO breeding population (DCCOs = 9,772 breeding pairs, BRACs = 748 breeding pairs) was observed on ESI during Week 12 (July 3), after cormorants returned to the island. The use of 3-D enumeration methods and ground survey data improved our ability to differentiate between DCCO and BRAC nests. The observed peak DCCO breeding population was about 20% less compared to the peak breeding population reported for the 2015 breeding season (12,150). The peak breeding population in 2016 was observed during Week 12 (July 3), which is similar to 2015 (July 1). In both 2015 and 2016, ground surveys were not conducted in the weeks leading up to the peak nesting count. In 2016, this was due to birds leaving the colony and, in 2015, this was due to logistical constraints. The peak BRAC breeding

population (1,515 breeding pairs) was observed on ESI in Region P during Week 17 (August 10). The observed peak BRAC breeding population was about 27% less compared to the peak breeding population reported for the 2015 breeding season (2,071 nesting pairs). The peak breeding population of BRAC was observed later in 2016 (August 10) than in 2015 (July 6), which could be associated with the birds leaving the colony in mid-May and returning at the end of June. Lower Columbia River Estuary Colonies At the non-ESI DCCO colonies in the LCRE, the number of nests peaked at 2,928 during Week 5—the same week cormorants left ESI. The largest of these colonies was found at the Astoria-Megler Bridge (river mile [RM] 13) and the peak number of nests occurred here during Week 9 (peak of 549 nests). During weeks with many birds present on the Astoria-Megler Bridge, counting the number of nests was difficult. Other notable colonies included the Longview Bridge (RM 66) and Troutdale Towers (RM 120). Conclusions and Recommendations The peak breeding population of DCCOs observed at ESI in 2016 was 9,772 breeding pairs, with nesting densities ranging from 0.026 to 0.862 (nests/m2). This is a lower density than in 2015, when nesting densities ranged from 0.586 to 1.146 (nests/m2). The peak number of breeding DCCO pairs was approximately 20% lower than observations in 2015, representing a reduction of 2,378 breeding pairs. The peak abundance during the nesting season on ESI was 19,544 DCCOs, which is consistent with the predicted mean abundance (18,306 to 21,594 individuals) established in the Management Plan. Based on results in 2016, we recommend the following considerations in future monitoring years: • Continue to adjust seasonal monitoring according to cormorant behavior. • The habitat-use area in Monitoring Region P is far from the blind, making it difficult to enumerate birds and classify species. Therefore, we recommend constructing a blind that is closer to where the birds nest and loaf and/or surveying from a boat. • To more accurately transcribe the location of species from the ground observations to the GIS-based tablet during the nesting season, we recommend placing a survey grid or survey markers at regular intervals in the monitoring regions before the nesting season begins. • The accuracy, precision, and efficiency of nesting status and species counts are greatest when ground survey data, 2-D, and 3-D photogrammetric aerial counts are used. Accordingly, we recommend the following action: – Continue ground-based survey data and 2-D aerial photograph counts using automated and manual GIS methods to identify potential nesting cormorants weekly during the breeding season and to identify peak counts of breeding birds throughout the course of the breeding season. – Conduct manual 3-D aerial photograph counts on the week (or weeks) with peak counts to further refine species-specific counts during analysis conducted after the breeding season has ended. • To more efficiently perform ground surveys, consider installing a retractable covering for the windows in the blinds. This could improve visibility out of the blinds, reduce effort in cleaning the windows, and reduce potential for flushing birds.

Anderson, C. D. (2002). *Factors Affecting Colony Size, Reproductive Success, and Foraging Patterns of Double-crested Cormorants Nesting on East Sand Island in the Columbia River Estuary* [Oregon State University]. https://ir.library.oregonstate.edu/concern/parent/rf55zc09f/file_sets/3t945v343

The purpose of this study was to investigate the primary factors affecting colony size, reproductive success, and foraging patterns of Double-crested Cormorants (Phalacrocorax auritus albociliatus) nesting at East Sand Island in the Columbia River estuary, the largest colony of this species on the Pacific Coast of North America. This colony grew dramatically over the past 13 years and appears to represent a substantial proportion (>40%) of the West Coast population. Due to

increasing concern over avian predation on juvenile salmonids in the Columbia River estuary, there was a need to understand the factors limiting the size and productivity of this large and growing cormorant colony and how breeding adults exploit the available forage fish resources in the estuary. The East Sand Island colony recently fragmented into separate sub-colonies that differed in reproductive success; clutch size, hatching success, brood size at fledging, nesting success, and overall productivity were all higher at a recently-formed satellite sub-colony compared to the main colony. Depredation of cormorant nest contents by Glaucous-winged/Western Gulls (Larus glaucescens X L. occidentalis) following disturbances caused by Bald Eagles (Haliaetus leucocephalus) appeared to be the primary factor limiting reproductive success. During my study, nesting habitat and food supply did not appear to be limiting colony size or reproductive success. I predict that the colony will continue to expand unless forage fish stocks decline and/or eagle disturbances increase. I used radio-telemetry to investigate the spatial and temporal patterns of foraging male and female Double-crested Cormorants. Nesting adults tended to commute over 5 km from the colony to forage in either the estuarine-mixing zone or the freshwater zone of the estuary, where forage fishes were presumably more available than in the marine zone near the colony. The sexes exhibited striking differences in foraging distribution. Males commuted longer distances to forage in the freshwater zone compared to females, which tended to forage in the estuarine-mixing zone; however, females took longer foraging trips than males on average. Gender differences in foraging patterns may enhance the foraging efficiency of pairs nesting at a large colony such as East Sand Island. The cormorant breeding colony on East Sand Island seems to be avoiding density-dependent constraints of food supply by foraging over a wide area of the estuary on a diversity of marine forage fishes whose stocks are currently high. I predict that in years when stocks of marine forage fish within the estuary are low (e.g., due to poor ocean conditions), Double-crested Cormorants may become more reliant on the more predictable fish resources of the estuary, such as out-migrating salmonid smolts.

Anderson, C. D., Roby, D. D., & Collis, K. (2004a). Foraging patterns of male and female Double-crested Cormorants nesting in the Columbia River estuary. *Canadian Journal of Zoology*, *82*(4), 541–554. https://doi.org/10.1139/z04-019

The nesting colony of Double-crested Cormorants, Phalacrocorax auritus (Lesson, 1831), on East Sand Island in the Columbia River estuary is currently the largest for this species on the Pacific Coast of North America. We used radiotelemetry to investigate the spatial and temporal foraging patterns of nesting cormorants to better understand how this colony of piscivores meets its resource needs. We determined that nesting adults tended to forage >5 km from the colony and foraging distribution was distinctly different between the sexes. On average, males commuted nearly twice the distance to forage compared with females. Females typically foraged in the estuarine mixing zone, reportedly the region of the estuary with the greatest densities of schooling fishes, while males tended to commute more than 15 km to forage in the freshwater zone. Foraging intensity of both sexes varied by time of day, tide stage, and tide series; foraging generally intensified during ebb tides. These gender differences in foraging patterns, combined with the ability to forage at considerable distance from the colony on a wide variety of prey, may allow this large and growing colony to remain productive while potentially competing for food with many thousands of other piscivorous waterbirds that use East Sand Island.

Anderson, C. D., Roby, D. D., & Collis, K. (2004b). Conservation Implications of the Large Colony of Double-crested Cormorants on East Sand Island, Columbia River Estuary, Oregon, U.S.A. *Waterbirds*, *27*(2), 155–160. https://doi.org/10.1675/1524-4695(2004)027[0155:CIOTLC]2.0.CO;2

The breeding colony of the Double-crested Cormorant (Phalacrocorax auritus) on East Sand Island in the Columbia River estuary has grown dramatically over the last 13 years, in contrast to declines at other colonies along the coast of the Pacific Northwest. Immigration from other colonies has occurred and the East Sand Island colony is now the largest for the species on the Pacific coast of North America. Despite substantial increases in the size of the East Sand Island colony, overall numbers of the West Coast subspecies (P. a. albociliatus) appear to be slowly increasing relative to the interior population (P. a. auritus). Based on the most recent regional population data available, a conservative estimate indicates that the colony on East Sand Island represents over 30% of P. a. albociliatus breeding adults. We advocate that the subspecies P. a. albociliatus be considered a distinct population segment and managed according to overall population size and trends for this subspecies.

Anderson, J. G. T. (1991). Foraging Behavior of the American White Pelican (Pelecanus erythrorhyncos) in Western Nevada. *Colonial Waterbirds*, *14*(2), 166. https://doi.org/10.2307/1521506

The foraging behavior of American White Pelicans (Pelecanus erythrorhyncoLs inn.) breeding at Pyramid Lake in western Nevada was examined between 1984 and 1986. Pelicans seen feeding at Pyramid Lake during February and early March pirated fish from Double Crested Cormorants (Phalacrocoraxauritus). When feeding with conspecifics, pelicans usually engaged in some form of “cooperative herding,” either driving fish into shallow water or surrounding them in more open areas. Members of groups of two to six birds caught significantly more fish than single birds or those in larger groups. Strike frequency initially increased with group size, reaching an upper asymptote at a flock size of four. Tests with decoys revealed that pelicans were attracted to areas by the presence of other pelicans.

Anderson, S. K. (2003). *Foraging Ecology, Colony Attendance, and Chick Provisioning of Caspian Terns (Sterna caspia) in the Columbia River Estuary* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/mk61rk766?locale=en

This study was designed to enhance understanding of factors influencing foraging distribution, diet composition, and overall reproductive success of Caspian terns (Sterna caspia) nesting on East Sand Island in the Columbia River estuary. This colony of nearly 10,000 breeding pairs is of concern to regional resource managers because Caspian terns consume large numbers of juvenile salmonids (Oncorhynchus spp.) listed under the Endangered Species Act. In addition, Caspian terns at this colony consume marine forage fishes, the abundance of which fluctuates on annual and decadal scales. I found that average foraging distance from the colony was 6.6 km (38%) greater in 2000 compared to 2001, associated with lower availability of marine forage fishes in the estuary and lower prevalence of marine prey in tern diets. Also, colony attendance was much lower (37.0% vs. 62.5% of daylight hours), average foraging trip duration was 40% longer (38.9 min), and nesting success was much lower (0.57 young fledged pair-1 vs. 1.40 young fledged pair-1) in 2000 compared to 2001. In 2001, average meal delivery rates to 2-chick broods (0.88 meals hour-1) was 2.6 times greater than to 1-chick broods (0.33 meals hour-1). Parents delivered more juvenile salmonids to their young during ebb tides than during flood tides,

suggesting diet composition reflected short-term changes in relative availability of prey near the colony. Foraging trips resulting in delivery of juvenile salmonids took 68% longer than foraging trips resulting in delivery of schooling marine forage fishes, indicating higher availability of marine prey. High proportion of salmonids in the diet was associated with high use of the freshwater zone of the estuary by radio-tagged terns, suggesting that diet composition also reflected the distribution of foraging terns in the estuary. High availability of marine forage fish in 2001 was apparently responsible for high colony attendance, relatively brief foraging trips close to the colony, high food delivery rates to young, and high nesting success of Caspian terns on East Sand Island. Lower availability of marine prey in 2000 apparently limited Caspian tern nesting success by markedly reducing colony attendance and lengthening foraging trips by nesting terns, thereby increasing chick mortality rates from predation, exposure, and starvation. The foraging behavior and nesting success of Caspian terns at the East Sand Island colony is apparently highly dependent on the fluctuating availability of marine forage fishes in the Columbia River estuary. Diet studies indicate that the primary alternative prey for this tern colony are out-migrating juvenile salmonids from throughout the Columbia River basin.

Anderson, S. K., Roby, D. D., Lyons, D. E., & Collis, K. (2005). Factors Affecting Chick Provisioning by Caspian Terns Nesting in the Columbia River Estuary. *Waterbirds*, *28*(1), 95–105. https://doi.org/10.1675/1524-4695(2005)028[0095:FACPBC]2.0.CO;2

We investigated factors affecting chick provisioning by radio-tagged Caspian Terns (Sterna caspia) nesting in a large colony on East Sand Island in the Columbia River estuary during 2001. Caspian Tern predation on juvenile salmonids (Oncorhynchus spp.) in the estuary prompted resource managers to relocate ca. 9,000 pairs of terns nesting on Rice Island (river km 34) to East Sand Island (river km 8), where terns were expected to consume fewer salmonids in favor of marine forage fishes. This study investigated factors influencing foraging success, diet composition, and overall reproductive success at the managed Caspian Tern colony. Our results indicated that daytime colony attendance by nesting terns averaged 64% and decreased throughout the chick-rearing period, while duration of foraging trips averaged 47 min and increased during the same period; these seasonal changes were more strongly related to date than chick age. Average meal delivery rates to 2-chick broods (0.88 meals h-1) were 2.6 times greater than to 1-chick broods (0.33 meals h-1). Parents delivered more juvenile salmonids to chicks during ebb tides than flood tides, but meal delivery rates to the nest remained constant, suggesting diet composition tracks relative availability of prey species. Foraging trips resulting in delivery of juvenile salmonids averaged 68% longer than foraging trips for schooling marine forage fishes, indicating higher availability of marine prey near the colony. High availability of marine forage fish in the Columbia River estuary during 2001 was apparently responsible for high colony attendance, short foraging trips, high chick meal delivery rates, and high nesting success of Caspian Terns on East Sand Island.

Anderson, S. K., Roby, D. D., Lyons, D. E., & Collis, K. (2007). Relationship of Caspian tern foraging ecology to nesting success in the Columbia River estuary, Oregon, USA. *Estuarine, Coastal and Shelf Science*, *73*(3–4), 447–456. https://doi.org/10.1016/j.ecss.2007.02.006

The prevalence of juvenile salmonids (Oncorhynchus spp.) and marine forage fishes in the diet of Caspian terns (Hydroprogne caspia) nesting in the Columbia River estuary has been established, but the relationship between diet composition, foraging distribution, and productivity of these birds has received little attention. We used radio-telemetry and on-colony observations to relate

changes in off-colony distribution to patterns of colony attendance, diet composition, and productivity of adult terns nesting on East Sand Island during two years of different river and prey conditions. Average distance from the East Sand Island colony (located in the marine zone of the estuary) was 38% (6.6 km) greater in 2000 compared to 2001, associated with lower availability of marine forage fish near East Sand Island and lower prevalence of marine prey in tern diets. Colony attendance was much lower (37.0% vs. 62.5% of daylight hours), average trip duration was 40% longer (38.9 min), and nesting success was much lower (0.57 young fledged/pair vs. 1.40 young fledged/pair) in 2000 compared to 2001. Higher proportions of juvenile salmonids in the diet were associated with relatively high use of the freshwater zone of the estuary by radio-tagged terns, which occurred prior to chick-rearing and when out-migrating salmonid smolts were relatively abundant. Lower availability of marine prey in 2000 apparently limited Caspian tern nesting success by markedly reducing colony attendance and lengthening foraging trips by nesting terns, thereby increasing chick mortality rates from predation, exposure, and starvation.

Anthony, J. A., Roby, D. D., & Turco, K. R. (2000). Lipid content and energy density of forage fishes from the northern Gulf of Alaska. *Journal of Experimental Marine Biology and Ecology*, *248*(1), 53–78. https://doi.org/10.1016/S0022-0981(00)00159-3

Piscivorous predators can experience multi-fold differences in energy intake rates based solely on the types of fishes consumed. We estimated energy density of 1151 fish from 39 species by proximate analysis of lipid, water, ash-free lean dry matter, and ash contents and evaluated factors contributing to variation in composition. Lipid content was the primary determinant of energy density, ranging from 2 to 61% dry mass and resulting in a five-fold difference in energy density of individuals (2.0–10.8 kJ g21 wet mass). Energy density varied widely within and between species. Schooling pelagic fishes had relatively high or low values, whereas nearshore demersal fishes were intermediate. Pelagic species maturing at a smaller size had higher and more variable energy density than pelagic or nearshore species maturing larger. High-lipid fishes had less water and more protein than low-lipid fishes. In some forage fishes, size, month, reproductive status, or location contributed significantly to intraspecific variation in energy density. Differences in quality are sufficient to potentially affect diet selection of breeding seabirds, especially when transporting food for their young to the nest site. Published by Elsevier Science B.V.

Antolos, M. (2002). *Breeding and Foraging Ecology of Caspian Terns (Sterna caspia) in the Mid-Columbia River: Predation on Juvenile Salmonids and Management Implications* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/cz30pw05t?locale=en

I investigated Caspian terns (Sterna caspia) breeding at colonies on the Columbia Plateau (southeastern Washington and northeastern Oregon), with emphasis on the breeding and foraging ecology of Caspian terns nesting at colonies in the mid-Columbia River. I focused research at colonies where Caspian terns foraged on juvenile salmonids (Oncorhynchus spp.) because of potential impacts to stocks listed under the U.S. Endangered Species Act. Caspian tern colony size on the Columbia Plateau ranged from tens of breeding pairs to nearly 700 pairs at Crescent Island in the mid-Columbia River; total population size in the study area was about 1,000 pairs and appeared to be stable. The size and number of Caspian tern colonies in the Columbia Plateau region are likely constrained by the availability of suitable nesting habitat near abundant prey, a

resource that appears limited within the study area. Productivity of Caspian terns was not affected by nest density at Crescent Island, information that may be helpful for resource managers deciding minimum area requirements for breeding Caspian terns at managed colony sites. At colonies on the mid-Columbia River, the majority of Caspian tern prey items consisted of juvenile salmonids. I estimated that Caspian terns nesting at Crescent Island in the mid-Columbia River consumed 382,000-547,000 and 533,000-825,000 juvenile salmonids during the breeding season in 2000 and 2001, respectively. Total salmonid predation by Crescent Island Caspian terns was less than that reported for some other predators in the Columbia River that have been managed to reduce predation rates on juvenile salmonids. The results of this research will be used by state, federal, and tribal resource managers to decide whether Caspian tern management is warranted at Crescent Island.

Antolos, M., Roby, D. D., & Collis, K. (2004). Breeding Ecology of Caspian Terns at Colonies on the Columbia Plateau. *Northwest Science*, *78*(4), 303–312.

We investigated the breeding ecology and diet of Caspian terns on the Columbia Plateau in southeastern Washington and northeastern Oregon. We examined trends in colony size and area during 1996-2001, and estimated number of breeding pairs, nesting density, fledging success, and diet composition at selected colony sites in 2000 and 2001. We found six tern colonies totaling ~1,000 breeding pairs, ranging in size from < 50 to nearly 700 pairs. Predation by mink caused complete abandonment of one of these colonies in 2000 and 2001. The relocation of ~9,000 Caspian tern breeding pairs from Rice Island to East Sand Island in the Columbia River estuary did not result in an obvious increase in the number of tern breeding pairs on the Columbia Plateau during the study period. The majority of Caspian tern prey items at colonies on the mid-Columbia River consisted of juvenile salmonids. At a colony in Potholes Reservoir, Washington, Caspian terns commuted over 100 km round-trip to the Columbia River to forage on juvenile salmonids, suggesting that locally abundant food may be limiting. High nesting densities at other mid-Columbia River colonies suggest that availability of breeding habitat may limit colony size. The small size of Caspian tern colonies on the Columbia Plateau, and possible constraints on availability of suitable nesting habitat within the study area, suggest that the level of predation on ESA-listed juvenile salmonids in this region will likely remain well below that currently observed in the Columbia River estuary.

Antolos, M., Roby, D. D., Lyons, D. E., Anderson, S. K., & Collis, K. (2006). Effects of Nest Density, Location, and Timing on Breeding Success of Caspian Terns. *Waterbirds*, *29*(4), 465–472. https://doi.org/10.1675/1524-4695(2006)29[465:EONDLA]2.0.CO;2

One of the proposed benefits of colonial nesting in birds is the protection afforded against avian predators. This advantage may be counter-balanced by the negative effects of intraspecific aggression on breeding success. Effects of nest density, nest location within the colony, and timing of nest initiation on productivity of Caspian Terns (Sterna caspia) were investigated on Crescent Island in the mid-Columbia River, Washington, USA. In the absence of intense nest predation at the Crescent Island tern colony, it was hypothesized that nest density would be negatively associated with productivity. A rangefinder was used to determine spatial distribution of Caspian Tern nests, and these data used to calculate nest characteristics (nest density, nearest neighbor distance, and distance to colony edge) for a randomly-selected subset of nests monitored for nest chronology and productivity. Productivity did not differ between nests in high- and low-density areas of the colony, and was positively associated with earlier nest initiation. Early nests were more productive, were located in areas of higher nest density, and were further from the colony edge than late nests. The strong effect of timing may have been attributable to seasonal declines in prey resources for terns at this site. Our results suggest that Caspian Terns nesting at the highest densities observed in this study did not incur immediate reproductive costs, despite increased potential for encounters between chicks and aggressive conspecific adults.

Antolos, M., Roby, D. D., Lyons, D. E., Collis, K., Evans, A. F., Hawbecker, M., & Ryan, B. A. (2005). Caspian Tern Predation on Juvenile Salmonids in the Mid-Columbia River. *Transactions of the American Fisheries Society*, *134*(2), 466–480. https://doi.org/10.1577/T04-043.1

We used a bioenergetics approach to determine the magnitude of predation by Caspian terns Sterna caspia on juvenile salmonids Oncorhynchus spp. in the mid-Columbia River during 2000 and 2001. Caspian terns nesting on Crescent Island, Washington, located below the confluence of the Snake and Columbia rivers, consumed several hundred thousand juvenile salmonids each year of the study. Tern consumption of smolts was higher in 2001 (679,000 smolts; 95% confidence interval [CI]: 533,000–825,000 smolts) than in 2000 (465,000 smolts; 95% CI: 382,000–547,000 smolts) as a result of an increase in tern breeding pairs, fledging success, and percentage of salmonids in the diet. On-colony detection rates of passive integrated transponder tags from inriver migrating smolts were also higher in 2001 (0.90–12.40%) than in 2000 (0.03–1.60%); the higher predation rates in 2001 were probably caused by extreme drought conditions that resulted in reduced spill from hydroelectric dams, lower river flows, and increased travel times for in-river migrating smolts. Tern predation rates on juvenile steelhead O. mykiss were higher than those on yearling Chinook salmon O. tshawytscha in both years. The impacts of tern predation on steelhead smolts and yearling Chinook salmon from the Snake River were slight after accounting for the high proportion of smolts collected for transportation above Crescent Island. Survival of steelhead smolts from the upper Columbia River that are not transported above Crescent Island may be significantly affected by tern predation, particularly in low-flow years. Appreciably higher predation rates on salmonids by Crescent Island terns than those observed in 2001 are unlikely considering the constraints on tern colony expansion, limited capacity for increased per capita smolt consumption by terns, and current high transportation rates for Snake River smolts.

Bailey, O. A. (2018). *Extrinsic and Intrinsic Factors Associated with Reproductive Success of Caspian Terns (Hydroprogne caspia) at East Sand Island, Columbia River Estuary* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/b2774199q

Declines in wild salmonid (Oncorhynchus spp.) populations in the Columbia River basin have resulted in managers identifying that avian predation on juvenile salmonids is an important limiting factor for salmonid recovery. Caspian Terns (Hydroprogne caspia), particularly those nesting in the Columbia River estuary, were identified as key avian predators that reduce the survival of juvenile salmonids in the Columbia River basin. To reduce the numbers of juvenile salmonids consumed by Caspian Terns in the Columbia River estuary, the amount of available nesting habitat for Caspian Terns on East Sand Island (ESI) was reduced from 2 ha in 2008 to 0.64 ha in 2012, and then was further reduced to 0.4 ha in 2015. The objective of this management was to reduce the size of the Caspian Tern breeding colony on ESI to about a third of its former size. Caspian Terns are facultative colonial nesters and generally nest in ephemeral

habitats. Caspian Terns nesting at ESI, however, have demonstrated very high colony site fidelity due to the consistent maintenance of nesting habitat, as well as the proximity to an abundant food supply and the paucity of terrestrial predators. Reproductive success for the ESI Caspian Tern colony has, on average, declined since 2001, and in both 2011 and 2017 no young were raised at the colony. The objective of my study was to understand variation in reproductive success of Caspian Terns at the ESI colony by investigating potential factors associated with nesting success at the scale of the colony and the individual. I investigated both top-down and bottom-up factors that may have affected the average annual reproductive success at the Caspian Tern colony on ESI during 2001-2017, as well as the relative importance of several intrinsic factors that may have affected reproductive success of individual Caspian Terns over two consecutive breeding seasons, 2015 and 2016. I found that study year and the rate of kleptoparasitism on Caspian Tern bill-load fish by gulls (Larus spp.) during the chick-rearing period best explained the inter-annual variation in average annual reproductive success at the ESI colony during 2001-2017. My results suggest that year was acting as a surrogate variable for other factors that were changing in a gradual, consistent manner at or near the tern colony during the study period, such as nesting habitat availability, nest density, Bald Eagle (Haliaeetus leucocephalus) disturbance rates, and gull predation rates on tern eggs and chicks. The impact of average Columbia River discharge in May/June as a driving factor for Caspian Tern reproductive success was particularly evident in 2011 and 2017, the two years when river discharge was the highest recorded during the study period, and the only two years when no young were produced at the colony. My results support the hypothesis that both bottom-up factors (e.g., food availability) and top-down factors (e.g., gull kleptoparasitism rates) are drivers of reproductive success at the East Sand Island Caspian Tern colony. The bottom-up factor of average Columbia River discharge in May/June apparently affected the top-down factor of gull kleptoparasitism rates by altering the food supply of nesting gulls, thus prompting them to switch to stealing Caspian Tern bill-loads. The second study in my thesis sought to gain a better understanding of which factors may influence reproductive success of individual Caspian Terns, based on data collected at the ESI colony in 2015 and 2016. I investigated the relative importance of (1) age, (2) previous breeding experience, (3) timing of breeding, (4) density of nearby conspecific nests, and (5) nest location relative to the colony edge for explaining variation in individual reproductive success. The date when an individual tern initiated its nesting attempt was ranked highest in relative importance among these explanatory variables, with nest success decreasing as the date of nest initiation increased. The density of conspecific nests within 1 meter of an individual's nest was strongly and positively associated with the odds that the nest was successful. Nests located further from the colony edge were more likely to be successful, but only early in the breeding season; later in the season, nest location had no effect on individual reproductive success. Individuals that initiated nests earlier in the breeding season had more time to lay replacement clutches in the event that their earlier nesting attempts failed, and laying more than one clutch per breeding season was common at the ESI colony during the study period. Some individuals attempted to nest as many as four times in a single breeding season. My study provides a better understanding of those extrinsic and intrinsic factors that are associated with reproductive success of Caspian Terns on two different scales – the breeding colony at ESI as a whole, and the individual Caspian Terns nesting at ESI. Understanding factors influencing reproductive success at each scale increases our knowledge of Caspian Tern breeding ecology at East Sand Island, and can inform managers about which factors likely regulate the size and productivity of the largest Caspian Tern breeding colony in North America. This study can also provide insight into factors that

affect other seabird species and organisms that live in seasonal environments, as well as long-lived organisms that may experience considerable variation in overall reproductive success.

Bailey, V. (1902). Unprotected Breeding Grounds. *Condor*, *4*(3 (May-June)), 62–64.

Baird, P. A. (1976). *Comparative Ecology of California and Ring-billed Gulls (Larus californicus and L. Delawarensis)* [University of Montana]. https://scholarworks.umt.edu/cgi/viewcontent.cgi?article=11002&context=etd

The ecology of mixed and single species colonies of Ring-billed and California Gulls was studied in insular and peninsular locations in Montana. The purpose of this study was to investigate the foraging and nesting niches of these sympatric congeners and to ascertain what enabled them to coexist, what possible differences in lifestyles existed between them, and possible causes of these differences. The adaptive significance of patterns of habitat choice of the 2 species was also investigated with respect to reproductive success. The inter – and intraspecific behavior of the 2 species was described. Vegetation height, cover, volume, and species composition, distance to water of each nest, nest density, and nearest neighbor distances were examined as possible factors influencing nest construction on a particular site. Resource utilization was examined with respect to choice of feeding sites, interspecific interaction at feeding sites, and types of food eaten. Reproductive success of each species with respect to colony type, location in colony, vegetation profile, nearest neighbor distance, and species of nearest neighbor was investigated. Egg and chick success were determined and multivariate regression used to determine what factors influenced mortality. California Gulls arrive 2 weeks in advance of the Ring-billed Gulls and establish territories in specific areas of the colony. There is little interspecific interaction and although the California Gulls are more aggressive and occasionally predate the Ring-billed chicks, the behavior is usually one of avoidance. The 2 species segregate the nesting habitat with respect to vegetation characteristics and nest in monospecific subgroups. Both prefer the middle of the colony to the edges. California Gulls nested in the higher denser vegetation. The nearest neighbor distances differed between the 2 species, and for Ring-billed Gulls, this distance is related to species of nearest neighbor. In the monospecific colony of California Gulls, the nesting niche is wider. California and Ring-billed Gulls segregate the food niche mainly by distance from the colony and by habitat type of the foraging areas, and less by food type. They had a 62% overlap in their diets. California Gulls forage farther from the colony on dryland farmlands and prairie while Ring-billed Gulls forage near the colony in irrigated farmlands. Chick survival from the egg stage was higher on the mixed species insular than on the peninsular colony, and least on the monospecific colony. Death rates of chicks were positively correlated with nearest neighbor distance and clutch size, and negatively correlated with vegetation cover, in most colonies. There is an indication that an optimal density exists within colonies and that densities above or below this cause a higher chick death rate.

Barth, J. A., Menge, B. A., Lubchenco, J., Chan, F., Bane, J. M., Kirincich, A. R., McManus, M. A., Nielsen, K. J., Pierce, S. D., & Washburn, L. (2007). Delayed upwelling alters nearshore coastal ocean ecosystems in the northern California current. *Proceedings of the National Academy of Sciences*, *104*(10), 3719–3724. https://doi.org/10.1073/pnas.0700462104

Wind-driven coastal ocean upwelling supplies nutrients to the euphotic zone near the coast. Nutrients fuel the growth of phytoplankton, the base of a very productive coastal marine ecosystem [Pauly D, Christensen V (1995) Nature 374:255–257]. Because nutrient supply and phytoplankton biomass in shelf waters are highly sensitive to variation in upwelling-driven circulation, shifts in the timing and strength of upwelling may alter basic nutrient and carbon fluxes through marine food webs. We show how a 1-month delay in the 2005 spring transition to upwelling-favorable wind stress in the northern California Current Large Marine Ecosystem resulted in numerous anomalies: warm water, low nutrient levels, low primary productivity, and an unprecedented low recruitment of rocky intertidal organisms. The delay was associated with 20- to 40-day wind oscillations accompanying a southward shift of the jet stream. Early in the upwelling season (May–July) off Oregon, the cumulative upwelling-favorable wind stress was the lowest in 20 years, nearshore surface waters averaged 2°C warmer than normal, surf-zone chlorophyll-a and nutrients were 50% and 30% less than normal, respectively, and densities of recruits of mussels and barnacles were reduced by 83% and 66%, respectively. Delayed early-season upwelling and stronger late-season upwelling are consistent with predictions of the influence of global warming on coastal upwelling regions.

Beamish, R. J., & Mahnken, C. (2001). A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Progress in Oceanography*, *49*(1), 423–437. https://doi.org/10.1016/S0079-6611(01)00034-9

We hypothesise that salmon year class strength is determined in two stages during the first year in the ocean. There is an early natural mortality that is mostly related to predation, which is followed by a physiologically-based mortality. Juvenile salmon that fail to reach a critical size by the end of their first marine summer do not survive the following winter. In this study we describe our initial tests of this critical size and critical period hypothesis using data from ocean surveys of juvenile salmon and from experimental feeding studies on coho. Conservative swept volume abundance estimates for juvenile coho, and possibly chinook, indicate that there is high mortality in fall and winter during their first year in the sea. Studies of otolith weight show that the length and otolith-weight relationship for young coho changes in the early fall of their first ocean year. Studies of growth and associated hormone levels in feeding studies show that slow growing juvenile coho are stunted and deficient in an insulin-like growth factor-I (IGF-I). Juvenile coho sampled in September had low IGF-I values, indicative of poor growth. The results of these studies provide evidence for the general hypothesis that growth-related mortality occurs late in the first marine year and may be important in determining the strength of the year class (brood year). The link between total mortality and climate could be operating via the availability of nutrients regulating the food supply and hence competition for food (i.e. bottom–up regulation).

Beeman, J. W., & Maule, A. G. (2006). Migration Depths of Juvenile Chinook Salmon and Steelhead Relative to Total Dissolved Gas Supersaturation in a Columbia River Reservoir. *Transactions of the American Fisheries Society*, *135*(3), 584–594. https://doi.org/10.1577/T05-193.1

The in situ depths of juvenile salmonids Oncorhynchus spp. were studied to determine whether hydrostatic compensation was sufficient to protect them from gas bubble disease (GBD) during exposure to total dissolved gas (TDG) supersaturation from a regional program of spill at dams meant to improve salmonid passage survival. Yearling Chinook salmon O. tshawytscha and juvenile steelhead O. mykiss implanted with pressure-sensing radio transmitters were monitored from boats while they were migrating between the tailrace of Ice Harbor Dam on the Snake River and the forebay of McNary Dam on the Columbia River during 1997–1999. The TDG generally decreased with distance from the tailrace of the dam and was within levels known to cause GBD signs and mortality in laboratory bioassays. Results of repeated-measures analysis of

variance indicated that the mean depths of juvenile steelhead were similar throughout the study area, ranging from 2.0 m in the Snake River to 2.3 m near the McNary Dam forebay. The mean depths of yearling Chinook salmon generally increased with distance from Ice Harbor Dam, ranging from 1.5 m in the Snake River to 3.2 m near the forebay. Juvenile steelhead were deeper at night than during the day, and yearling Chinook salmon were deeper during the day than at night. The TDG level was a significant covariate in models of the migration depth and rates of each species, but no effect of fish size was detected. Hydrostatic compensation, along with short exposure times in the area of greatest TDG, reduced the effects of TDG exposure below those generally shown to elicit GBD signs or mortality. Based on these factors, our results indicate that the TDG limits of the regional spill program were safe for these juvenile salmonids.

Bell, D. A. (1997). Hybridization and Reproductive Performance in Gulls of the Larus Glaucescens-Occidentalis Complex. *The Condor*, *99*(3), 585–594. https://doi.org/10.2307/1370471

The Glaucous-winged Gull (Larus glaucescens) and the Western Gull (L. occidentalis occidentalis) hybridize along the Pacific Coast from Cape Flattery, Washington, south through central Oregon. A hybrid index, based on plumage and soft part colors, was used to study the distribution of morphotypes (e.g., pure and hybrid birds), mating patterns and reproductive performance at eight sympatric and two allopatric colonies. Mate choice appears to be weakly positive-assortative. In 1989 in the hybrid zone, L. o. occidentalis experienced significantly greater reproductive performance, measured as clutch size and egg volume difference, than either L. glaucescens or mixed pairs containing at least one hybrid individual. Although the hybrid zone has expanded somewhat in recent times, the midpoint of the zone and the relative proportion of morphotypes has remained stable. The hybrid zone is situated on a marine-ecotone. Within the hybrid zone, relative reproductive performance of L. o. occidentalis and hybrids may shift between years, whereas L. glaucescens may experience poor reproductive performance in all years. The selection-hybridization balance hypothesis may best explain the L. glaucescens-occidentalis hybrid zone.

Berggren, T. J., & Filardo, M. J. (1993). An Analysis of Variables Influencing the Migration of Juvenile Salmonids in the Columbia River Basin. *North American Journal of Fisheries Management*, *13*(1), 48–63. https://doi.org/10.1577/1548-8675(1993)013<0048:AAOVIT>2.3.CO;2

The amount of time that it takes juvenile chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss to migrate (travel time) at different river flows through index reaches in the Snake and Columbia rivers was analyzed with bivariate- and multiple-regression models. Smolt travel time estimates for yearling chinook salmon and steelhead in the Snake River, steelhead in the middle Columbia River, and subyearling chinook salmon in the lower Columbia River were inversely related to average river flows. In the multiple-regression analyses, additional predictor variables that were related either to flow or to smoltification were used. These predictor variables were calculated over the same time period as the travel time estimates. Flow-related variables were referenced at a key hydroelectric site within each index reach, and included average river flow, minimum river flow, and absolute change in river flow. The smoltification-related variables provided indirect indices of smoltification. They included water temperature, date of entry into an index reach, chinook salmon race, and travel time prior to entry into an index reach. The final models included those predictor variables explaining significant variation in smolt travel time, The variables in the final multiple-regression models explained 74% and 39% of the variation in the travel time for yearling chinook salmon within the Snake and middle Columbia river index reaches, respectively; 90% and 62% for steelhead within the Snake and middle Columbia reaches; and 65% for subyearling chinook salmon in the lower Columbia reach. Average river flow made the largest contribution to explaining variation in smolt travel time in the majority of the multiple-regression models. Additional variation in smolt travel time could be explained by including other flow- and smoltification-related variables in the models.

Bergman, G. (1980). Single-breeding versus colonial breeding in the Caspian Tern Hydroprogne caspia, the Common Tern Sterna hirundo and the Arctic Tern Sterna paradisaea. *Ornis Fennica*, *57*, 141–152.

The Baltic population of the Caspian Tern, c. 2300 pairs, tends to breed either in single pairs (146 of 204 recorded localities) or in dense colonies (around 50 islets with 9-164 pairs). The pronounced sociability is partly an adaptation to coastal regions where suitable breeding localities are scarce and the Caspian Tern and other larids are forced to gather on the few localities available. The first Caspian Terns arriving in the Baltic archipelagoes were single pairs. They could not find any colonies of conspecifics and accepted colonies of other larids as substitutes. Single-breeding pairs defend their whole islet against conspecifics, preventing other single pairs from joining them. In this way single-breeding has been preserved for centuries in the Baltic. The difference in aggressiveness between single-breeders and colonial breeders is obviously related to differences in conditioning and imprinting of the young: in colonies they constantly live close to numerous conspecifics, whereas the young of the single-breeders hardly see any foreign conspecifics but many other larids . Earlier, only single-breeders occurred in the Baltic archipelagoes, but around 1880 a colony from Sleswig (North Sea) moved into the Baltic and settled south of Stockholm. It increased and divided into several colonies, situated in Sweden, Finland and Estonia. Since the colonies attract single pairs, the single-breeding system has begun to vanish from the vicinity of the colonies. Even the colonies of Caspian Terns settle only on islets occupied by other larids, including conspecifics. In the Common and Arctic Tern the few single pairs do not prevent other single pairs from joining them. Their colonies are not very dense and fighting at territory borders is infrequent. The conditions for conditioning to conspecifics is almost identical for all young. Therefore, offspring of single pairs do not develop any especial aggressiveness towards conspecifics which would preserve the single-breeding. The mutual attraction between the Common and Arctic Tern frequently cause breeding in the same locality. Single pairs of these terns occur only in particularly attractive environments. For breeding in less suitable environments both species need the additional stimulus offered by a colony of terns, but they do not accept other larids as substitutes.

Blankenship, S. M., Campbell, M. R., Hess, J. E., Hess, M. A., Kassler, T. W., Kozfkay, C. C., Matala, A. P., Narum, S. R., Paquin, M. M., Small, M. P., Stephenson, J. J., Warheit, K. I., & Moran, P. (2011). Major Lineages and Metapopulations in Columbia River Oncorhynchus mykiss Are Structured by Dynamic Landscape Features and Environments. *Transactions of the American Fisheries Society*, *140*(3), 665–684. https://doi.org/10.1080/00028487.2011.584487

It is widely recognized that genetic diversity within species is shaped by dynamic habitats. The quantitative and molecular genetic patterns observed are the result of demographics, mutation, migration, and adaptation. The populations of rainbow trout Oncorhynchus mykiss in the Columbia River basin (including both resident and anadromous forms and various subspecies) present a special challenge to understanding the relative roles of those factors. Standardized

microsatellite data were compiled for 226 collections (15,658 individuals) from throughout the Columbia and Snake River basins to evaluate the genetic patterns of structure and adaptation. The data were primarily from fish of the anadromous life history form, and we used a population grouping procedure based on principal components and hierarchical k-means clustering to cluster populations into eight aggregates or groups with similar allele frequencies. These aggregates approximated geographic regions, and the two largest principal components corresponded to ancestral lineages of Sacramento redband trout O. m. stonei, coastal rainbow trout O. m. irideus, and interior Columbia River redband trout O. m. gairdneri. Genetic data were partitioned among primary aggregates (lower Columbia, middle–upper Columbia, and Snake rivers), and the magnitude of genetic divergence relative to genetic diversity was analyzed (per locus) to test for evidence of selection and subsequent signals of adaptation. Two loci showed higher divergence than expected by chance (i.e., positive selection); however, both of these loci were on the fringe of the 99% confidence level and are potential false positives. Genetic patterns were also significantly correlated with certain environmental and habitat parameters (e.g., precipitation), but the extent to which those correlations are causal as opposed to effectual remains unclear. Despite the remaining questions, these data provide a foundation for more detailed investigations of harvest, admixture, and introgression between hatchery- and natural-origin fish and differences in reproductive success among individuals as well as monitoring trends in productivity.

Blokpoel, H., & Courtney, P. (1980). Site Tenacity in a New Ring-Billed Gull Colony. *Journal of Field Ornithology*, *51*(1), 1–5. JSTOR.

Boström, M. K., Lunneryd, S.-G., Karlsson, L., & Ragnarsson, B. (2009). Cormorant impact on trout (Salmo trutta) and salmon (Salmo salar) migrating from the river Dalälven emerging in the Baltic Sea. *Fisheries Research*, *98*(1), 16–21. https://doi.org/10.1016/j.fishres.2009.03.011

Cormorant (Phalacrocorax carbo sinensis) population increases and the resulting predation, can lead to severe effects on fish stocks. In the Dalälven River in Sweden, it was observed that the number of trout and salmon returning to spawn decreased, while the number of cormorants along the coast had increased simultaneously. This study estimated the predatory impact that cormorants had on stocked trout (Salmo trutta) and salmon (Salmo salar) populations in 2005 and 2006 by using Coded Wire Tags and Carlin tags recovered in cormorant pellets. Predatory impact on salmon was found to be low, as no tags were recovered. Impact on trout was estimated 1.9%. Additional inspections of material within and around nests for tags gave similar estimates within a low range 0.8–2.3%.

Bottom, D. L., Baptista, A., Burke, J., Campbell, L., Casillas, E., Hinton, S., Jay, D. A., Lott, M. A., Mccabe, G., Mcnatt, R., Ramirez, M., Roegner, G. C., Simenstad, C. A., Spilseth, S., Stamatiou, L., Teel, D., Zamon, J. E., & E, M. B. (2011). *Estuarine habitat and juvenile salmon: Current and historical linkages in the lower Columbia River and estuary* (p. 216). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.386.4191&rep=rep1&type=pdf

Our studies in the lower 100-km of the Columbia River estuary quantified historical habitat changes and provided new information about contemporary abundance patterns, life histories, and habitat associations of Chinook salmon. The conceptual framework for this research defined salmon performance in the estuary as the product of three factors: habitat opportunity, habitat capacity, and the structure/life histories of source populations. Our 2002-2008 survey results provided empirical data to support this framework by quantifying Chinook salmon performance in terms of temporal abundance, life history and stock-group diversity, foraging success, and growth, as well as by quantifying the relationships between stock groups and one or more of these factors. In Part I, we detail our reconstruction of historical habitat opportunities and changes in the estuary as influenced by the tide, river flows, and temperature. In Part II, we depict contemporary habitat opportunities based on present-day patterns of salmon distribution and abundance and upon various physical factors that influence fish access to shallow-water rearing areas. In Part III, we compare the capacity of different wetland and nearshore habitats in supporting juvenile Chinook salmon as indicated by variations in prey availability, salmon diet, and rates of consumption. Finally, in Part IV, we examine the effects of upriver population structure and life histories on estuary rearing behavior and performance, including the genetic sources of individual Chinook salmon found within particular habitats and stock-specific patterns of residency and growth. These surveys provided new information about the present estuarine habitat associations of juvenile salmon. They also provided data for estimates of historical change in habitat conditions, estimates of historical change in salmon life histories, and analyses of food webs. Below we summarize major conclusions drawn from these evaluations.

Bottom, D. L., & Jones, K. K. (1990). Species composition, distribution, and invertebrate prey of fish assemblages in the Columbia River Estuary. *Progress in Oceanography*, *25*(1), 243–270. https://doi.org/10.1016/0079-6611(90)90009-Q

The fish community of the Columbia River Estuary was sampled with trawl, beach seine, and purse seine over an 18 month period during 1980–1981. Seasonality of abundance and species richness in the estuary reflect the timing of migrations and the reproductive cycles of marine and anadromous species. Composition of the fish community and dominant species in the Columbia River estuary are similar to many smaller estuaries in the Pacific Northwest. These similarities reflect the influence of the nearshore marine environment on fish community structure throughout the West Coast as well as the wide geographic distribution and considerable physiological tolerance of many dominant euryhaline species. The distribution of fish assemblages within the Columbia River estuary is influenced by large seasonal variation in river discharge and salinity. Within large areas or salinity zones, species assemblages use different habitats and invertebrate prey. The distribution of abundance and the stomach fullness of fishes vary directly with the density of potential prey. We hypothesize that fish production may be limited by dynamic physical processes that control prey availability or the feeding efficiencies of predators in the highly turbid estuary.

BRNW (Bird Research Northwest). (1998). *Avian Predation on Juvenile Salmonids in the Lower Columbia River, 1997* (p. 63). http://www.birdresearchnw.org/97RPT.pdf

Virtually every evolutionarily significant unit (ESU) of anadromous salmonid (Oncorhynchus spp.) in the Columbia River Basin is currently or soon will be listed under the Endangered Species Act of 1973. Colonial waterbirds (i.e., terns, cormorants, and gulls) may be important predators on juvenile salmonids in the lower Columbia River. Consequently, we initiated a study in 1997 to assess the impacts of fish-eating birds on the survival of juvenile salmonids during the out-migration. The objectives of this study were to (1) estimate the size of fish-eating waterbird colonies in the lower Columbia River and determine population trends, (2) estimate the number of juvenile salmonids consumed by these populations, (3) identify the factors that influence avian predation rates on smolts, and (4) recommend ways to reduce avian predation on smolts, if warranted by the study results. There were nine major colonies of fish-eating birds that nested on islands in the lower Columbia River and estuary in 1997. Most of these islands are unnatural, created by either the dumping of dredge material or rising water levels associated with mainstem dam impoundments. Population censuses indicated that the number of fish-eating colonial waterbirds totaled roughly 170,000 individuals, a substantial increase over previous estimates. Rice Island, a dredge material disposal island in the Columbia River estuary, supported the largest known Caspian tern (Sterna caspia) colony in North America (over 16,000 birds in 1997), which had grown by over 600% since the colony originated in 1987. Two colonies of double-crested cormorants (Phalacrocorax auritus) in the estuary were the first and second largest on the entire Pacific coast of the U.S. and Canada. The nesting period for these colonies (mid-April to mid-July) generally coincided with the period of smolt out-migration. Nesting success at the Rice Island Caspian tern colony was low (ca. 5% of breeding pairs successfully raised a chick), due mostly to predation on eggs and chicks by glaucous-winged/western gulls (Larus glaucescens X L. occidentalis). Nesting success of double-crested cormorants, in contrast, was over 50%. Diet analysis indicated that juvenile salmonids were an important part of the diet of some fish-eating waterbirds nesting in the Columbia River estuary. Caspian terns appeared to be most dependent on salmonids (roughly 75% of the diet), followed by double-crested cormorants (roughly 24% of the diet) and glaucous-winged/western gull hybrids (roughly 11% of the diet). The large California and ring-billed gull (Larus californicus and L. delawarensis) colonies up-river relied less on juvenile salmonids as a food source compared to fish-eating waterbirds in the estuary, perhaps due to high flows in 1997 and measures implemented at Columbia River dams to reduce bird predation. Juvenile salmonids were especially prevalent in the diets of fish-eating waterbirds in the estuary during May. Steelhead smolts were most prevalent in Caspian tern diets during early May, followed by coho smolts in late May - early June, and then chinook smolts in late June - late July. Over a thousand salmonid smolt PIT tags were found on the Rice Island Caspian tern colony and we estimated that over 30,000 PIT tags have been deposited there over the last nine years. The recovered PIT tags indicate that steelhead smolts were consumed in greater proportion to availability than other salmonid species, and that juvenile salmonids of hatchery origin were consumed in greater proportion to availability than wild fish. We estimate that 6 - 25 million juvenile salmonids were consumed by Caspian terns nesting on Rice Island in 1997, or approximately 6 - 25 % of the estimated 100 million out-migrating smolts that reach the estuary. We lack sufficient data to estimate the number of juvenile salmonids lost to cormorants and gulls in the estuary (collection of these data is proposed in 1998), but preliminary data suggest it is in the millions. Various management alternatives to reduce predation by Caspian terns on juvenile salmonids are discussed, including translocating the colony to a previous colony site on East Sand Island where a greater diversity of non-salmonid prey is available.

BRNW (Bird Research Northwest). (1999). *Caspian Tern Predation on Juvenile Salmonids in the Columbia River Estuary, 1999* (p. 3) [Interim]. http://www.birdresearchnw.org/99.Interim.Report.pdf

BRNW (Bird Research Northwest). (2000). *Avian Predation on Juvenile Salmonids in the Lower Columbia River, 1998* (p. 100). http://www.birdresearchnw.org/98Rpt.pdf

We initiated a field study in 1997 to assess the impacts of fish-eating colonial waterbirds (i.e., terns, cormorants, and gulls) on the survival of juvenile salmonids in the lower Columbia River. Here we present results from the 1998 breeding season, the second field season of work on this

project. The research objectives in 1998 were to: (1) determine the location, size, nesting chronology, nesting success, and population trajectories of breeding colonies of fish-eating birds in the lower Columbia River; (2) determine diet composition of fish-eating birds, including taxonomic composition and energy content of various prey types; (3) estimate forage fish consumption rates, with special emphasis on juvenile salmonids, by breeding adults and their young; (4) determine the relative vulnerability of different groups of juvenile salmonids to bird predation; (5) identify foraging range, foraging strategies, and habitat utilization by piscivorous waterbirds; and (6) test the feasibility of various alternative methods for managing avian predation on juvenile salmonids and develop recommendations to reduce avian predation, if warranted by the results. Populations of Caspian terns (Sterna caspia) and double-crested cormorants (Phalacrocorax auritus) in the Columbia River estuary continued to increase in 1998, while the population of glaucous-winged/western gulls (Larus glaucescens X L. occidentalis) in the estuary declined. Populations of California and ring-billed gulls (Larus californicus and L. delawarensis) at up-river colonies were stable or declined somewhat. Rice Island, a dredge material disposal island in the Columbia River estuary, again supported the largest known Caspian tern colony in North America (about 8,000 breeding pairs in 1998), and the only known breeding colony of this species in coastal Oregon and Washington. The colony of double-crested cormorants on East Sand Island in the estuary is the largest of its kind on the Pacific coast of North America. Diet analysis indicated that juvenile salmonids were an important part of the diet of fish-eating colonial waterbirds in the Columbia River estuary. As in 1997, Caspian terns were most dependent on salmonids (74% of diet mass), followed by double-crested cormorants (21% of diet mass) and glaucous-winged/western gulls (approx. 8% of diet mass). Juvenile salmonids were especially prevalent in the diets of fish-eating waterbirds in the estuary during April and May. The diet samples from California and ring-billed gulls nesting at up-river colonies included few fish and very few juvenile salmonids. Aerial surveys of the estuary during the Caspian tern nesting season indicated that most foraging by terns occurred within 8 km of the Rice Island colony, and 90% of all tern sightings off-colony were within 21 km of the colony. Cormorants, in particular, aggregated to feed around pile dikes, where juvenile salmonids may be more vulnerable to avian predation. Analysis of over 49,000 smolt PIT tags recovered from the Caspian tern and double-crested cormorant breeding colonies on Rice Island revealed that avian predation rates on steelhead smolts were greater than those on coho or chinook smolts and that hatchery-reared smolts were more vulnerable to tern predation than wild smolts. For the 1998 migration year, tern predation rates on transported chinook smolts were greater than for non-transported chinook smolts, whereas predation rates on transported steelhead smolts were less than for non-transported steelhead smolts. We estimated that Caspian terns in the Columbia River estuary consumed 10.8 million juvenile salmonids (range = 7.4 – 15.2 million), or approximately 11% (range = 8% - 16%) of the estimated 95 million out-migrating smolts that reached the estuary during the 1998 migration year. The best estimate the number of juvenile salmonids consumed by double-crested cormorants in the estuary was 4.6 million (range = 2.2 – 9.2 million), or approximately 5% of out-migrating smolts (range = 2% - 10%) that reached the estuary in 1998. A rough estimate of the number of juvenile salmonids consumed by glaucous-winged/western gulls in the estuary was 1.3 million (range = 0.4 – 3.9 million). Thus the estimated total consumption of juvenile salmonids by fish-eating colonial waterbirds in the Columbia River estuary was 16.7 million smolts (range = 10.0 – 28.3 million smolts), or 18% (range = 11% – 30%) of those smolts that reached the estuary in 1998. Given the magnitude of smolt losses to colonial waterbirds in the estuary, it seems justifiable to develop management

options that will reduce avian predation on juvenile salmonids, preferably without damaging colonial waterbird resources. Relocation of part or all of the Rice Island Caspian tern colony to sites where greater diversities of marine forage fishes are available may achieve this goal. We tested the feasibility of using social attraction (tern decoys and audio playback systems) to encourage Caspian terns to nest on a site not previously occupied. This approach succeeded in attracting terns to nest and lay eggs at the new site, but all nesting attempts failed because of intense egg predation by gulls and crows. We recommend relocation of part of the Rice Island Caspian tern colony to East Sand Island in 1999 to test whether this approach will reduce smolt losses to terns. In the longer term, it would probably benefit both salmonids and terns if much of the tern population was relocated to other coastal colony sites, possibly restored former colony sites in Grays Harbor, Willapa Bay, and Puget Sound, where greater diversities of non-salmonid prey are presumably available.

BRNW (Bird Research Northwest). (2002a). *Cormorant and Brown Pelican Use of Excluder-fitted Pile Dikes in the Columbia River Estuary, 2001* (p. 33). http://www.birdresearchnw.org/2001_Pile_Dike_Report.pdf

The purpose of this study was to monitor the use of pile dikes in the Columbia River estuary by piscivorous (fish-eating) birds. Most of the pile dikes had been fitted with bird excluders (wire spike strips) to discourage cormorants from perching, roosting, and staging foraging activities on out-migrating juvenile salmonids from these structures. A primary objective of the study was to evaluate the efficacy of these excluders for reducing the numbers of cormorants perching on and foraging near pile dikes (see Figures 1 and 2 for maps of the study area). The study species were double-crested cormorants (Phalacrocorax auritus), pelagic cormorants (P. pelagicus), and Brandt's cormorants (P. penicillatus), all of which nest in the estuary. California brown pelicans (Pelecanus occidentalis californicus), a species listed as endangered under the U.S. Endangered Species Act, are also known to use pile dikes as perching sites, so the effects of excluders on use of pile dikes by pelicans was also of interest. A total of 19 pile dikes in the estuary were 2001 Final Report 1/8/02 2 monitored, 17 of which were at least partly fitted with bird excluders (Table 1). Pile dikes included in this study were located from river mile 3.00 (West Sand Island) to river mile 51.42 (Eureka Bar; Figure 1). The study was conducted from 7 May to 30 September 2001. This time period generally coincided with the breeding season for cormorants in the Columbia River estuary and the post-breeding season for California brown pelicans (brown pelicans do not breed in the study area). In this report, individual pile dikes are referenced by their location on the lower Columbia River in river miles (e.g., pile dikes 3.00 and 51.42 are the lower- and uppermost dikes in the study area, respectively; see Figure 1).

BRNW (Bird Research Northwest). (2002b). *Caspian Tern Research on the Lower Columbia River, 2001* (p. 35). http://www.birdresearchnw.org/01SeasonSummary.pdf

We initiated a field study in 1997 to assess the impacts of Caspian terns (Sterna caspia) on the survival of juvenile salmonids in the lower Columbia River. Rice Island, a dredged material disposal site at river mile 21, supported an expanding colony of about 17,000 nesting terns in 1998. This colony was the largest known Caspian tern breeding colony in the world, and supported about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America. Diet analysis indicated that Caspian terns nesting on Rice Island ate mostly juvenile salmonids (73% of prey items in 1998). Using bioenergetics modeling, we estimated that in 1998 this tern colony consumed about 11.2 million juvenile salmonids (95% c.i. = 8.5 – 14.1 million),

or approximately 12% (95% c.i. = 8% - 15%) of the estimated 95 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.3% of all PIT-tagged steelhead smolts that reached the estuary were consumed by terns in 1998. The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999. A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 16 miles closer to the ocean on East Sand Island (river mile 5), where it was hoped terns would consume fewer salmonids. Habitat restoration, social attraction (decoys and audio playback systems), and selective gull removal were used to encourage terns to nest on East Sand Island. About 1,400 pairs of Caspian terns nested at the new colony site in 1999, where nesting success was considerably higher than on Rice Island. In 2000, about 8,500 pairs of Caspian terns nested on East Sand Island, or 94% of all terns nesting in the estuary, and nesting success was again much higher than at Rice Island. During 1999 and 2000, the terns nesting on East Sand Island foraged more in marine and brackish water habitats than did the terns nesting on Rice Island. The diet of East Sand Island terns consisted of 46% and 47% salmonids in 1999 and 2000, respectively, compared to the diet of Rice Island terns, which consisted of 77% and 90% salmonids, respectively. The relocation of nearly all the nesting terns from Rice Island to East Sand Island in 2000 resulted in a sharp drop in consumption of juvenile salmonids by terns nesting in the Columbia River estuary; total consumption was estimated at 7.3 million smolts (95% c.i. = 6.1 – 8.6 million smolts), a reduction in smolt consumption of about 4.4 million (38%) compared to 1999. In 2001, all Caspian terns nesting in the Columbia River estuary used 3.9 acres of the restored habitat on East Sand Island. The estimated size of the East Sand Island colony (8,900 pairs) was not significantly different from 2000. Tern nesting success at the East Sand Island colony in 2001 (1.4 young raised per nesting pair) was the highest ever recorded for Caspian terns nesting in the Columbia River estuary, apparently a reflection of high forage fish availability. The proportion of juvenile salmonids in the diet (33%) was the lowest ever recorded for terns nesting in the estuary. This resulted in another decline in consumption of juvenile salmonids by terns in the Columbia River estuary; consumption in 2001 was estimated at 5.9 million smolts (95% c.i. = 4.8 – 7.0 million smolts). This represents a reduction in smolt consumption by terns of about 5.9 million (50%) compared to the 1999 consumption estimate. To achieve further reductions in annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary, regional resource managers are considering the restoration of tern colonies outside the estuary and the relocation of a portion of the East Sand Island colony to these alternative sites. Caspian tern colonies on or near the mid-Columbia River show little promise as alternative nest sites for terns currently nesting in the estuary. The tern colony on Three Mile Canyon Island, which formerly consisted of 200-400 breeding pairs, completely failed for the second year in a row due to mink predation. The tern colony on Crescent Island (ca. 720 breeding pairs) increased 26% compared to 2000 and experienced good nesting success (0.84 young raised per breeding pair). But juvenile salmonids comprised 68% of prey items, suggesting that adult terns shifting from the East Sand Island colony to the Crescent Island colony would have a greater impact on survival of juvenile salmonids. Also, the high density of tern nests on Crescent Island and the high nesting densities of gulls on the remainder of the island suggest that there is little opportunity for expansion of the tern colony. The Caspian tern colony on Miller Rocks was new in 2001, but is very small (15-20 pairs) and also appears to be strongly limited by nest site competition with gulls. The Solstice Island tern colony in Potholes Reservoir does not appear to be limited by nesting habitat, but terns from this colony are known

to regularly commute over 30 miles to the Columbia River to prey on juvenile salmonids and have been the subject of considerable lethal control at the mid-Columbia River dams. The best prospects for restoration or augmentation of Caspian tern colonies seem to exist on the coast of the Pacific Northwest. The welfare of other listed or beleaguered salmonid stocks has been a primary concern in coastal areas under consideration for restoration of Caspian tern colonies, yet for most former coastal colony sites there is little or no evidence that juvenile salmonids were a significant component of tern diets. Restoration of permanent colony sites for Caspian terns along the coast of the Pacific Northwest appears unlikely without empirical evidence that local salmonid stocks will not be at risk. In 2001, we tested the feasibility of attracting Caspian terns to nest on barges as temporary colony sites so that the suitability of alternative sites for tern colony restoration can be assessed. A small barge covered with sand and equipped with tern decoys and audio playback systems was anchored in Commencement Bay, Washington. Caspian terns began nesting on the barge within one month of deployment. Approximately 388 tern nests were initiated on the barge at a density of 1.5 nests/m2 , the highest Caspian tern nest density reported in the Pacific Northwest. Tern diets were 65% juvenile salmonids; a variety of marine forage fishes comprised the remainder of the diet. The barge was removed prior to hatching of tern eggs because of a breakdown in inter-agency coordination on the project. Nevertheless, the study demonstrated that Caspian terns can rapidly colonize a suitable barge and that temporary colonies on barges can help assess prospective colony restoration sites along the coast of the Pacific Northwest. The rapid and overwhelming response of Caspian terns to the habitat provided on the barge in Commencement Bay is strong evidence for the acute shortage of suitable nesting habitat along the coast of the Pacific Northwest.

BRNW (Bird Research Northwest). (2002c). *Caspian Tern Research on the Lower Columbia River, 2000* (p. 26). http://www.birdresearchnw.org/00SeasonSummary.pdf

We initiated a field study in 1997 to assess the impacts of Caspian terns on the survival of juvenile salmonids in the Columbia River estuary. Rice Island, a dredged material disposal island, supported an expanding population of 14,000-17,000 nesting Caspian terns until 2000. This breeding colony was the largest of its kind ever recorded in the world, and supported about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America. Diet analysis indicated that Caspian terns nesting on Rice Island consumed more juvenile salmonids than any other prey type (73% of prey items in 1998). Using bioenergetics modeling, we estimated that in 1998 Caspian terns nesting on Rice Island consumed about 12.4 million juvenile salmonids (95% c.i. = 9.1 – 15.7 million), or approximately 13% (95% c.i. = 9% - 16%) of the estimated 97 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that steelhead smolts were more vulnerable to tern predation than other species of salmonids, and that over 13.3% of all PIT-tagged steelhead smolts that reached the estuary were consumed by terns nesting on Rice Island in 1998. Hatchery-raised yearling Chinook salmon smolts were more vulnerable to tern predation than their wild counterparts. ESA-listed and unlisted salmonid smolts were consumed in proportion to their availability. The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999. A pilot study was conducted to determine whether part of the Rice Island tern colony (river mile 21) could be relocated 16 miles closer to the ocean on East Sand Island (river mile 5), where it was hoped terns would consume fewer salmonids. Habitat restoration, social attraction (decoys and audio playback systems), and selective gull removal were used to encourage terns to nest on East

Sand Island. About 1,400 pairs of Caspian terns nested at the new colony site on East Sand Island in 1999, where nesting success was good (ca. 1.2 young raised per nesting pair). The terns nesting on East Sand Island foraged more in marine and brackish water habitats than did the terns nesting on Rice Island, and the diet of East Sand Island terns consisted of 46% salmonids, or 40% fewer salmonids than were consumed by terns nesting on Rice Island. Despite the success of the pilot study, an estimated 11.7 million juvenile salmonids (95% c.i. = 9.4 – 14.1 million) were consumed by Caspian terns in the Columbia River estuary in 1999. The management plan in 2000 sought to prevent all nesting by Caspian terns on Rice Island and to attract all the terns that formerly nested at Rice Island to 4 acres of tern nesting habitat on East Sand Island. However, a court-ordered temporary restraining order precluded the elimination of all tern nesting on Rice Island. Nevertheless, 94% of the terns nesting in the estuary chose the colony site on East Sand Island. Tern nesting success at the East Sand Island colony was only about half the nesting success recorded at the East Sand Island colony in 1999, but was nearly four times higher than that at the Rice Island colony in 2000. Juvenile salmonids comprised 47% of the diet of terns nesting at East Sand Island, compared to 90% of the diet of terns nesting at Rice Island. The relocation of nearly all the nesting terns from Rice Island to East Sand Island resulted in a sharp drop in consumption of juvenile salmonids. Total consumption of juvenile salmonids by Caspian terns nesting in the Columbia River estuary in 2000 was estimated at 7.3 million (95% c.i. = 6.1 – 8.6 million). This represents a reduction in smolt consumption by terns of about 4.4 million (38%) compared to the 1999 consumption estimate. To achieve further reductions in the annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary, regional fish and wildlife managers are considering the restoration of tern colonies outside the estuary and the relocation of a portion of the East Sand Island colony to these alternative sites.

BRNW (Bird Research Northwest). (2003a). *Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon, 2003* (p. 51). http://www.birdresearchnw.org/03_Final_Site_Feasibility_Report.pdf

The goal of this study was to develop a better understanding of Caspian tern (Sterna caspia) colony status and diet composition at representative colonies in coastal and interior habitats of northern California and interior Oregon. Information from this study will be used in the development of a Caspian Tern Management Plan and Environmental Impact Statement (EIS) by the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and NOAA Fisheries. The Caspian Tern Management Plan and EIS are mandated by a court-mediated settlement agreement with the goal of reducing predation on salmonids by Caspian terns nesting on East Sand Island. This annual report summarizes data collected on nesting Caspian terns during the 2003 breeding season at five different colonies in the San Francisco Bay area (Brooks Island, Knight Island, Baumberg Pond, A-7 Pond, and Agua Vista Park) and two colonies in interior Oregon (Summer Lake and Crump Lake). The purpose of this report is to present results to the funding agency, resource management agencies, and other stakeholders. This report addresses diet composition, colony size, nesting success, and factors limiting colony size and nesting success at these seven colonies. The findings presented in this report may change with further review and analysis; results have not yet undergone peerreview. Consequently, these data are not for citation or publication without prior permission from the authors. There were five known breeding colonies of Caspian terns in the San Francisco Bay area in 2003, where a total of approximately 1,190 breeding pairs nested. Most breeding pairs in the San Francisco Bay area (72%) nested at the

Brooks Island colony, by far the largest tern colony in the Bay area. Marine forage fishes, in particular anchovies (Engraulidae), surfperch (Embiotocidae), herring (Clupeidae), and silversides (Atherinidae), were the predominant component of Caspian tern diets at all five colonies. Small numbers of juvenile salmonids (chinook salmon smolts, O. tshawytscha) were identified in the diet of terns nesting at four of the five colonies; salmon comprised less than 10% of the diet at Knight Island, less than 2% of the diet at Brooks Island, and much less than 1% of the diet at Baumberg Pond, A7 Pond, and Agua Vista Park. Nesting success at each colony ranged from 0.08 to 0.70 young fledged/breeding pair; this is fair to poor productivity compared to other well-studied Caspian tern colonies in the region. Nesting success tended to be higher at the larger tern colonies in the Bay area. All five colonies appeared to be primarily limited both in size and productivity by the availability of suitable nesting habitat and/or the quality of nesting substrate. Other factors limiting nesting success for at least some of the colonies were mammalian nest predators, displacement by other colonial waterbirds, and human disturbance. Food availability may be a limiting factor for nesting success in some years, but it did not appear to be a significant constraint on productivity in 2003. We studied Caspian tern nesting ecology at two sites in interior Oregon: Summer Lake Wildlife Area and Crump Lake in the Warner Valley. Both these sites have a recent history of Caspian tern nesting activity, but neither site apparently supported successful Caspian tern nesting in the last two years. Colony failure at both sites was evidently the result of fluctuating water levels that either flooded the available nesting habitat or 2 connected nesting islands to the mainland, allowing access by mammalian nest predators. To evaluate factors that limit nesting success at these two sites, we built an elevated nesting platform on Keister Island in Crump Lake (where the former colony site was flooded) and attempted to attract terns to nest on a small island in an impoundment in Summer Lake Wildlife Area (where the former colony site was connected to the mainland). Caspian terns nested successfully at both managed sites, and at no other sites in the respective areas, suggesting that suitable nesting sites for Caspian terns were very limited in these areas. The diet of terns nesting at both sites consisted mostly of Tui chubs (Siphateles bicolor) an unlisted species; no anadromous salmonids were detected in tern diets at either site. One Warner sucker (Catostomus warnerensis), a federally-listed threatened species, was identified in the diet of terns nesting on Crump Lake, but this species comprised less than 0.1% of tern diets. Nesting success at the two sites was only fair and was limited by the availability of suitable nesting habitat at Crump Lake and the quality of nesting substrate at Summer Lake Wildlife Area. The preliminary conclusions from this Caspian tern study in 2003 are (1) breeding Caspian terns at all seven study sites preyed mostly on forage fishes that are neither listed under the ESA nor of significant economic value for commercial, recreational, or subsistence fisheries, (2) availability of suitable sites for breeding colonies was the main factor limiting the number and size of tern colonies in both the San Francisco Bay area and interior Oregon, and (3) nesting success at existing colonies was limited by attributes of those colony sites as they influence (a) quality of nesting substrate, (b) vulnerability to mammalian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance.

BRNW (Bird Research Northwest). (2003b). *Caspian Tern Research on the Lower Columbia River, 2002* (p. 31). http://www.birdresearchnw.org/02_Season_Summary.pdf

We initiated a field study in 1997 to assess the impact of predation by Caspian terns (Sterna caspia) on the survival of juvenile salmonids in the lower Columbia River and estuary. Rice Island, a dredged material disposal island at river mile 21, supported an expanding population of about

17,000 nesting Caspian terns in 1998. This colony was the largest known breeding colony of Caspian terns in the world, and supported about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America. Diet analysis indicated that Caspian terns nesting on Rice Island consumed more juvenile salmonids than any other prey type (73% of prey items in 1997 and 1998). Using bioenergetics modeling, we estimated that in 1998 Caspian terns nesting on Rice Island consumed about 12.4 million juvenile salmonids (95% c.i. = 9.1 – 15.7 million), or approximately 13% (95% c.i. = 9% - 16%) of the estimated 97 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.3% of all PIT-tagged steelhead smolts that reached the estuary were consumed by terns in 1998. The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999. A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 26 km (16 miles) closer to the ocean on East Sand Island (river mile 5), where it was hoped terns would consume fewer salmonids. Habitat restoration, social attraction (decoys and audio playback systems), and selective gull removal were used to encourage terns to nest on East Sand Island. About 1,400 pairs of Caspian terns nested at the new colony site on East Sand Island in 1999. In 2000, about 8,500 pairs of Caspian terns nested on East Sand Island, or 94% of all terns nesting in the estuary. In 2001 and 2002, all Caspian terns nesting in the Columbia River estuary used East Sand Island, with approximately 9,000 and 9,900 pairs nesting at the site in 2001 and 2002, respectively. Our results also indicate that relocating the tern colony to East Sand Island enhanced the productivity of Caspian terns nesting in the Columbia River estuary. Nesting success of Caspian terns on East Sand Island (0.57–1.39 young raised per breeding pair on average during 1999-2002) was consistently higher than for terns nesting on Rice Island, both prior to tern management (1997–1998: 0.06–0.45 young raised per breeding pair) and post-management (1999–2000: 0.15–0.55 young raised per breeding pair). The productivity measured at Rice Island was considerably lower than at other well-studied Caspian tern colonies in North America (range of 0.6–1.6 young raised per breeding pair; Cuthbert and Wires 1999). Terns nesting on East Sand Island foraged more in marine and brackish water habitats than did the terns nesting on Rice Island. The diet of East Sand Island terns averaged between 31% and 47% salmonids during the years 1999-2002, compared to the diet of Rice Island terns, which consisted of 77% and 90% salmonids in 1999 and 2000, respectively. The relocation of all nesting terns from Rice Island to East Sand Island resulted in a sharp drop in consumption of juvenile salmonids by terns nesting in the Columbia River estuary. Total consumption of juvenile salmonids in 2000, when most terns nested on East Sand Island, was estimated at 8.2 million (95% c.i. = 6.7 – 9.7 million), a reduction of about 4.2 million (34%) compared to 1998. Total smolt consumption by terns nesting on East Sand Island in 2001 and 2002, when all terns nested on East Sand Island, was approximately 5.8 million and 6.5 million, respectively. This represents 53% and 48% reductions in estimates of smolt consumption compared to 1998. Caspian terns nesting on East Sand Island in 2002 still consumed an estimated 5.5 - 7.6 million smolts, with some ESA-listed stocks still suffering significant losses to tern predation (Ryan et al. 2001a, Ryan et al. 2001b). To achieve further reductions in consumption of juvenile salmonids by Caspian terns in the estuary it will likely be necessary to relocate a portion of the East Sand Island colony to alternative sites outside the estuary. Caspian tern colonies on or near the mid-Columbia River show little promise as alternative nest sites for terns currently nesting in the estuary. Terns attempting to nest on Three Mile Canyon Island, which formerly consisted of 200-400 breeding pairs, completely failed in 2000 and 2001 due to mink predation; while in 2002 terns did not attempt to nest there. The tern colony on Crescent Island consisted of 550-700 breeding pairs in 2000-2002 and has experienced fair nesting success (0.67, 1.07, and 0.65 young raised per breeding pair in 2000, 2001, and 2002, respectively). But juvenile salmonids comprised 68% of identified prey items in 2001 and 2002, suggesting that adult terns shifting from the East Sand Island colony to the Crescent Island colony would have a greater impact on survival of juvenile salmonids. Also, the high density of tern nests on Crescent Island and the high nesting densities of gulls on the remainder of the island suggest that there is little opportunity for expansion of the tern colony. The Caspian tern colony that first became established on Miller Rocks in 2001 (15-20 pairs), was not reoccupied by terns in 2002. Tern colonies in Potholes Reservoir do not appear to be limited by nesting habitat, but terns from this colony are known to regularly commute over 50 km (30 miles) to the Columbia River to prey on juvenile salmonids. Terns from this colony have evidently been the subject of considerable lethal control at hydroelectric dams on the mid-Columbia River. The best prospects for restoration or augmentation of Caspian tern colonies seem to exist on the coast of the Pacific Northwest. The welfare of other listed or beleaguered salmonid stocks has been a primary concern in coastal areas under consideration for restoration of Caspian tern colonies, yet for most former coastal colony sites there is little or no evidence that juvenile salmonids were a significant component of tern diets. Restoration of permanent colony sites for Caspian terns along the coast of the Pacific Northwest appears unlikely without empirical evidence that local salmonid stocks will not be at risk. In 2001, we tested the feasibility of attracting Caspian terns to nest on barges as temporary colony sites so that the suitability of alternative sites for tern colony restoration could be assessed. A small barge covered with sand and equipped with tern decoys and audio playback systems was anchored in Commencement Bay, Washington. Caspian terns began nesting on the barge within one month of deployment. Approximately 388 tern nests were initiated on the barge at a density of 1.5 nests/m2 , the highest Caspian tern nest density reported in the Pacific Northwest. Tern diets were 65% juvenile salmonids; a variety of marine forage fishes comprised the remainder of the diet. The barge was removed prior to hatching of tern eggs because of a breakdown in inter-agency coordination on the project. Nevertheless, the study demonstrated that Caspian terns can rapidly colonize a suitable barge and that temporary colonies on barges can help assess prospective colony restoration sites along the coast of the Pacific Northwest. The rapid and overwhelming response of Caspian terns to the habitat provided on the barge in Commencement Bay is strong evidence for the acute shortage of suitable nesting habitat along the coast of the Pacific Northwest. Restoration of former colony sites or establishment of new sites for Caspian terns outside the Columbia River estuary would likely benefit both salmonid stocks from the Columbia Basin and Caspian terns. Currently, approximately two-thirds of all Caspian terns belonging to the Pacific Coast population nest on East Sand Island. The population is particularly vulnerable to local catastrophes, such as storms, disease outbreaks, oil spills, predation events, or human disturbance. Redistributing the tern population to a number of smaller colonies over a larger geographic area will reduce this risk.

BRNW (Bird Research Northwest). (2004). *Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Dungeness National Wildlife Refuge* (p. 52). http://www.birdresearchnw.org/04_Final_Site_Feasibility_Report.pdf

The goal of this 2-year study was to develop a better understanding of Caspian tern (Sterna caspia) colony status and diet composition at representative colonies in coastal and interior habitats of California, Oregon, and Washington. Information from this study will be used in the development of a Caspian Tern Management Plan and Environmental Impact Statement (EIS) by the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and NOAA Fisheries. The Caspian Tern Management Plan and EIS are mandated by a court-mediated settlement agreement with the goal of reducing predation on salmonids by Caspian terns nesting on East Sand Island in the Columbia River estuary. This annual report on the second year of the study summarizes data collected on nesting Caspian terns during the 2004 breeding season at five different colonies in the San Francisco Bay area (Brooks Island, Knight Island [South Colony], Baumberg Ponds [B10], Alviso Ponds [A-7], and Agua Vista Park) and one colony in coastal Washington (Dungeness Spit, Dungeness National Wildlife Refuge). The purpose of this report is to present results to the funding agency, resource management agencies, and other stakeholders. This report addresses diet composition, colony size, nesting success, and factors limiting colony size and nesting success at these six colonies. The findings presented in this report may change with further review and analysis; results have not yet undergone peer-review. Consequently, these data are not for citation or publication without prior permission from the authors. There were five known breeding colonies of Caspian terns in the San Francisco Bay area in 2004, where approximately 1,350 breeding pairs nested. As was the case in 2003, most breeding pairs in the San Francisco Bay area in 2004 (> 75%) nested at the Brooks Island colony, by far the largest tern colony in the Bay area. Marine forage fishes, in particular anchovies (Engraulidae), surfperch (Embiotocidae), herring (Clupeidae), and silversides (Atherinidae), were the predominant prey types for terns nesting at both the Brooks Island and Agua Vista colonies. At the Knight Island tern colony, however, salmon smolts were the most prevalent prey type (26.1% of prey items), consisting mostly or entirely of Central Valley fall-run chinook salmon (not ESA-listed). In general, juvenile salmonids were more prevalent in tern diets in the San Francisco Bay area in 2004 compared to the previous year, but remained a relatively minor proportion of the diet (< 4% of prey items) at four of the five colonies. The higher prevalence of salmonids in 2004 tern diets was apparently not a result of higher availability of salmonids, but instead a lower availability of marine forage fishes, particularly northern anchovy and surfperch. These two marine prey types were less prevalent in the diet at all Caspian tern colonies in the Bay area in 2004 compared to 2003. Nesting success at Caspian tern colonies in the San Francisco Bay area ranged from 0.00 to 0.82 young fledged/breeding pair, and was lower in 2004 (0.42 young fledged/breeding pair) compared to 2003 (0.59 young fledged/breeding pair). The level of productivity observed at colonies in the San Francisco Bay area over the past two 4 years is considered fair to poor compared to other well-studied Caspian tern colonies in the region. In 2004, the size of the five Caspian tern colonies in the San Francisco Bay area appeared to be primarily limited by the availability of suitable nesting habitat above the high high tide line. Productivity at these colonies was primarily limited by mammalian nest predators (Brooks Island, B-10), tidal inundation of active nests (Knight Island, Brooks Island), human disturbance (Brooks Island), and nest predation by gulls during mammalian nest predator and human disturbance events. The lower overall nesting success in 2004 compared to 2003 was primarily due to higher disturbance and nest predation by mammalian predators (Brooks Island) and a higher incidence of nest inundation during spring tide series (Knight Island). Lower availability of marine forage fishes, particularly northern anchovy and surfperch, may also have been a contributing factor in lower nesting success in 2004. We also studied Caspian tern nesting ecology and diet composition at a colony on the Washington coast in 2004. This Caspian tern colony on Dungeness Spit in Dungeness National Wildlife Refuge evidently formed for the first time during the 2003 nesting season, and was located on sandy substrate amongst driftwood

approximately one mile southwest of the Dungeness Lighthouse National Historic Site. We estimated that there were 233 – 293 breeding pairs at the site, and that 211 – 295 young were fledged or 0.80 – 1.12 young fledged/breeding pair in 2004. Nesting success at Dungeness Spit, considered good compared to other well-studied Caspian tern colonies in the region, was surprisingly high considering that most early nesting attempts at the site failed due to frequent visits to the colony by a coyote. In addition, raccoon, opossum, weasel, and river otter tracks were seen near the colony and a river otter was observed on the colony site during the day. Mammalian predators, and to a lesser extent gull predation and human disturbance, were the primary limiting factors for colony size and nesting success at Dungeness Spit. The diet of terns nesting at Dungeness NWR consisted mostly of surfperch (Embiotocidae; 36%) and salmonids (Salmonidae; 29%). Presumably, some of the salmonid smolts consumed by this tern colony were released from the Dungeness Hatchery, located on the Dungeness River approximately 9 miles upstream from the mouth. We conclude from studies during the 2004 nesting season that (1) juvenile salmonids were a minor component of Caspian tern diets at Brooks Island, B-10, A-7, and Agua Vista, but a major component of the diet at Knight Island and Dungeness Spit, (2) availability of suitable nesting habitat at sites free of mammalian predators was the main factor limiting the number and size of tern colonies in both the San Francisco Bay area and coastal Washington, and (3) nesting success at existing colonies was limited by attributes of those colony sites as they influence (a) vulnerability to mammalian nest predators, (b) vulnerability to inundation during spring tide series, and (c) vulnerability to nest predation from gulls during disturbances caused by human and other mammalian nest predators.

BRNW (Bird Research Northwest). (2005a). *Caspian Tern Nesting Ecology and Diet in San Francisco Bay* (p. 17). http://www.birdresearchnw.org/2005_Final_Site_Feasibility_Report_SFB.pdf

This report summarizes preliminary data collected during the first half of the 2005 breeding season on Caspian terns (Sterna caspia) nesting at six current or former colony sites in the San Francisco Bay Area, California (Brooks Island, Knight Island, Baumberg Ponds [B10], Alviso Ponds [A7], Agua Vista Park, and Coyote Hills [N2A-N3A]). The purpose of this mid-season report is to present preliminary results to the funding agencies, resource management agencies, and other stakeholders on colony size, nesting success, diet composition, and factors limiting colony size and nesting success at these Caspian tern nesting sites. These results are preliminary because they may change as the breeding season progresses and with further analysis; this report has not undergone peerreview. Consequently, these preliminary results are not for citation or publication without prior permission from the authors. Tables 1 – 6 present data on the chronology of Caspian tern nesting activities at the six colony sites under study. Table 7 presents data on the numbers of Caspian terns counted at each of the study colonies each week. Tables 8 - 9 present the currently available data on diet composition at Brooks Island and Knight Island in the San Francisco Bay Area.

BRNW (Bird Research Northwest). (2005b). *Caspian Tern Nesting Ecology and Diet on the Olympic Peninsula, Washington* (p. 26). http://www.birdresearchnw.org/2005_Final_Site_Feasibility_Report_WA.pdf

This 2005 final annual report presents results from the second year of a study investigating colony status and diet composition of Caspian terns (Sterna caspia) nesting on Dungeness Spit in Dungeness National Wildlife Refuge, Washington. We also present data for an incipient Caspian tern colony on warehouse rooftops in the Puget Sound Naval Shipyard, Bremerton, Washington. The purpose of this report is to present results to the funding agency, resource management agencies, and other stakeholders. This report addresses diet composition, colony size, nesting success, and factors limiting colony size and nesting success at these two colony sites. The findings presented in this report may change with further review and analysis; results have not yet undergone peerreview. Consequently, these data are not for citation or publication without prior permission from the authors. The Caspian tern colony on Dungeness Spit in Dungeness National Wildlife Refuge evidently formed for the first time during the 2003 nesting season, and was located on sandy substrate amongst driftwood approximately one kilometer southwest of the Dungeness Lighthouse National Historic Site. In 2005, this tern colony consisted of about 680 breeding pairs, and 417-754 young were fledged (0.61-1.11 fledglings/breeding pair). This represents an increase of about 150% in colony size and similar nesting success, compared to 2004. The Dungeness Spit colony had the highest nesting success of any Caspian tern colony that we monitored during the 2005 nesting season. Unlike 2004, when most early season nesting attempts failed due to frequent visits to the tern colony by a coyote, mammalian predation was not a major factor limiting nesting success at the Dungeness tern colony in 2005. In 2005, gull predation and human disturbance were the primary factors limiting colony size and nesting success at Dungeness Spit; there was no indication that nesting habitat or food availability were limiting factors. The diet of terns nesting at Dungeness NWR consisted mostly of surfperch (Embiotocidae; 31%), salmonids (Salmonidae; 17%), sculpins (Cottidae; 15%), herring and sardines (Clupeidae; 13%), and smelt (Osmeridae; 12%). Salmonid smolts were 45% less prevalent in the diet in 2005 compared to 2004. Presumably, some (most?) of the salmonid smolts consumed by terns nesting at this colony were outmigrants from the nearby Dungeness River, where the Dungeness Hatchery is located approximately 15 km upstream from the mouth. The Caspian tern colony at the Puget Sound Naval Shipyard in Bremerton, estimated to consist of 130 breeding pairs, had low nesting success (49 young were fledged or 0.38 fledglings/breeding pair) compared to the Dungeness Spit colony and other colonies in the region. The primary factors limiting colony size and nesting success were human disturbance and the quality and availability of suitable nesting habitat. The diet of Caspian terns at the Bremerton Naval Shipyard consisted primarily of salmonids (Salmonidae; 34%), surfperch (Embiotocidae; 32%), and herring and sardines (Clupeidae; 19%). We conclude from these studies of Caspian terns nesting on the Olympic Peninsula that (1) terns nesting at Dungeness Spit will continue to be vulnerable to mammalian nest predators without some form of protection (e.g., predator fencing, predator control), (2) in the absence of mammalian nest predators, nesting success at Dungeness Spit will probably be limited by predation by gulls and human disturbance, and (3) the incipient tern colony on warehouse rooftops at the Bremerton Naval Shipyard, as well as documented tern nesting on other rooftops in the Puget Sound area in previous years, provides strong evidence that the availability of suitable nesting habitat for Caspian terns in the Puget Sound region is very limited. Food availability for Caspian terns nesting at Dungeness Spit was good in 2005, despite poor ocean conditions along the coast of the Pacific Northwest, which resulted in widespread nesting failure among piscivorous seabirds. This suggests that, barring disturbance by mammalian nest predators, the Dungeness Spit colony may continue to increase in size in future years.

BRNW (Bird Research Northwest). (2006a). *Caspian Tern Research on the Lower Columbia River, 2003* (p. 38). http://www.birdresearchnw.org/03_Season_Summary.pdf

We initiated a field study in 1997 to assess the impact of predation by Caspian terns (Sterna caspia) on the survival of juvenile salmonids in the lower Columbia River and estuary. Rice Island, a dredged material disposal island at river mile 21, supported a breeding colony of about 17,000 Caspian terns in 1998. This colony was the largest known breeding colony of Caspian terns in the world, and included about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America. Diet analysis indicated that Caspian terns nesting on Rice Island consumed more juvenile salmonids than any other prey type (73% of prey items in 1997 and 1998). Using bioenergetics modeling, we estimated that in 1998 Caspian terns nesting on Rice Island consumed about 12.4 million juvenile salmonids (95% confidence interval = 9.1–15.7 million), or approximately 13% (95% c.i. = 9%–16%) of the estimated 97 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.3% of all PIT-tagged steelhead smolts that reached the estuary were consumed by terns in 1998. The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999. A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 26 km (16 miles) closer to the ocean on East Sand Island (river mile 5), where it was hoped terns would consume fewer salmonids. Habitat restoration, social attraction (decoys and audio playback systems), and selective gull removal were used to encourage terns to nest on East Sand Island. About 1,400 pairs of Caspian terns nested at the new colony site on East Sand Island in 1999. In 2000, about 8,500 pairs of Caspian terns nested on East Sand Island, or 94% of all terns nesting in the estuary. During 2001–2003, all Caspian terns nesting in the Columbia River estuary used East Sand Island. Our results indicated that relocating the tern colony to East Sand Island enhanced the productivity of Caspian terns nesting in the Columbia River estuary. Nesting success of Caspian terns on East Sand Island (1.06 young raised per breeding pair on average during 1999–2003) was consistently higher than for terns nesting on Rice Island, both prior to tern management (0.06 young raised per breeding pair in 1997, 0.45 young per breeding pair in 1998) and post-management (0.55 young per breeding pair in 1999, 0.15 young per breeding pair in 2000). The productivity measured at Rice Island was considerably lower than at other well-studied Caspian tern colonies in North America (range of 0.6– 1.6 young raised per breeding pair; Cuthbert and Wires 1999). Terns nesting on East Sand Island foraged more in marine and brackish water habitats than did the terns nesting on Rice Island. The diet of East Sand Island terns averaged from 31% to 47% salmonids during 1999–2002, compared to the diet of Rice Island terns, which averaged from 73% to 90% salmonids during 1997–2000. The relocation of all nesting terns from Rice Island to East Sand Island resulted in a sharp drop in consumption of juvenile salmonids by terns nesting in the Columbia River estuary. Total consumption of juvenile salmonids in 2000, when most terns nested on East Sand Island, was estimated at 8.2 million (95% c.i. = 6.7–9.7 million), a reduction of about 4.2 million (34%) compared to 1998. Total smolt consumption by Caspian terns nesting on East Sand Island in 2001 and 2002, when all terns nested on East Sand Island, was approximately 5.8 million and 6.5 million, respectively, a 53% and 48% reduction in estimated smolt consumption compared to 1998. In 2003 the estimated size of the Caspian tern colony on East Sand Island was 8,325 nesting pairs. This represents about a 16% decline in the size of the colony compared to the 2002 breeding season. Nesting success at the East Sand Island colony remained high, with an average productivity of 1.08 young raised per breeding pair in 2003. During the 2003 breeding season, the diet of East Sand Island terns averaged 24% salmonids, the lowest proportion of salmonids in the diet so far recorded for this tern colony. Consumption of juvenile salmonids by the East Sand

Island tern colony in 2003 was approximately 4.2 million smolts (95% c.i. = 3.5–4.8 million), ca. 8.2 million fewer smolts consumed compared to 1998, when all terns nested on Rice Island. The factor(s) responsible for the decline in the size of the tern colony in 2003 are not known, but there was no evidence of significant increases in the size of other colonies or formation of sizable new colonies within the breeding range of the Pacific Coast population of Caspian terns. The area of quality nesting habitat prepared for Caspian terns on East Sand Island (6.5 acres) and the area of habitat used by nesting terns (4.5 acres) was very similar to 2002. Marine forage fishes were abundant in the Columbia River estuary and nesting success in 2003 was very similar to 2002, revealing no apparent incentive for Caspian terns to shift to alternative colony sites. The only known Caspian tern breeding colony in the mid-Columbia River during 2003 was on Crescent Island, just below the confluence of the Snake and Columbia rivers. For the second year in a row, no terns attempted to nest at the former colony site on Three Mile Canyon Island, which formerly supported a colony of 200–400 breeding pairs. The tern colony on Crescent Island consisted of about 510 breeding pairs in 2003, a significant decline from the ca. 650 breeding pairs that nested on Crescent Island in 2001. Average nesting success of Caspian terns on Crescent Island in 2003 (0.55 young raised per breeding pair) was also less than in 2001 (1.1 young per breeding pair). The diet of Caspian terns nesting on Crescent Island in 2003 consisted of ca. 68% juvenile salmonids, similar to diets of Crescent Island terns during the 2000-2002 breeding seasons. The tern colony on Crescent Island is the second largest colony of Caspian terns in the Pacific Northwest, second only to the colony on East Sand Island. The trend of declining size at this colony over the last two years supports the hypothesis that Caspian terns that formerly nested on East Sand Island are not shifting to other colonies in the region. Also, the limited area of suitable tern nesting habitat on Crescent Island and the large colony of California gulls on the island suggest that there is little opportunity for expansion of the Crescent Island tern colony. Caspian terns nesting on East Sand Island in 2003 still consumed an estimated 4.2 million smolts, including some ESA-listed stocks. To achieve further reductions in consumption of juvenile salmonids by Caspian terns in the estuary it will likely be necessary to relocate a portion of the East Sand Island colony to alternative sites outside the estuary. Management of island sites for nesting terns has proven to be an effective method to assure adequate distribution of nesting colonies for several tern species, as well as restore colonies that have been abandoned (Kress 2000; Kress and Hall 2002). Food habits studies of terns at sites outside of the Columbia River basin are especially crucial because these data are necessary to assess the potential impacts of larger, permanent tern colonies in a variety of interior and coastal areas. Studies have been initiated recently to develop a better understanding of Caspian tern colony status and diet composition at representative colonies in coastal and interior habitats outside the Columbia River basin. Information from these studies will be used in the development of a Caspian Tern Management Plan and Environmental Impact Statement (EIS) by the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and NOAA Fisheries. The Caspian Tern Management Plan and EIS are mandated by a court-mediated settlement agreement with the goal of reducing predation on salmonids by Caspian terns nesting on East Sand Island while ensuring the protection and conservation of Caspian terns in the Pacific Coast/Western region. Preliminary results from Caspian tern studies conducted in Commencement Bay, Washington, in 2001 and in the San Francisco Bay area and south-central Oregon in 2003 suggest: (1) Caspian terns breeding in the San Francisco Bay area and southcentral Oregon prey mostly on forage fish that are neither listed under the ESA nor of significant economic value for commercial, recreational, or subsistence fisheries, while Caspian terns breeding in Commencement Bay consumed mostly juvenile salmonids, at least early in the nesting season; (2) availability of suitable sites for breeding colonies was the main factor limiting the number and size of tern colonies in each study area, and (3) nesting success at existing colonies was limited by attributes of those colony sites as they influenced (a) quality of nesting substrate, (b) vulnerability to nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance (see Collis et al. 2002 and Roby et al. 2003a). Studies of Caspian tern colony status and diet composition in the Pacific Coast/Western region are ongoing and will be used to help develop management actions aimed at reducing predation on salmonids by Caspian terns nesting on East Sand Island, while ensuring the protection and conservation of Caspian terns in the Pacific Coast/Western region.

BRNW (Bird Research Northwest). (2006b). *Piscivorous Waterbird Research on the Columbia River, 2004* (p. 91). http://www.birdresearchnw.org/04_Season_Summary.pdf

We initiated a study in 1997 to investigate the impacts of piscivorous colonial waterbirds on the survival of juvenile salmonids (Oncorhynchus spp.) in the lower Columbia River (Roby et al. 1998; Collis et al. 2002). The study area included the Columbia River from the mouth (river km 0) to the head of the impoundment created by McNary Dam (river km 553). The species of piscivorous waterbirds investigated were Califonia gulls (Larus californicus), ring-billed gulls (L. delawarensis), glaucous-winged/western gulls (L. glaucescens X L. occidentalis), Caspian terns (Sterna caspia), double-crested cormorants (Phalacrocorax auritus), and, more recently, American white pelicans (Pelecanus erythrorhynchos) and California brown pelicans (Pelecanus occidentalis californicus). This study revealed differences in diet composition among the various bird species and colony locations (Collis et al. 2002). Terns, cormorants, and pelicans were strictly piscivorous, whereas the three gull species consumed a diverse array of food types. Gulls nesting at up-river colonies consumed primarily anthropogenic food items (e.g., cherries, potatoes, human refuse). In general, piscivorous waterbirds nesting in the Columbia River estuary consumed more juvenile salmonids than those nesting up-river. On Rice Island (river km 34), salmonids accounted for 74% of the diet in Caspian terns, 46% in double-crested cormorants, and 11% in glaucous-winged/western gulls (Collis et al. 2002). Juvenile salmonids were especially prevalent in the diets of colonial waterbirds on Rice Island during April and May. By comparison, juvenile salmonids were significantly less prevalent in the diets of cormorants and gulls nesting lower in the estuary on East Sand Island (river km 8), presumably due to the greater availability of marine forage fishes. These results indicated that avian predation on juvenile salmonids in the lower Columbia River is more prevalent in the estuary than near the large up-river gull colonies. Furthermore, the high incidence of salmonids in the diets of Caspian terns, cormorants, and gulls nesting on Rice Island suggested that the impact of avian predation on survival of smolts would be reduced by discouraging piscivorous birds from nesting there, while encouraging nesting on East Sand Island and other sites nearer marine foraging areas. In 1997 and 1998, Caspian terns nesting on Rice Island consumed the highest percentage of juvenile salmonids of those species of piscivorous colonial waterbirds nesting in the estuary (Collis et al. 2002). Rice Island, a dredged material disposal site, supported an expanding colony of about 8,500 breeding pairs of terns in 1998 (Collis et al. 2002). This colony was the largest known Caspian tern breeding colony in the world, and supported about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America (Cuthbert and Wires 1999). Using bioenergetics modeling, it was estimated that in 1998 this tern colony consumed about 12.4 million juvenile salmonids (95% c.i. = 9.1– 15.7 million), or approximately 13% (95% c.i. = 9.1%–16.9%; Roby et al. 2003) of the estimated 96.6 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.5% of all PIT-tagged steelhead smolts (O. mykiss) that reached the estuary were consumed by terns in 1998 (Collis et al. 2001). The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999 (Roby et al. 2002). A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 26 km closer to the ocean on East Sand Island (river km 8), where it was hoped terns would consume fewer salmonids. Efforts to attract terns to nest on East Sand Island included creation of nesting habitat, use of social attraction techniques, and predator control, with concurrent efforts to discourage terns from nesting on Rice Island. This approach was successful, and in three years all nesting terns shifted from Rice Island to East Sand Island. Juvenile salmonids decreased and marine forage fishes (e.g., Pacific herring [Clupea pallasi], anchovies [Engraulidae], smelt [Osmeridae], and surfperch [Embiotocidae]) increased in the diet of Caspian terns nesting on East Sand Island, compared with terns nesting on Rice Island. Our monitoring of tern management in the Columbia River estuary continued in 2004. In 2004 the estimated size of the Caspian tern colony on East Sand Island was approximately 9,500 nesting pairs. This represents about a 14% increase in the size of the colony compared to the 2003 breeding season. Nesting success at the East Sand Island colony remained high, with an average productivity of 0.92 young raised per breeding pair in 2004. During the 2004 breeding season, the diet of East Sand Island terns averaged 17% salmonids, the lowest proportion of salmonids in the diet so far recorded for this tern colony. Consumption of juvenile salmonids by the East Sand Island tern colony in 2004 was approximately 3.5 million smolts (95% c.i. = 2.9–4.0 million), ca. 9 million fewer smolts consumed compared to 1998, when all terns nested on Rice Island. The area of quality nesting habitat prepared for Caspian terns on East Sand Island (6.5 acres) and the area of habitat used by nesting terns (4.7 acres) were similar to the previous two years. Marine forage fishes were abundant in the Columbia River estuary and nesting success in 2004 was similar to 2002 and 2003, revealing no apparent incentive for Caspian terns to shift to alternative colony sites. Although numbers of Caspian terns nesting in the Columbia River estuary have remained stable over the last 8 years, the numbers of double-crested cormorants nesting on East Sand Island have nearly tripled during the same period to ca. 12,500 breeding pairs. This colony is now the largest known breeding colony for the species in North America. Although juvenile salmonids represented only ca. 5% of the diet of cormorants nesting on East Sand Island in 2004, estimated smolt consumption by the cormorant colony (6.4 million smolts; 95% c.i. = 2.5–10.3 million) is now comparable to or greater than that of the East Sand Island tern colony. This is due largely to the greater size of the cormorant colony on East Sand Island and the greater food requirements of cormorants relative to terns. The double-crested cormorant colony on East Sand Island experienced high nesting success in 2004 (2.05 young/breeding pair), more than twice the nesting success experienced by the East Sand Island Caspian tern colony in 2004. This colony is expected to continue to expand for the foreseeable future, perhaps posing an increasing risk to survival of juvenile salmonids in the estuary. The only other known Caspian tern breeding colony on the lower Columbia River during 2004 was on Crescent Island, just below the confluence of the Snake and Columbia rivers. The tern colony on Crescent Island consisted of about 530 breeding pairs in 2004, similar in size to the previous year. Average nesting success of Caspian terns on Crescent Island in 2004 (0.62 young raised per breeding pair) was somewhat greater than in 2003 (0.55 young per breeding pair). The diet of Caspian terns nesting on Crescent Island in 2004 consisted of ca. 70% juvenile salmonids, similar to diets of Crescent Island terns during the 2000-2003 breeding seasons. An estimated 470,000 (95% c.i. = 370,000– 570,000) juvenile salmonids were consumed by Caspian terns nesting on Crescent Island in 2004. Despite the much smaller numbers of salmonid smolts consumed annually by the Crescent Island tern colony compared to the tern and cormorant colonies on East Sand Island, predation rates on particular salmonid stocks were surprisingly high, particularly in low flow years. Preliminary results from 2004 suggest the predation rate by Crescent Island terns on Snake River steelhead smolts was 23%, based on the number of PIT-tagged smolts interrogated at Lower Monumental Dam that were subsequently recovered on the Crescent Island tern colony and corrected for PIT tag collision and detection efficiencies on-colony. In-river steelhead smolts from the Snake River were more vulnerable to tern predation than in-river steelhead smolts from the Upper Columbia (4% of PIT-tagged smolts interrogated at Rock Island Dam were subsequently recovered on the Crescent Island tern colony, corrected for tag collision and detection efficiency). The high predation rate on in-river migrants from the Snake River was, however, offset by the transportation of most juvenile salmonids around the McNary Pool. Conversely, juvenile salmonids from the upper and mid-Columbia River (upstream of McNary Dam) were not transported past Crescent Island, resulting in a much larger proportion of those runs being susceptible to predation by Crescent Island terns. Predation rates on salmonids by Crescent Island terns are unlikely to increase appreciably over those observed in 2004 considering constraints on tern colony expansion, limited capacity for increased per capita smolt consumption by terns, and current high transportation rates for Snake River smolts. In 2004, the largest colony of double-crested cormorants on the Mid-Columbia River consisted of ca. 300 pairs on Foundation Island, near Crescent Island, and the diet of Foundation Island cormorants during the chick-rearing period consisted of < 8% salmonids. The American white pelican colony on nearby Badger Island is also small (< 500 pairs) and, based on smolt PIT tag detections on the pelican colony by NOAA Fisheries, is not a source of significant smolt mortality. A system-wide assessment of avian predation using the available data indicates that the most significant impact on survival of juvenile salmonids occurs in the estuary. Caspian terns and double-crested cormorants nesting on East Sand Island together consumed ca. 10 million smolts in 2004. Additionally, when compared to predation impacts further up river, avian predation that occurs in the estuary affects juvenile salmonids that have survived freshwater migration to the estuary and presumably have a higher probability of survival compared to those fish that have not yet completed their outmigration. Finally, juvenile salmonids from every listed stock from the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary. For these reasons, management of terns and cormorants on East Sand Island has the greatest potential to benefit Columbia River salmonid populations across the basin, when compared to potential management of other bird populations. One possible exception is the Caspian tern colony on Crescent Island, where tern management may benefit some stocks in some years (e.g., Upper Columbia River steelhead ESU, particularly in low flow years). Further management of Caspian terns to reduce losses of juvenile salmonids in the estuary is imminent; the Final Environmental Impact Statement for Caspian tern management in the Columbia River estuary lists the redistribution of approximately two-thirds of the East Sand Island colony to alternative colony sites in Washington, Oregon, and California as the preferred alternative (USFWS 2005). Management options to reduce or cap smolt losses to the expanding double-crested cormorant colony have yet to be considered and will require additional research and NEPA analysis. Relocation of a portion of the cormorants nesting on East Sand Island to alternative sites outside the estuary may be an option. Pilot studies designed to test the feasibility

of employing habitat enhancement and social attraction (i.e., decoys, audio playback systems) to relocate nesting cormorants showed some promise; cormorants were induced to nest at two sites on East Sand Island where they had not previously nested. Restoration, enhancement, or establishment of tern and cormorant colony sites outside the Columbia River estuary would likely benefit Columbia Basin salmonids without negatively affecting protected populations of fish-eating birds.

BRNW (Bird Research Northwest). (2006c). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2005* (p. 130). http://www.birdresearchnw.org/05_Final_Season_Summary.pdf

We initiated a study in 1997 to investigate the impacts of piscivorous colonial waterbirds on the survival of juvenile salmonids (Oncorhynchus spp.) in the lower Columbia River (Roby et al. 1998; Collis et al. 2002). The study area included the Columbia River from the mouth (river km 0) to the head of the impoundment created by McNary Dam (river km 553). The species of piscivorous waterbirds investigated were California gulls (Larus californicus), ring-billed gulls (L. delawarensis), glaucous-winged/western gulls (L. glaucescens X L. occidentalis), Caspian terns (Sterna caspia), double-crested cormorants (Phalacrocorax auritus), and, more recently, American white pelicans (Pelecanus erythrorhynchos) and California brown pelicans (Pelecanus occidentalis californicus). This study revealed differences in diet composition among the various bird species and colony locations (Collis et al. 2002). Terns, cormorants, and pelicans were strictly piscivorous, whereas the three gull species consumed a diverse array of food types. Gulls nesting at up-river colonies consumed primarily anthropogenic food items (e.g., cherries, potatoes, human refuse). In general, piscivorous waterbirds nesting in the Columbia River estuary consumed more juvenile salmonids than those nesting up-river. On Rice Island (river km 34), salmonids accounted for 74% of the diet in Caspian terns, 46% in double-crested cormorants, and 11% in glaucous-winged/western gulls (Collis et al. 2002). Juvenile salmonids were especially prevalent in the diets of colonial waterbirds on Rice Island during April and May. By comparison, juvenile salmonids were significantly less prevalent in the diets of cormorants and gulls nesting above The Dalles Dam, although Caspian terns nesting in the John Day and McNary pools also consumed a high proportion of juvenile salmonids. These up-river Caspian tern colonies combined, however, were only about 1/10th the size of the Rice Island tern colony. These results indicated that avian predation on juvenile salmonids is more prevalent in the Columbia River estuary than in the Lower and Middle Columbia River. Furthermore, the high incidence of salmonids in the diets of Caspian terns, cormorants, and gulls nesting on Rice Island suggested that the impact of avian predation on survival of smolts would be reduced by discouraging piscivorous birds from nesting there, while encouraging nesting on East Sand Island and other sites closer to marine foraging areas. In 1997 and 1998, Caspian terns nesting on Rice Island consumed the highest percentage of juvenile salmonids of those species of piscivorous colonial waterbirds nesting in the Columbia River estuary (Collis et al. 2002). Rice Island, a dredged material disposal site, supported an expanding colony of about 8,500 breeding pairs of terns in 1998 (Collis et al. 2002). This colony was the largest known Caspian tern breeding colony in the world. Using bioenergetics modeling, we estimated that in 1998 this tern colony consumed approximately 13% (95% c.i. = 9.1%–16.9%; Roby et al. 2003) of the estimated 96.6 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.5% of all PIT-tagged steelhead smolts (O. mykiss) that

reached the estuary were consumed by terns in 1998 (Collis et al. 2001). The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999 (Roby et al. 2002). A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 26 km closer to the ocean on East Sand Island (river km 8), where it was hoped terns would consume fewer salmonids. Efforts to attract terns to nest on East Sand Island included creation of nesting habitat, use of social attraction techniques, and predator control, with concurrent efforts to discourage terns from nesting on Rice Island. This approach was successful, and in three years all nesting terns shifted from Rice Island to East Sand Island. Juvenile salmonids decreased and marine forage fishes (e.g., Pacific herring [Clupea pallasi], anchovies [Engraulidae], smelt [Osmeridae], and surfperch [Embiotocidae]) increased in the diet of Caspian terns nesting on East Sand Island compared with terns nesting on Rice Island. Our monitoring of tern management in the Columbia River estuary has continued through the 2005 nesting season. In 2005, the size of the Caspian tern colony on East Sand Island was approximately 8,800 nesting pairs, nearly the same size as the Rice Island tern colony in 1998. Consumption of juvenile salmonids by the East Sand Island tern colony in 2005 was approximately 3.6 million smolts (95% c.i. = 2.0–4.2 million), ca. 9 million fewer smolts consumed compared to 1998, when all terns nested on Rice Island. Caspian terns nesting on East Sand Island continue to rely primarily on marine forage fishes as a food supply, even in 2005 when availability of marine forage fishes declined due to poor ocean conditions. Although numbers of Caspian terns nesting in the Columbia River estuary have remained stable over the last 8 years, the numbers of double-crested cormorants nesting on East Sand Island have nearly tripled during the same period to ca. 12,500 breeding pairs. This colony is now the largest known breeding colony for the species in North America. Although juvenile salmonids represented only ca. 5% of the diet of cormorants nesting on East Sand Island in 2004, estimated smolt consumption by the cormorant colony (6.4 million smolts; 95% c.i. = 2.5–10.3 million) was comparable to or greater than that of the East Sand Island tern colony (CBR 2005). This is due mostly to the larger size of the cormorant colony on East Sand Island and the greater food requirements of cormorants relative to terns. The nesting success of the double-crested cormorant colony on East Sand Island in 2005 (1.38 young/breeding pair) was more than three times the nesting success of the East Sand Island Caspian tern colony. The double-crested cormorant colony is expected to continue to expand for the foreseeable future, perhaps posing an increasing risk to survival of juvenile salmonids in the estuary. The Caspian tern colony on Crescent Island in the mid-Columbia River is the largest of its kind on the Columbia Plateau (Antolos et al. 2004). But the Crescent Island tern colony, which consisted of ca. 476 nesting pairs in 2005, is roughly 1/20th the size of the East Sand Island tern colony in the Columbia River estuary. At Crescent Island, salmonid smolts represented about 65% of tern prey items in 2005. Consumption of juvenile salmonids by the Crescent Island tern colony was approximately 440,000 smolts (95% c.i. = 340,000–550,000 smolts) in 2005, compared to about 3.6 million smolts consumed by East Sand Island terns during the same year. Despite the much smaller numbers of salmonid smolts consumed annually by the Crescent Island tern colony, predation rates on certain salmonid stocks have been unexpectedly high, particularly on some steelhead stocks during years of low river flow. For example, PIT tag recoveries on the tern colony in 2004 and 2005 (low flow years) indicate that the predation rate by Crescent Island terns on in-river Snake River steelhead smolts was 34% and 17%, respectively (based on the proportion of PIT-tagged smolts interrogated at Lower Monumental Dam that were subsequently recovered on the Crescent Island tern colony). In-river steelhead smolts from the Snake River were more vulnerable to tern predation than in-river steelhead smolts from the Upper and Middle Columbia River (predation rates between ca. 6% and 4%, based on the proportion of PIT-tagged smolts interrogated at Rock Island Dam that were subsequently recovered on the Crescent Island tern colony in 2004 and 2005). The higher predation rate on in-river migrants from the Snake River, however, was offset by the transportation of > 95% of Snake River steelhead smolts past Crescent Island. Conversely, no juvenile salmonids that originated from the Upper Columbia River were transported past Crescent Island, resulting in the entire run being susceptible to predation by Crescent Island terns. Predation rates on salmonids by Crescent Island terns are unlikely to increase appreciably considering habitat constraints on tern colony expansion, limited capacity for increased per capita smolt consumption by terns, and current high transportation rates past Crescent Island for Snake River smolts. The colony of double-crested cormorants on Foundation Island, near the confluence of the Snake and Columbia rivers and less than 8 Rkm from Crescent Island, is the largest cormorant colony on the mid-Columbia River. This colony consisted of over 315 breeding pairs in 2005, only about 1/40th the size of the cormorant colony on East Sand Island in the Columbia River estuary. The proportion of juvenile salmonids in the diet of Foundation Island cormorants was much less than that of Crescent Island terns, but the incidence of salmonids in the diet of Foundation Island cormorants was much higher early in the nesting season than during the chick-rearing period. A comparison of PIT tag recovery rates between the Crescent Island tern colony and Foundation Island cormorant colony suggests that the cormorants consumed ca. 1/4th as many smolts as the terns in 2005. The Foundation Island cormorant colony is growing slowly, however, and the consumption of salmonids, especially early in the season, appears to be increasing. The American white pelican colony on nearby Badger Island is also growing (> 500 pairs in 2005), but based on smolt PIT tag detections on the pelican colony by NOAA Fisheries, this colony is not a source of significant smolt mortality. For example, only 611 smolt PIT tags were recovered on the Badger Island pelican colony in 2005, compared to 16,003 smolt PIT tags and 4,101 smolt PIT tags recovered from the upriver tern and cormorant colonies, respectively. A system-wide assessment of avian predation using the available data indicates that the most significant impact on survival of juvenile salmonids occurs in the estuary. Caspian terns and double-crested cormorants nesting on East Sand Island together consumed ca. 10 million smolts in 2004 (CBR 2005). Additionally, when compared to the impact of avian predation further up-river, avian predation that occurs in the estuary affects juvenile salmonids that have survived freshwater migration to the estuary and presumably have a higher probability of survival compared to those fish that have not yet completed their out-migration. Finally, juvenile salmonids from every ESA-listed stock in the Columbia River Basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary. For these reasons, management of terns and cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonids across the Columbia Basin, compared to management of other bird populations. One possible exception is the Caspian tern colony on Crescent Island, where tern management may benefit certain ESA-listed ESUs of steelhead. Further management of Caspian terns to reduce losses of juvenile salmonids in the estuary is imminent; the Caspian Tern Management Plan for the Columbia River Estuary lists as the management goal the redistribution of approximately two-thirds of the East Sand Island colony to alternative colony sites in Washington, Oregon, and California (USFWS 2005). Management to reduce or limit smolt losses to the expanding double-crested cormorant colony in the estuary and the Caspian tern colony on Crescent Island in the mid-Columbia River are under consideration. Options for management initiatives to reduce the impact of these avian predators

on survival of ESA-listed salmonid smolts include partial or complete relocation of these colonies to alternative sites where Columbia Basin salmonids would not constitute a significant proportion of the diet. Colony relocation would likely involve a combination of attraction to the new site using habitat enhancement, social attraction, and nest predator deterrence, coupled with reductions in the availability of suitable nesting habitat at the old colony site. Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., decoys, audio playback systems) for relocating nesting cormorants have shown some promise; cormorants were induced to nest at two sites on East Sand Island where they had not previously nested, and one site on Miller Sands Spit where they had not attempted to nest in several years. Restoration, enhancement, or establishment of tern and cormorant colony sites outside the Columbia River estuary would likely benefit Columbia Basin salmonids without negatively affecting protected populations of fish-eating birds. If resource management agencies decide that further management of avian predators (e.g., the East Sand Island cormorant colony, the Crescent Island tern colony) is warranted to increase survival of ESA-listed salmonids, additional research in support of a Draft EIS will be required.

BRNW (Bird Research Northwest). (2006d). *Observations of Caspian Terns Nesting at Dungeness National Wildlife Refuge and Distribution of Gull Colonies in Puget Sound, Washington* (p. 21). http://www.birdresearchnw.org/06_Final_Site_Feasibility_Report_v2.pdf

This 2006 draft annual report presents observations from the third year of an ongoing study investigating colony status of Caspian terns (Hydroprogne caspia) at Dungeness National Wildlife Refuge. In addition, we present data collected during a visit to the Naval Base Kitsap Bremerton, where another colony of Caspian terns exists, as well as results from an aerial survey of the Puget Sound area to document the distribution of nesting gulls (Larus spp.). This report includes observations on colony size, nesting success, factors limiting colony size and nesting success, and diet composition of Caspian terns nesting at Dungeness NWR, but due to budget constraints the quantity and frequency of data collected at this colony in 2006 is much less than in 2004 and 2005. Consequently, interpretations of the results from 2006 are more prone to error. For the first time in 2006, we flew an aerial survey of much of the Puget Sound coastline, searching for colonies of gulls, especially colonies on the roofs of warehouses and other anthropogenic structures. The purpose of this report is to present results to the funding agency for review. The findings presented in this report may change with further review and analysis; results have not yet undergone peer-review. Consequently, these data are not for citation or publication without prior permission from the authors. The Caspian tern colony on Dungeness Spit in Dungeness National Wildlife Refuge in 2006 was located close to the colony site used in 2003-2005. Our best estimate of the peak number of breeding pairs of Caspian terns at the Dungeness Spit colony in 2006 was 795, but this estimate is approximate because the colony was highly asynchronous. This represents a 17% increase in colony size compared to 2005 and a 202% increase in colony size from 2004. We estimate that in 2006 149-301 young fledged or 0.19-0.38 young were fledged/breeding pair. Nesting success in 2006 was much lower than that of the previous two years (0.80-1.12 and 0.61-1.11 fledglings/breeding pair in 2004 and 2005, respectively), and is considered low compared to other colonies in the region. In 2006, we observed nest predation by coyotes, resulting in a complete failure of the first nesting attempt at the colony. The diet of terns nesting at Dungeness NWR in 2006 consisted mostly of surfperch (Embiotocidae; 33%), sculpin (Cottidae; 24%) and salmonids (Salmonidae; 22%), but these percentages are based on limited sample sizes of visually identifiable prey fish (n = 552).

Relatively low food availability may have contributed to the lower nesting success in 2006. The Caspian tern colony at the Naval Base Kitsap in Bremerton was observed on only one occasion during the breeding season. The colony was estimated to consist of as many as 500 breeding pairs; no estimate of nesting success was possible. A total of 9,882 gulls and 3,640 gull nests were counted in aerial photographs of gull colonies taken in the Puget Sound area. Of the gull colonies photographed, about 1,550 gull nests were counted on Protection Island (42%), about 300 on Graveyard Spit in Dungeness NWR (8%), about 300 on Smith Island (8%), about 300 at Pier 90 in Seattle (8%), about 250 on Padilla Bay dredge spoil islands (7%), about 250 at the Naval Base in Bremerton (7%), and about 200 in the Port of Tacoma (5%). The counts of gull nests at Protection Island and Bremerton are likely underestimates. At least 71% of all gull nests at the surveyed colonies were in natural habitat and at most 29% were located on rooftops in urban areas.

BRNW (Bird Research Northwest). (2007). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2006* (p. 153). http://www.birdresearchnw.org/06_Final_Season_Summary.pdf

This study investigates predation by piscivorous waterbirds on juvenile salmonids (Oncorhynchus spp.) from throughout the Columbia River Basin. During 2006, study objectives in the Columbia River estuary, work funded by the Bonneville Power Administration, were to (1) monitor and evaluate previous management initiatives to reduce Caspian tern (Hydroprogne caspia) predation on juvenile salmonids (smolts); (2) measure the impact of double-crested cormorant (Phalacrocorax auritus) predation on smolt survival, and assess potential management options to reduce cormorant predation; and (3) monitor large colonies of other piscivorous waterbirds in the estuary (i.e., glaucous-winged/western gulls [Larus glaucescens/occidentalis]) to determine the potential impacts on smolt survival. Study objectives on the mid-Columbia River, work funded by the Walla Walla District of the U.S. Army Corps of Engineers, were to (1) measure the impact of predation by Caspian terns and double-crested cormorants on smolt survival; and (2) monitor large nesting colonies of other piscivorous waterbirds (i.e., California gulls (L. californicus], ring-billed gulls [L. delawarensis], American white pelicans [Pelecanus erythrorhynchos]) on the mid-Columbia River to determine the potential for significant impacts on smolt survival. Our efforts to evaluate system-wide losses of juvenile salmonids to avian predation indicated that Caspian terns and double-crested cormorants were responsible for the vast majority of smolt losses to avian predators in the Columbia Basin, with most losses occurring in the Columbia River estuary. In 2006, East Sand Island in the Columbia River estuary supported the largest known breeding colonies of Caspian terns and double-crested cormorants in the world. The Caspian tern colony on East Sand Island consisted of about 9,200 breeding pairs in 2006, up slightly (but not significantly so) from the estimate of colony size in 2005 (8,820 pairs). There has not been a statistically significant change in the size of the Caspian tern colony on East Sand Island since 2000. Tern nesting success averaged 0.72 fledglings per breeding pair in 2006, significantly higher than in 2005 (0.37 fledglings per breeding pair), a year of poor ocean conditions. Despite the presumably higher availability of marine forage fishes in 2006, the proportion of juvenile salmonids in diets of Caspian terns (32% of prey items) averaged higher than in 2005 (23% of prey items) and 2004 (18% of prey items). Steelhead smolts were particular vulnerable to predation by East Sand Island terns in 2006, with predation rates as high as 20% on particular groups of PIT-tagged fish reaching the estuary. Consumption of juvenile salmonids by terns nesting at the East Sand Island colony in 2006 was approximately

5.3 million smolts (95% c.i. = 4.4 – 6.2 million), significantly higher than the estimated 3.6 million smolts consumed in 2005, but still roughly 7 million fewer smolts consumed compared to 1998 (when all terns nested on Rice Island in the upper estuary). Caspian terns nesting on East Sand Island continue to rely primarily on marine forage fishes as a food supply, even in 2005 when availability of marine forage fishes declined due to poor ocean conditions. Further management of Caspian terns to reduce losses of juvenile salmonids would be implemented under the Caspian Tern Management Plan for the Columbia River Estuary; the Records of Decision (RODs) authorizing implementation of the plan were signed in November 2006. The ROD lists as the management goal the redistribution of approximately half of the East Sand Island Caspian tern colony to alternative colony sites in interior Oregon and San Francisco Bay, California (USFWS 2006). Implementation of the management plan is stalled, however, because of the lack of appropriated funds. The double-crested cormorant colony on East Sand Island consisted of about 13,740 breeding pairs in 2006, a record high estimate for size of this colony, up about 10% from the estimate in 2005 (12,290 pairs) and 2004 (12,480 pairs). Since our monitoring began in 1997, this cormorant colony has increased by about 275%. Nesting success in 2006 (1.92 fledglings per breeding pair) was up considerably from 2005 (1.38 fledglings per breeding pair), when it was comparatively low due to poor ocean conditions. Despite relatively low availability of marine forage fish in 2005, juvenile salmonids represented only ca. 2% of cormorant diets, compared with 23% of Caspian tern diets in the same year. Because of the low proportion of salmonids in the diet of East Sand Island cormorants during 2005, the estimate of total smolt consumption by cormorants (3.0 ± 1.0 million) was similar to that of East Sand Island Caspian terns (3.6 ± 0.3 million) in the same year; in 2004 the estimate of salmonid smolt consumption by East Sand Island cormorants (6.4 ± 2.0 million) exceeded the estimated consumption by East Sand Island terns (3.5 ± 0.3 million). In 2005, estimated losses of spring/summer (yearling) Chinook salmon, coho salmon, and steelhead smolts due to cormorant predation in the estuary were significantly less than losses due to Caspian tern predation, but losses of fall (subyearling) Chinook salmon due to cormorant predation were much greater than losses due to tern predation. Data on diet composition and smolt consumption of double-crested cormorants nesting on East Sand Island (based on analysis of adult foregut samples) in 2006 are pending. A relative comparison of predation rates on juvenile salmonids between terns and cormorants in 2006 was, however, calculated based on smolt PIT tag recoveries on the two colonies. These data indicated that East Sand Island cormorants consumed more PIT-tagged salmonid smolts than did East Sand Island terns in 2006. PIT tags from all species of anadromous salmonids (i.e., Chinook salmon, coho salmon, sockeye salmon, steelhead, and sea-run cutthroat trout), from all run-types (fall, winter, summer, and spring), and from all ESUs were recovered on the East Sand Island cormorant colony in 2006. The numbers of PIT tags from the various salmonid species that were recovered on the cormorant colony were mostly proportional to the relative availability of PIT-tagged salmonids, suggesting that cormorant predation on salmonids was less selective than tern predation. In contrast, PIT tag recoveries on the East Sand Island tern colony indicated that steelhead were far more vulnerable to Caspian tern predation as compared to other salmonid species in the estuary. If the cormorant breeding colony on East Sand Island continues to expand and/or the proportion of salmonids in cormorant diets increases, cormorant predation rates on juvenile salmonids may far exceed those of Caspian terns nesting in the estuary. Resource management agencies have not decided whether management of the large and expanding colony of double-crested cormorants on East Sand Island is warranted. Elsewhere in North America, management of double-crested cormorants has consisted primarily of lethal control (i.e., shooting of adults, egg oiling, and destruction of nests in trees). Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the coast of Oregon and Washington, seem more appropriate in the context of the cormorant colony on East Sand Island, which constitutes nearly 50% of the entire breeding population of the Pacific Coast subspecies P. auritus albociliatus. Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., decoys, audio playback systems) to relocate nesting cormorants have shown some promise; cormorants were attracted to nest and nested successfully (raised young to fledging) on Miller Sands Spit and Rice Island, two islands in the upper estuary where no successful cormorant nesting attempts have been recorded recently. In order to reduce cormorant predation on juvenile salmonids from the Columbia Basin, however, it will be necessary to relocate nesting cormorants to suitable habitat outside the Columbia River estuary. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses will likely require additional research and NEPA analysis, including assessments of (1) population status of the Pacific Coast subspecies of double-crested cormorant, (2) available suitable nesting habitat for the subspecies outside the Columbia River estuary, and (3) the potential enhancement of salmonid recovery rates in the Columbia River Basin due to management of cormorants in the estuary. The Caspian tern colony on Crescent Island in the mid-Columbia River has received comparatively little attention from salmon management agencies because of its relatively small size (ca. 500 nesting pairs, ca. 1/20th the size of the tern colony in the estuary) and low annual consumption of juvenile salmonids (ca. 500,000 smolts, ca. 1/10th the consumption of the tern colony in the estuary). In 2006, there were two breeding colonies of Caspian terns on the mid-Columbia River; about 448 pairs nested on Crescent Island (Rkm 510 in the McNary Pool), and about 110 pairs nested at a new colony site on Rock Island (Rkm 445 in the John Day Pool). The Crescent Island tern colony declined by 6% from 2005, but is still the largest Caspian tern colony on the Columbia Plateau and the third largest colony in the Pacific Northwest. The Rock Island Caspian tern colony increased dramatically from 2005, the first year that Caspian terns were known to nest there, when only 6 pairs nested. Nesting success at the Crescent Island tern colony was only 0.43 young fledged per breeding pair, down 22% from 2005, and the lowest nesting success so far recorded at this colony. The Rock Island Caspian tern colony completely failed in 2006 due to mink predation on eggs and chicks. At Crescent Island, salmonid smolts represented 63% of prey items in tern diets during 2006, similar to 2005. Although no diet data were collected at the Rock Island tern colony prior to nesting failure, 731 smolt PIT tags were recovered on the colony, indicating that salmonids were a significant part of the diet. A comparison of smolt PIT tags recovered from the Crescent Island and Rock Island tern colonies suggests that Rock Island terns consumed roughly 1/6th as many PIT-tagged salmonid smolts as Crescent Island terns. Total salmonid consumption by Crescent Island terns in 2006 was ca. 402,000 smolts, about 9% lower than in 2005 (ca. 442,000 smolts). However, the estimate of steelhead consumption by Crescent Island terns in 2006 was 56,000 smolts, up 22% from the 2005 estimate. Based on smolt PIT tag recoveries on the Crescent Island Caspian tern colony, the predation rate on in-river migrants from the Snake River (all species and run types) was about 3.8% in 2006, down substantially from 7.5% in 2005. These predation rates were corrected for both the detection efficiency of PIT tags on-colony and the proportion of PIT tags ingested by terns that were subsequently deposited on-colony. As in previous years, predation rates on PIT-tagged steelhead smolts were greater than for other salmonid species. In 2006, ca. 12.3% of hatchery-reared, in-river steelhead smolts from the

Snake River were consumed by Crescent Island terns, compared to about 7.5% of wild, in-river steelhead smolts. The comparable predation rates in 2005 were 18.6% and 14.5%, respectively (these predation rates are based on the number of PIT-tagged fish interrogated passing Lower Monumental Dam between 1 April and 31 July that were subsequently detected on the Crescent Island tern colony). Because fewer Snake River steelhead were transported around McNary Pool in 2006 compared to 2005, however, a larger proportion of the Snake River steelhead population was susceptible to predation from Crescent Island terns in 2006, which corresponds with the higher total consumption of steelhead by Crescent Island terns in 2006 compared to 2005. In 2006, the double-crested cormorant colony on Foundation Island in the mid-Columbia River consisted of > 360 nesting pairs, about 14% larger than in 2005. The largest cormorant colony on the Columbia Plateau, however, was on Potholes Reservoir, where about 1,160 pairs nested in trees at the north end of the reservoir, also an increase over 2005. Colony counts suggest that both the number of cormorant colonies and the size of the cormorant breeding population on the Columbia Plateau are increasing. The limited diet data for Foundation Island cormorants suggest that juvenile salmonids represent 10- 20% of the diet. Predation rates on smolts by cormorants nesting on Foundation Island, based on smolt PIT tags recovered on-colony, were roughly 1/3rd of those by Crescent Island terns, an increase compared to 2005, when cormorant predation rates were about 1/4th those of terns. Similar to predation by Crescent Island terns, Snake River steelhead were particular vulnerability to predation by Foundation Island cormorants in 2006. Unlike terns, however, Foundation Island cormorants also keyed in on groups of Chinook salmon (both yearlings and sub-yearlings) from the Walla Walla and Yakima rivers. Currently, there is very little evidence to suggest that cormorants nesting at the colony on Potholes Reservoir are affecting the survival of juvenile salmonids from the Columbia and Snake rivers, based on the paucity of PIT tags from Columbia Basin salmonid smolts recovered at the colony in recent years. Compared to Caspian terns and double-crested cormorants, other piscivorous colonial waterbirds (i.e., California gulls, ring-billed gulls, American white pelicans) that nest on the Columbia Plateau are having little impact on the survival of juvenile salmonids from the Columbia and Snake rivers. Previous research indicated that fish, and salmonids in particular, constituted a very small proportion of the diet of California and ring-billed gulls nesting at up-river colonies in 1997 and 1998 (Collis et al. 2002). PIT tag recoveries during 2006 indicated that gulls nesting at up-river colonies on Miller Rocks and Three Mile Canyon Island, plus American white pelicans nesting on Badger Island, consumed between 0.04 and 0.61 PIT-tagged smolts per nesting adult. In contrast, Caspian terns and double-crested cormorants nesting at Crescent Island and Foundation Island consumed between 7.2 and 15.1 PIT-tagged smolts per adult. The size of some up-river gull colonies (> 10,000 breeding pairs on several islands) and the Badger Island pelican colony (> 500 pairs), however, exceeds that of the up-river tern and cormorant colonies and should be taken into account when evaluating over-all impacts on salmonid survival. Furthermore, the high variability in per-capita PIT tag consumption rates suggests that certain gull colonies (i.e., Miller Rocks) may pose a greater threat to survival of juvenile salmonids than others (i.e., Three Mile Canyon Island), and continued monitoring of certain gull colonies may be warranted. In contrast to the gulls and pelicans nesting at up-river locations, previous research on glaucous-winged/western gulls nesting in the Columbia River estuary indicated that these birds consumed primarily fish (Collis et al. 2002). Gulls nesting on Rice Island (river km 34) also ate mostly riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice

Island/Miller Sands Spit and East Sand Island, respectively. PIT tag studies have not been conducted on these colonies, nor have diet data been collected since 1998. As such, the current impact of gulls nesting at these estuary colonies on survival of salmonid smolts is unknown. A system-wide assessment of avian predation on juvenile salmonids using the available data from recent years indicates that the most significant impact to smolt survival occurs in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combining to consume ca. 7-10 million smolts in 2004 and 2005. Although estimates of smolt consumption for East Sand Island cormorants in 2006 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2006 are in this range, if not higher. The PIT tag recovery data from 2006 corroborates this prediction. Estimated smolt losses to piscivorous birds that nest in the estuary are more than an order of magnitude greater than what has been observed on the mid-Columbia River. Additionally, when compared to the impact of avian predation on the mid-Columbia, avian predation in the estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults compared to those fish that have yet to complete outmigration. Finally, juvenile salmonids belonging to every ESA-listed stock from the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary to reach the ocean. For these reasons, management of terns and cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other bird populations. The Caspian tern colony on Crescent Island may be an exception to this rule; management of this small, up-river colony may benefit certain salmonid stocks, particularly steelhead in low flow years.

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This study investigates predation by piscivorous colonial waterbirds on juvenile salmonids (Oncorhynchus spp.) from throughout the Columbia River Basin. The study objectives for the Columbia River estuary in 2007, work funded by the Bonneville Power Administration, were to (1) monitor and evaluate previous management initiatives to reduce Caspian tern (Hydroprogne caspia) predation on juvenile salmonids (smolts); (2) measure the impact of double-crested cormorant (Phalacrocorax auritus) predation on smolt survival; (3) assess potential management options to reduce cormorant predation; and (4) monitor large colonies of other piscivorous waterbirds in the estuary (i.e., glaucous-winged/western gulls [Larus glaucescens/occidentalis]) to determine potential impacts on smolt survival. The study objectives for the middle Columbia River in 2007, work funded by the Walla Walla District of the U.S. Army Corps of Engineers, were to (1) measure the impact of predation by Caspian terns and double-crested cormorants on smolt survival in the mid-Columbia River; and (2) monitor large nesting colonies of other piscivorous waterbirds (i.e., California gulls (L. californicus], ring-billed gulls [L. delawarensis], and American white pelicans [Pelecanus erythrorhynchos]) on the mid-Columbia River to determine the potential for significant impacts on smolt survival. Our previous studies to evaluate system-wide losses of juvenile salmonids to avian predation indicated that Caspian terns and double-crested cormorants nesting in the Columbia River estuary were responsible for the vast majority of smolt losses to avian predators in the Columbia Basin. Again in 2007, East Sand Island in the Columbia River estuary supported the largest known breeding colonies of Caspian terns and double-crested cormorants in the world. The Caspian tern colony on East Sand Island consisted of ca. 9,900 breeding pairs in 2007, not significantly different than in 2006 (ca. 9,200 pairs). The size of the Caspian tern colony at East Sand Island has remained nearly stable since 2000. Tern nesting success averaged 0.64 fledglings per breeding pair in 2007, similar to 2006 (0.72 fledglings per breeding pair). Nesting success during 2005-2007 has been lower than during 2001-2004, when nesting success averaged 1.12 fledglings per breeding pair. The proportion of juvenile salmonids in the diet of East Sand Island Caspian terns during the 2007 nesting season averaged 30% of prey items, similar to 2006 (31% of prey items), but higher than in 2004 (17% of prey items) or 2005 (23% of prey items). Consumption of juvenile salmonids by terns nesting at the East Sand Island colony in 2007 was approximately 5.5 million smolts (95% c.i. = 4.8 – 6.2 million), similar to smolt consumption the previous year (best estimate = 5.4 million smolts; 95% c.i. = 4.6 – 6.1 million). This is less than half the annual consumption of juvenile salmonids by Caspian terns in the estuary prior to 2000, when their breeding colony was located on Rice Island in the upper estuary. Caspian terns nesting on East Sand Island continued to rely primarily on marine forage fishes (i.e., northern anchovy, shiner perch, Pacific herring) as a food supply. Based on smolt PIT tag recoveries on the East Sand Island Caspian tern colony, predation rates on steelhead smolts were particularly high during 2007, at about 14.1% for in-river migrant smolts and 7.7% for transported smolts. Predation rates on steelhead were 2-12 times higher than those for other salmonid species and run-types. In 2008, the U.S. Army Corps of Engineers will begin implementing the plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary," outlined in the Final Environmental Impact Statement (FEIS) and Records of Decision (RODs) signed in November 2006. This management plan seeks to redistribute a portion of the East Sand Island tern colony to alternative colony sites in Oregon and California by 2015. The plan calls for the creation of up to 7 acres of new or enhanced tern nesting habitat in interior Oregon (i.e., Fern Ridge Lake, Crump Lake, and Summer Lake) and coastal California (i.e., the San Francisco Bay Area) and to actively attract terns to nest there. As alternative tern nesting habitat is created or enhanced, the available tern nesting habitat on East Sand Island will be reduced from its current size (6 acres) to 1.5 – 2 acres. Habitat enhancement at alternative sites will be accomplished in stages and the reduction of tern nesting habitat at East Sand Island will occur at a ratio of one acre reduced for each 2 acres of habitat created elsewhere. Once fully implemented, the plan would reduce the East Sand Island Caspian tern colony from its current size (approximately 9,500 nesting pairs) to approximately 3,100 – 4,400 nesting pairs. This reduction in the size of the East Sand Island tern colony is intended to reduce tern predation on smolts in the Columbia River estuary by an estimated 2.4 – 3.1 million smolts annually. The double-crested cormorant colony on East Sand Island consisted of about 13,770 breeding pairs in 2007, similar to the estimate of colony size last year (13,740 pairs). Since our monitoring began in 1997, this cormorant colony has increased by about 275%. Nesting success in 2007 (2.78 fledglings per breeding pair) was the highest ever recorded for this colony, and up considerably from 2006 (1.92 fledglings per breeding pair). As in previous years, salmonids made up a small portion (9%) of the cormorant diet in 2007, while marine forage fish (i.e., northern anchovy) and estuarine resident fish (i.e., sculpin, flounder) made up over 50% of the diet. Despite the lower reliance on salmonids as a food source by cormorants compared to terns, total smolt consumption by cormorants was similar to or greater than that by terns. This is because double-crested cormorants are about four times larger than Caspian terns and the cormorant colony consists of about 40% more nesting pairs than the tern colony. In 2006, cormorants nesting on East Sand Island consumed an estimated 10.3 million juvenile salmonids (95% c.i. = 4.7 – 15.9 million), compared to an estimated 5.4 million juvenile salmonids (95% c.i. = 4.6 – 6.1 million) consumed by terns nesting on East Sand Island (estimates of cormorant consumption of salmonid smolts in 2007 are pending further analyses). An analysis of salmonid PIT tags detected at the double-crested cormorant colony on East Sand Island indicated that all species of anadromous salmonids (i.e., Chinook salmon, coho salmon, sockeye salmon, steelhead, and sea-run cutthroat trout) from all run-types (fall, winter, summer, and spring), and from all tagged ESUs were susceptible to cormorant predation in 2007. The numbers of PIT tags from the various salmonid species and run-types that were recovered on the cormorant colony were roughly proportional to the relative availability of PIT-tagged salmonids released in the basin, suggesting that cormorant predation on salmonid smolts in the estuary was less selective than tern predation. In contrast, PIT tag recoveries on the East Sand Island tern colony indicated that steelhead were far more vulnerable to Caspian tern predation as compared to other salmonid species. An analysis of salmonid predation rates, based on the proportion of available PIT-tagged fish subsequently deposited on the cormorant colony, indicated that both hatchery and wild smolts were consumed, with rates averaging between 2 and 5% for most species and run-types of PIT-tagged fish originating upstream of Bonneville Dam. Predation rates in excess of 20% were observed for some groups of hatchery fall Chinook salmon released in or near the estuary. If the cormorant breeding colony on East Sand Island continues to expand and/or the proportion of salmonids in cormorant diets increases, cormorant predation rates on juvenile salmonids may far exceed those of Caspian terns nesting in the estuary. The discrepancy in predation rates for the two colonies will be even greater if the Caspian tern colony is reduced in size by >50% by 2015, as intended under the management plan now being implemented. Resource management agencies have not decided whether management of the large and expanding colony of double-crested cormorants on East Sand Island is warranted. Elsewhere in North America, management of double-crested cormorants has consisted primarily of lethal control (i.e., shooting of adults, oiling of eggs, and destruction of nests in trees). Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the coast of Oregon and Washington, seem more appropriate in the context of the cormorant colony on East Sand Island, which constitutes nearly 50% of the entire breeding population of the Pacific Coast subspecies P. auritus albociliatus. Studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., old tires with nest material, decoys, audio playback systems) to relocate nesting cormorants have shown some promise; cormorants were previously attracted to nest and nested successfully (raised young to fledging) on Miller Sands Spit and Rice Island, two islands in the upper estuary where no successful cormorant nesting attempts have been recorded recently. In 2007, habitat enhancement and social attraction were retained at Miller Sands Spit, but removed from Rice Island; the cormorant colony on Miller Sands Spit was again successful in raising young, while there was no cormorant nesting on Rice Island. In order to reduce cormorant predation on juvenile salmonids from the Columbia Basin, however, it will be necessary to relocate nesting cormorants to suitable habitat outside the Columbia River estuary. In 2007, we conducted a pilot study to test the feasibility of attracting double-crested cormorants to nest at a site remote from the Columbia River estuary and where cormorants had not previously been known to nest. We placed old tires with nest material, cormorant decoys, and audio playbacks of cormorant colony sounds on a floating platform in the Fern Ridge Wildlife Area, adjacent to Fern Ridge Lake near Eugene, Oregon. While double-crested cormorants were repeatedly seen in the area, no cormorants were seen on the platform and no nesting attempts occurred there. This pilot study will be repeated in 2008. While studies of the use of habitat enhancement and social attraction in the Columbia River estuary have been promising, results to date indicate that double-crested cormorants are not as responsive to these techniques as Caspian terns. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses will likely require additional research and analysis under NEPA, including assessments of (1) the population status of the Pacific Coast subspecies of double-crested cormorant, (2) the availability of suitable nesting habitat for the subspecies outside the Columbia River estuary, and (3) the potential enhancement of salmonid recovery rates in the Columbia River Basin due to management of cormorants in the estuary. These and other related studies are planned for 2008 and beyond. The Caspian tern colony on Crescent Island in the mid-Columbia River has received comparatively little attention from salmon management agencies because of its relatively small size (ca. 500 nesting pairs, ca. 1/20th the size of the Caspian tern colony in the estuary) and low annual consumption of juvenile salmonids (ca. 0.5 million smolts, ca. 1/10th the consumption of the tern colony in the estuary). In 2007, there were two breeding colonies of Caspian terns on the mid-Columbia River; about 355 pairs nested on Crescent Island in the McNary Pool and about 40 pairs nested at a relatively new colony site on Rock Island in the John Day Pool. The Crescent Island tern colony declined by 21% from 2006, when 448 breeding pairs nested at the colony; this colony is now smaller than in any year since 1997. It is still the largest Caspian tern colony on the Columbia Plateau, however, and the third largest Caspian tern colony in the Pacific Northwest. The Rock Island Caspian tern colony in 2007 was substantially smaller than in 2006, when 110 breeding pairs attempted to nest there, but was larger than in 2005 (6 breeding pairs), the first year that Caspian terns were known to nest on Rock Island. Nesting success at the Crescent Island tern colony was 0.68 young fledged per breeding pair, up 58% from 2006 (0.43 young fledged per breeding pair). Tern productivity at the Crescent Island colony in 2006 was the lowest recorded at this colony since monitoring began in 2000. In 2007, the Rock Island Caspian tern colony failed to produce any young, apparently due to avian predation on all tern eggs and chicks. In 2006, the Rock Island Caspian tern colony also failed, apparently due to mink predation. At Crescent Island in 2007, salmonid smolts represented 69% of prey items in tern diets, up slightly from 2006 (63%). We estimated that Caspian terns nesting on Crescent Island in 2007 consumed 360,000 juvenile salmonids (95% c.i. = 250,000 – 460,000), a ca. 10% decline in smolt consumption compared to 2006 (best estimate = 402,000, 95% c.i. = 310,000–500,000). Steelhead comprised an estimated 20.5% of the identifiable salmonid smolts, or roughly 74,000 fish, an increase over the previous year (56,000 fish). Per capita smolt consumption by Crescent Island terns in 2007 (507 smolts per nesting tern across the breeding season) was also greater compared to 2006 (446 smolts per nesting tern). Although no data on diet composition were collected at the Rock Island tern colony, we estimate that 677 smolt PIT tags were deposited on the colony during the 2007 nesting season, indicating that salmonids were a significant part of the diet before the colony failed. A comparison of smolt PIT tags recovered from the Crescent Island and Rock Island tern colonies suggests that Rock Island terns consumed about 1/8th as many PIT-tagged salmonid smolts as did Crescent Island terns, or roughly 45,000 smolts. Based on smolt PIT tag recoveries on the Caspian tern colony at Crescent Island, the predation rate on in-river migrants from the Snake River (all species and run types) was about 1.1% in 2007, down substantially from 7.5% and 3.8% in 2005 and 2006, respectively. These predation rates have been corrected for both the detection efficiency of PIT tags on-colony and the proportion of PIT tags ingested by terns that were subsequently deposited on-colony. Although predation rates were dramatically down in

2007, the numbers of Snake River smolts available to terns foraging in McNary Pool were substantially up, as fewer fish were collected for transportation at Snake River dams. As in previous years, predation rates on PIT-tagged steelhead smolts were greater than for other salmonid species. In 2007, ca. 4.9% of the hatchery and 4.8% the wild steelhead smolts from the Snake River were consumed by Crescent Island terns (these predation rates are based on the proportion of PIT-tagged fish interrogated passing Lower Monumental Dam between 1 April and 31 July that were subsequently detected on the Crescent Island tern colony). Because fewer Snake River steelhead were transported around McNary Pool in 2007 compared to 2006, a larger proportion of the Snake River steelhead population was susceptible to predation from Crescent Island terns in 2007. Consequently, the total predation rate by Crescent Island terns on the Snake River steelhead ESU in 2007 was the highest observed since 2004. Predation rates on wild steelhead vs. hatchery steelhead from the Snake River were similar and not statistically different when pooled over the entire 2007 out-migration; this finding differs from results during 2004 – 2006, when predation rates on hatchery smolts were consistently higher than on wild smolts. In 2007, the double-crested cormorant colony on Foundation Island in the mid-Columbia River consisted of at least 330 nesting pairs, and was somewhat smaller than in 2006. The largest cormorant colony on the Columbia Plateau in 2007 was again on Potholes Reservoir, where about 1,015 pairs nested in trees at the north end of the reservoir. The size of this colony was also somewhat lower than in 2006. The limited diet data for Foundation Island cormorants suggest that juvenile salmonids represented 16-18% of the diet. For the first time since this research was initiated in 2004, smolt PIT tag recoveries, and in some cases reach and stock-specific salmonid predation rates, were higher for the Foundation Island cormorant colony than for the Crescent Island tern colony. In fact, of all the piscivorous waterbird colonies studied on the Columbia River in 2007, the Foundation Island cormorant colony had the highest per capita consumption rate of PIT-tagged juvenile salmonids (ca. 11.3 PIT-tagged fish per breeding adult), followed by the Rock Island tern colony (7.87) and the Crescent Island tern colony (7.24). These results suggest that predation rates on salmonid smolts by Foundation Island cormorants are increasing and may now be similar to or greater than that of Caspian terns nesting on nearby Crescent Island. Similar to predation by Crescent Island terns, steelhead were particular vulnerability to predation by Foundation Island cormorants in 2007. Unlike terns, however, Foundation Island cormorants also keyed in on groups of Chinook salmon (both yearlings and sub-yearlings) migrating through McNary Pool. In contrast to the Foundation Island cormorant colony, there is little evidence to suggest that cormorants nesting at the larger colony on Potholes Reservoir are affecting the survival of juvenile salmonids from the Columbia and Snake rivers during the nesting season, based on the paucity of PIT tags from Columbia Basin salmonid smolts recovered at the colony in 2007 (n = 6 smolt PIT tags). Unlike Caspian terns, which depart the Columbia Basin during the non-breeding season, some double-crested cormorants over-winter on the Columbia and Snake rivers. Overwintering cormorants could potentially affect the survival of hold-over fall Chinook salmon smolts, particularly near Snake River dams. A pilot study to investigate this potential impact suggested that small numbers of cormorants (< 100) over-winter near two lower Snake River dams (Little Goose and Lower Granite) and that salmonids make up a significant, although not predominant, proportion of their diet. Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 11.8% by mass of the diet of double-crested cormorants foraging at Little Goose and Lower Granite dams in 2007 (n = 40 fore-gut samples). Juvenile shad were the most abundant fish found in fore-gut contents, representing 47.7% of prey biomass, followed by centrarchids (22.0%). It should be noted, however, that these diet composition results are based on a small sample size and the counts of cormorants at two dams on the Snake River tell us little about the system-wide abundance and distribution of over-wintering cormorants on the Snake River and their potential impact on survival of juvenile salmonids. In 2008, we plan to conduct more comprehensive surveys of the distribution and abundance of over-wintering cormorants along the Snake River from the confluence with the Columbia River to Lewiston, Idaho. Additionally, we will increase our sampling efforts to measure diet composition in order to better assess the impacts on ESA-listed salmonid stocks, particularly hold-over fall Chinook salmon smolts, of double-crested cormorants overwintering along the lower Snake River. Compared to Caspian terns and double-crested cormorants, other piscivorous colonial waterbirds that nest along the mid-Columbia River (i.e., California gulls, ring-billed gulls, American white pelicans) are having less impact on the survival of juvenile salmonids from the Columbia and Snake rivers. One gull colony that may be having a significant impact on salmonid smolt survival, however, is the large California gull colony (ca. 3,500 nesting pairs) on Miller Rocks in The Dalles Pool, where 2,653 smolt PIT tags were recovered in 2007. Previous research in 1997 and 1998 indicated that salmonid smolts, and fish in general, constituted a very small proportion of the diet of California and ring-billed gulls nesting at up-river colonies (Collis et al. 2002a). At the American white pelican colony on Badger Island 1,160 smolt PIT tags were recovered in 2007; this represents about 0.64 PIT-tagged smolts consumed per nesting adult at this growing colony. In comparison, double-crested cormorants nesting at Foundation Island and Caspian terns nesting on Crescent Island consumed 11.3 and 7.2 PIT-tagged smolts per nesting adult, respectively. The size of some up-river gull colonies (= 7,000 breeding pairs on several islands) and the Badger Island white pelican colony (> 900 pairs), however, exceeds that of the up-river tern and cormorant colonies and should be taken into account when evaluating overall impacts of avian predation on salmonid smolt survival on the Columbia Plateau. Further research and monitoring is necessary to determine whether particular gull and pelican colonies might be having a significant effect on survival of juvenile salmonids in the lower and mid-Columbia River. In contrast to the gull and pelican colonies on the Columbia Plateau, previous research on glaucous-winged/western gulls nesting in the Columbia River estuary indicated that these birds consumed significant numbers of juvenile salmonids (Collis et al. 2002a). Gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, including out-migrating salmonids, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. PIT tag studies have not been conducted on these colonies, nor have diet data been collected since 1998. As such, the current impact on salmonid smolt survival of predation from gulls nesting at these estuary colonies is unknown. In 2007 we conducted a pilot study to investigate how smolt morphology, condition, and origin might be related to differences in smolt vulnerability to avian predation. We hypothesized that the probability of smolt mortality due to avian predation increases with the declining physical condition of the fish. We also hypothesized that river conditions and dam operational strategies may be associated with a smolt's vulnerability to avian predators. As part of this pilot study, we scored the condition of 7,088 steelhead smolts that were PIT-tagged and released at Lower Monumental and Ice Harbor dams. Subsequent recovery of some of these PIT tags on piscivorous waterbird colonies downstream indicated that avian predation is partially condition-dependent, with diseased steelhead or steelhead with severe external damage more likely to be consumed by birds than fish with little or no external damage or disease. For example, steelhead with severe external damage were 1.8 times more likely to be consumed by an avian predator than fish with no signs of external damage. Similarly, there was a positive relationship between the extent of de-scaling of smolts and their vulnerability to avian predation, slight to severely de-scaled fish were 1.2 to 2.4 times more likely to fall prey to birds than smolts with little to no de-scaling. Preliminary results indicate that at least some smolt mortality is compensatory, and that not all mortality due to avian predation is additive. A system-wide assessment of avian predation on juvenile salmonids based on recent available data indicates that the most significant impacts to smolt survival occur in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combined to consume ca. 7 – 16 million smolts annually during 2003-2006. Although estimates of smolt consumption for East Sand Island cormorants in 2007 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2007 are expected to be within this range. Estimated smolt losses to piscivorous birds that nest in the estuary are more than an order of magnitude greater than those observed on the mid-Columbia River. Additionally, when compared to the impact of avian predation on the mid-Columbia River, avian predation in the Columbia estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults, compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids belonging to every ESA-listed stock from the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary to reach the ocean. For these reasons, management of Caspian tern and double-crested cormorant colonies on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other colonies of other piscivorous waterbirds. The Caspian tern colony on Crescent Island and the double-crested cormorant colony on Foundation Island may be exceptions to this rule; management of these small, up-river colonies may benefit certain salmonid stocks, particularly steelhead.

BRNW (Bird Research Northwest). (2009). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2008* (p. 158). http://www.birdresearchnw.org/08%20Final%20Season%20Summary.pdf

This report describes investigations into predation by piscivorous colonial waterbirds on juvenile salmonids (Oncorhynchus spp.) from throughout the Columbia River basin during 2008. East Sand Island in the Columbia River estuary again supported the largest known breeding colony of Caspian terns (Hydroprogne caspia) in the world (approximately 10,700 breeding pairs) and the largest breeding colony of double-crested cormorants (Phalacrocorax auritus) in western North America (approximately 10,950 breeding pairs). The Caspian tern colony increased from 2007, but not significantly so, while the double-crested cormorant colony experienced a significant decline (20%) from 2007. Average cormorant nesting success in 2008, however, was down only slightly from 2007, suggesting that food supply during the 2008 nesting season was not the principal cause of the decline in cormorant colony size. Total consumption of juvenile salmonids by East Sand Island Caspian terns in 2008 was approximately 6.7 million smolts (95% c.i. = 5.8 – 7.5 million). Caspian terns nesting on East Sand Island continued to rely primarily on marine forage fishes as a food supply. Based on smolt PIT tag recoveries on the East Sand Island Caspian tern colony, predation rates were highest on steelhead in 2008; minimum predation rates on steelhead smolts detected passing Bonneville Dam averaged 8.3% for wild smolts and 10.7% for hatchery-raised smolts. In 2007, total smolt consumption by East Sand Island double-crested cormorants was about 9.2 million juvenile salmonids (95% c.i. = 4.4 – 14.0 million), similar to or greater than that of East Sand Island Caspian terns during that year (5.5 million juvenile salmonids; 95% c.i. = 4.8 – 6.2 million). The numbers of smolt PIT tags recovered on the cormorant colony in 2008 were roughly proportional to the relative availability of PIT-tagged salmonids released in the Basin, suggesting that cormorant predation on salmonid smolts in the estuary was less selective than tern predation. Cormorant predation rates in excess of 30%, however, were observed for some groups of hatchery-reared fall Chinook salmon released downstream of Bonneville Dam. Implementation of the federal plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary" was initiated in 2008 with construction by the Corps of Engineers of two alternative colony sites for Caspian terns in interior Oregon: a 1-acre island on Crump Lake in the Warner Valley and a 1-acre island on Fern Ridge Reservoir near Eugene. We deployed Caspian tern social attraction (decoys and sound systems) on these two islands and monitored for Caspian tern nesting. Caspian terns quickly colonized the Crump Lake tern island; about 430 pairs nested there, including 5 terns that had been banded at the East Sand Island colony in the Columbia River estuary, over 500 km to the northwest. No Caspian terns nested at the Fern Ridge tern island in 2008, but up to 9 Caspian terns were recorded roosting on the island after the nesting season. There were two breeding colonies of Caspian terns on the mid-Columbia River in 2008: (1) about 388 pairs nested at the historical colony on Crescent Island in the McNary Pool and (2) about 100 pairs nested at a relatively new colony site on Rock Island in the John Day Pool. Nesting success at the Crescent Island tern colony was only 0.28 young fledged per breeding pair, the lowest nesting success recorded at that colony since monitoring began in 2000, while only three fledglings were raised at the Rock Island tern colony. The diet of Crescent Island Caspian terns consisted of 68% salmonid smolts; total smolt consumption was estimated at 330,000. Since 2004, total smolt consumption by Crescent Island terns has declined by 34%, due mostly to a decline in colony size, while steelhead consumption has increased 10% during this same period. In 2008, approximately 64,000 steelhead smolts were consumed by Caspian terns nesting at Crescent Island. Based on smolt PIT tag recoveries on the Crescent Island Caspian tern colony, the average predation rate on in-river migrants from the Snake River (all species and run types combined based on interrogations at Lower Monumental Dam) was at least 1.4%. Predation rates on PIT-tagged steelhead smolts were greater than those for other salmonid species; 6.0% of wild steelhead smolts from the Snake River were consumed by Crescent Island terns. The double-crested cormorant colony on Foundation Island in the mid-Columbia River consisted of at least 360 pairs nesting in trees in 2008. The proportion of juvenile salmonids in stomach samples collected from cormorants nesting on Foundation Island during the peak of the smolt out-migration was about 45% of prey biomass. The average predation rate on in-river migrants from the Snake River (all species and run types combined based on interrogations at Lower Monumental Dam) by Foundation Island cormorants was at least 1.3%, similar to that for Crescent Island Caspian terns. Steelhead smolts from the Snake River were particular vulnerability to predation by Foundation Island cormorants. Some double-crested cormorants over-winter on the Columbia Plateau along the Snake River. Boat surveys conducted from October 2008 to February 2009 indicated that an average of 281 cormorants were present on the lower Snake River over-winter, with the highest concentration of cormorants observed between Little Goose and Lower Granite dams during the months of October and November. Stomach contents indicated that juvenile salmonids comprised about 12.5% by mass of the diet of these double-crested cormorants. Genetic analyses of salmonid tissues removed from cormorant stomachs are in progress. Other piscivorous colonial waterbirds that nest along the mid-Columbia River (i.e., California gulls, ring-billed gulls, American white pelicans) are having much less impact on the survival of juvenile salmonids from the Columbia and Snake rivers, compared to Caspian terns and double-crested cormorants. One gull colony that may be having an appreciable impact on salmonid smolt survival, however, is the large California and ring-billed gull colony (~ 4,500 nesting pairs) on Miller Rocks in The Dalles Pool, where an estimated 4,211 smolt PIT tags were deposited during the 2008 nesting season or 0.9 smolt PIT tags consumed per nesting adult. This colony's large size and proximity to John Day and The Dalles dams is of concern to some fisheries managers, especially given that the number of PIT tags recovered on Miller Rocks has increased in recent years. At the American white pelican colony on Badger Island in the mid-Columbia River, an estimated 2,101 smolt PIT tags were deposited in 2008; this represents about 1.6 PIT-tagged smolts consumed per nesting adult at this growing colony. Although the number of smolt PIT tags recovered on Badger Island has increased in recent years (coincident with an increase in colony size), total numbers of recovered smolt PIT tags are still relatively low compared to the nearby Crescent Island Caspian tern colony and Foundation Island double-crested cormorant colony; per capita PIT tag consumption was 13.6 and 14.7 PIT tags per nesting adult on the tern and cormorant colonies, respectively. In 2008 we investigated how smolt morphology, condition, and origin are related to differences in smolt vulnerability to avian predation. We condition scored and PIT-tagged 9,180 steelhead smolts on the lower Snake River and 7,271 steelhead smolts on the mid-Columbia River during the 2008 out-migration. Preliminary results indicate that 23% of the PIT-tagged steelhead that were released into the lower Snake River and 18% of the PIT-tagged steelhead that were released into the mid-Columbia River and survived to the Columbia River estuary were consumed by colonial waterbirds nesting in the estuary; the comparable percentages for lower Snake River steelhead smolts found on waterbird colonies in the McNary Pool and the John Day/The Dalles pools were 8.5% and 2.3%, respectively, and for mid-Columbia River steelhead smolts were 3.5% and 1.9%, respectively. Predation by Caspian terns nesting at an off-river colony in Potholes Reservoir, WA was an estimated 7.6% of steelhead smolts released into the mid-Columbia River. Smolt condition-scoring results demonstrated that smolts with severe external damage were, on average, 1.6 times more likely to be consumed by avian predators in McNary Pool compared to undamaged smolts. A Columbia Basin-wide assessment of avian predation on juvenile salmonids indicates that the most significant impacts to smolt survival occur in the Columbia River estuary, with the combined consumption of juvenile salmonids by Caspian terns and double-crested cormorants nesting on East Sand Island estimated at between 7 and 16 million smolts annually. This represents approximately 10% of all the salmonid smolts that survive to the estuary in an average year. Estimated smolt losses to piscivorous colonial waterbirds that nest in the Columbia River estuary are more than an order of magnitude greater than those observed on the mid-Columbia River. Additionally, when compared to the impact of avian predation on the Columbia Plateau, avian predation in the Columbia River estuary affects juvenile salmonids belonging to every ESA-listed stock of salmonid from throughout the Basin that have survived freshwater migration to the ocean and presumably have a higher probability of returning as adults. For these reasons, management of the colonies of Caspian terns and double-crested cormorants on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential benefits of management of other populations of piscivorous waterbirds. The Caspian tern colonies on Crescent and Goose (Potholes Reservoir) islands and the double-crested cormorant colony on

Foundation Island may be exceptions to this rule; management of these relatively small colonies on or near the mid-Columbia River may benefit certain salmonid populations, in particular steelhead. In order to reduce predation on juvenile salmonids by double-crested cormorants in the Columbia River estuary, it will be necessary to reduce the size of the cormorant colony on East Sand Island. Resource management agencies have not yet decided whether management of this large cormorant colony is warranted. Because the cormorant colony on East Sand Island constitutes nearly 50% of the entire Pacific Coast breeding population of double-crested cormorants, non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the coast of Oregon and Washington, seem more appropriate than lethal control. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses in the estuary will likely require an analysis under the National Environmental Policy Act (NEPA), including assessments of the (1) population status of Pacific Coast double-crested cormorants, (2) availability of suitable alternative nesting habitat outside the Columbia River basin, and (3) potential enhancement of salmonid recovery rates in the Columbia River basin should management of cormorants be implemented in the estuary. In 2008, work was initiated on an updated status assessment for the Pacific Coast population of double-crested cormorants.

BRNW (Bird Research Northwest). (2010a). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2009* (p. 146). http://www.birdresearchnw.org/09%20Final%20Columbia%20Basin%20Annual%20Report.pdf

We conducted field studies in 2009 to assess the impact of predation by Caspian terns, double-crested cormorants, and other piscivorous colonial waterbirds on juvenile salmonids in the Columbia River Basin. The Caspian tern colony on East Sand Island in the Columbia River estuary, the largest of its kind in the world, consisted of about 9,854 breeding pairs in 2009, not significantly different from 2008. The proportion of juvenile salmonids in the diet of terns nesting on East Sand Island was 37%, somewhat higher than the average percentage over the previous decade. Caspian terns nesting at the East Sand Island colony consumed about 6.4 million juvenile salmonids (95% c.i. = 5.6 – 7.2 million) in 2009, similar to the estimate in 2008. East Sand Island is also home to the largest double-crested cormorant colony in western North America, consisting of about 12,087 breeding pairs in 2009, about 10% larger than in 2008. Juvenile salmonids represented about 9.2% of the diet of double-crested cormorants nesting on East Sand Island in 2009, compared with 11.4% in 2008. Double-crested cormorants nesting at this colony consumed about 11.1 million juvenile salmonids (95% c.i. = 7.7 – 14.5 million) in 2009, mostly sub-yearling Chinook salmon. In 2009, smolt consumption by double-crested cormorants nesting on East Sand Island was significantly greater than smolt consumption by Caspian terns nesting on East Sand Island. Taken together, losses of juvenile salmonids to these two species of fish-eating birds nesting on East Sand Island were 15-20 million smolts, or about 15% of all juvenile salmonids estimated to reach the estuary during the 2009 out-migration. In order to track double-crested cormorants from the East Sand Island colony during post-breeding dispersal and identify over-wintering areas, satellite tags were used to follow 39 double-crested cormorants that nested on East Sand Island during 2008 or 2009. Most satellite-tagged cormorants were tracked to over-wintering sites in either the Salish Sea region (n = 16) or the lower Columbia and Willamette rivers (n = 11), but a few cormorants roosted at sites as far north as the northern Strait of Georgia in British Columbia and as far south as the Salton Sea, CA. Only one satellite-tagged cormorant traveled east of the Cascade/Sierra Nevada range, a bird that migrated up the

Columbia River to John Day Dam. These tracking data demonstrate direct connectivity between the double-crested cormorant colony at East Sand Island, which has experienced tremendous growth over the last two decades, and colonies to the north (i.e., Salish Sea region) and to the south (e.g., San Francisco Bay, CA and Salton Sea, CA) that have experienced declines over the same time period. Based on these results, double-crested cormorants from East Sand Island have the greatest connectivity with active and historical colony sites to the north in the Salish Sea region. If nesting habitat was limited on East Sand Island, most emigrants would likely search for alternative nesting habitat in the Salish Sea region. Implementation of the federal management agencies' Caspian Tern Management Plan for the Columbia River Estuary continued, with the USACE building two new tern nesting islands prior to the 2009 nesting season. Both islands are located at Summer Lake Wildlife Area in south-central Oregon and each is a half-acre in area; one is a rock-core island and the other a floating island. Caspian terns colonized both new islands during the 2009 breeding season, eight breeding pairs on the floating island and seven pairs on the rock-core island. Five terns that had been banded in the Columbia River estuary were resighted at the new Summer Lake tern islands. We continued to monitor two other tern islands that were constructed by the USACE prior to the 2008 nesting season, one on Crump Lake in the Warner Valley, Oregon, and one on Fern Ridge Reservoir near Eugene, Oregon. The Crump Lake tern island attracted nearly 700 breeding pairs of Caspian terns in 2009. Eighteen terns that had been banded in the Columbia River estuary were re-sighted on Crump Lake island. The diet of Caspian terns nesting at Crump Lake and Summer Lake consisted of > 80% tui chub, a native species that is not of conservation concern. As in 2008, no Caspian terns nested on the Fern Ridge Reservoir tern island in 2009, although at least eight different Caspian terns were seen on the island late in the nesting season. Caspian terns and double-crested cormorants are also responsible for most losses of salmonid smolts to avian predators along the mid-Columbia River, specifically Caspian terns nesting on Crescent Island and double-crested cormorants nesting on Foundation Island, both in McNary Pool. The Caspian tern colony at Crescent Island consisted of 349 breeding pairs in 2009, the smallest the colony has been since monitoring commenced in 1997. Salmonid smolts represented 64% of the prey items for terns nesting on Crescent Island in 2009, similar to diet composition during 2000-2008. Based on bioenergetics calculations, consumption of juvenile salmonids by Crescent Island terns was about 360,000 smolts in 2009. The largest Caspian tern colony on the Columbia Plateau in 2009 was on Goose Island in Potholes Reservoir, where about 486 pairs nested. Data on diet composition of terns nesting at the Potholes colony were limited to smolt PIT tags recovered on the colony after the nesting season. Recovered PIT tags indicated that the numbers of juvenile salmonids from the Columbia River consumed by terns nesting at this off-river colony were surprisingly high, particularly for steelhead from the endangered Upper Columbia ESU. PIT tag recoveries on the Potholes tern colony indicated that over 15.5% of Upper Columbia steelhead passing Rock Island Dam in 2009 were consumed by Caspian terns nesting at this colony. The only active double-crested cormorant colony on the mid-Columbia River during 2009 was on Foundation Island in McNary Pool, which consisted of about 310 nesting pairs. The largest cormorant colony on the Columbia Plateau, however, consisted of about 810 pairs that nested in trees at the north end of Potholes Reservoir. Both colonies have declined somewhat over the last four years, indicating that, in the short term, the cormorant breeding population in the region is not increasing. Based on limited diet data for cormorants nesting on Foundation Island, the proportion of salmonids in the diet was similar to 2007 and 2008. Smolt PIT tag recoveries on the Foundation Island cormorant colony were also similar in 2007, 2008, and 2009. The

magnitude of smolt PIT tag recoveries at the Foundation Island colony suggests that the impact of cormorants nesting at this colony on survival of juvenile salmonids is comparable to that of Caspian terns nesting at the Crescent Island colony. Stomach contents of 35 double-crested cormorants collected along the lower Snake River during the winter of 2009-10 indicated that salmonids comprised about 12.4% of the diet; most salmonids found in cormorant stomachs were from the ESA-listed run of Snake River fall Chinook. Surveys during the 2009-10 winter indicated that less than 250 cormorants over-wintered along the lower Snake River; on average, only 20% were observed at one of the four lower Snake River dams. The highest concentrations of cormorants over-wintering along the lower Snake River during 2009-10 were observed between Ice Harbor Dam and the confluence with the Columbia River. California and ring-billed gulls have nested in large numbers on islands on or near the mid-Columbia River, but these gulls have generally consumed few fish and even fewer juvenile salmonids. However, recent increases in numbers of smolt PIT tags recovered at the gull colony on Miller Rocks in The Dalles Pool, where about 4,600 pairs of gulls now nest, have raised concerns about the impact of gull predation on survival of salmonid smolts. In 2009, nearly 5,500 smolt PIT tags were deposited on the Miller Rocks colony by gulls nesting there, compared to 4,211 tags in 2008. The increase in consumption of PIT-tagged smolts by Miller Rocks gulls likely reflects both an increase in size of the gull colony (numerical response) as well as an increase in foraging intensity at nearby John Day Dam and The Dalles Dam (functional response). The magnitude of predation on salmonid smolts by Miller Rocks gulls appears to be unique among gull colonies along the mid-Columbia River.

BRNW (Bird Research Northwest). (2010b). *Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon, 2008* (p. 62). http://www.birdresearchnw.org/08%20Final%20SFB%20-%20Interior%20OR%20report.revised.pdf

In 2008, the U.S. Army Corps of Engineers (USACE) began implementing management actions for Caspian terns (Hydroprogne caspia) that were described in the January 2005 Final Environmental Impact Statement (FEIS) and November 2006 Records of Decision (RODs) for Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary (USFWS 2005, 2006). This management plan, which was developed jointly by the USACE, the U.S. Fish and Wildlife Service, and NOAA Fisheries, seeks to redistribute a portion of the Caspian tern colony on East Sand Island in the Columbia River estuary to alternative colony sites in interior Oregon and the San Francisco Bay area by 2015. The goal of the plan is to reduce Caspian tern predation on out-migrating juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary, and thereby enhance recovery of salmonid stocks from throughout the Columbia River basin. Thirteen of 20 evolutionarily significant units (ESUs) of Columbia Basin salmonids are currently listed as either threatened or endangered under the U.S. Endangered Species Act (ESA). As part of this management plan the USACE completed construction of two 1-acre islands specifically designed for tern nesting in interior Oregon prior to the 2008 breeding season: a 1-acre island on Fern Ridge Reservoir near Eugene, Oregon (completed February 2008) and a 1-acre island on Crump Lake in the Warner Valley, northeast of Lakeview, Oregon (completed March 2008). The constructed island in Crump Lake was at the site of a former island that supported colonial-nesting waterbirds, including Caspian terns. Following the construction of the islands and before the arrival of terns from their wintering grounds, Caspian tern decoys and audio playback systems that broadcast tern calls were deployed on both islands

to attract terns to nest. Video cameras were used to monitor the island in Fern Ridge Reservoir instead of direct observation by a field crew, and the island was visited periodically throughout the breeding season by project staff. Review of video footage and our site visits revealed that Caspian terns did not attempt to nest on the island in 2008, but visited the island after the breeding season. During the month of August the Fern Ridge tern island was visited by Caspian terns on 23 different days, with as many as nine terns observed on the island at one time. There is a history of Caspian terns attempting to nest on the remnant island at Crump Lake in the Warner Valley, so a field crew monitored the island throughout the nesting season. During May, a Caspian tern breeding colony formed on the Crump Lake island and grew to about 150 breeding pairs. Concurrently, about 500 pairs of California gulls (Larus californicus), about 850 pairs of ring-billed gulls (L. delawarensis), and 10 pairs of double-crested cormorants (Phalacrocorax auritus) initiated nesting on the new island. In early June the Caspian tern colony dropped to a low of 23 nesting pairs due to egg predation by gulls. We selectively removed 10 gulls that were depredating tern eggs, once the required depredation permits had been issued. Subsequently, the Caspian tern colony expanded to 428 breeding pairs, and ultimately raised about 145 young terns to fledging age. Hundreds of pairs of nesting California and ring-billed gulls and one pair of cormorants also successfully raised young on the Crump Lake island. The diet composition of Caspian terns nesting on Crump Lake consisted primarily of tui chub (Gala bicolor; 55.4% of the identifiable prey items), followed by bullhead catfish (Ameiurus sp.; 27.8%) and crappie (Pomoxis sp.; 15.0%). The remaining 1.8% of prey items consisted of rainbow trout (Oncorhynchus mykiss), lamprey (Entosphenus spp.), suckers (Catostomus spp.), bass (Micropterus spp.), and dace (Rhinichthys spp.). A total of 5 suckers (0.17% of identifiable prey items) were observed by researchers during the nesting season, one of which was positively identified as a Warner sucker (C. warnerensis). Warner suckers are listed as threatened under the ESA. Thirty of the Caspian terns that colonized the newly restored island in Crump Lake had been previously banded. Of these, 18 had been banded at the Crescent Island Caspian tern colony on the mid-Columbia River near Tri-Cities, Washington, about 450 km to the north. Five of the banded terns on Crump Lake island had been banded on East Sand Island in the Columbia River estuary, over 500 km to the northwest. Based on the number of terns banded on East Sand Island relative to the size of that colony, we estimate that perhaps as many as half the Caspian terns that colonized the new Crump Lake island had originated from the East Sand Island colony. These band re-sightings demonstrate that Caspian terns can be recruited to new colony sites from existing breeding colonies over considerable distances. Although no management action was undertaken to enhance Caspian tern nesting habitat in the San Francisco Bay area in 2008, we monitored existing Caspian tern colonies in the Bay area to gain a better understanding of current colony status, diet composition, and factors limiting colony size and nesting success in preparation for potential colony expansion at Brooks Island in the central Bay and island construction/restoration in the south Bay. There were four known breeding colonies of Caspian terns in the San Francisco Bay area in 2008, where a total of approximately 1,000 breeding pairs nested. This represents a decline over the last 3-5 years in both total number of breeding colonies (formerly 5) and total number of breeding pairs (1,085-1,372) in the San Francisco Bay area. As was the case in 2003-2005, most breeding pairs of Caspian terns in the San Francisco Bay area (81%) nested at the Brooks Island colony in 2008, by far the largest tern colony in the Bay area (ca. 810 breeding pairs). Marine forage fishes, in particular anchovies, surfperch, and herring, were the predominant component of Caspian tern diets at Brooks Island in 2008. In 2008, the proportion of the diet that was juvenile salmonids increased to about 9%, raising concerns that

relocation of Caspian terns from the Columbia River estuary to Brooks Island might reduce survival of ESA-listed salmonids from the Sacramento River basin. A radio telemetry study of Brooks Island terns, combined with recoveries of coded wire tags from smolts on the Brooks Island colony, revealed that the vast majority of salmonid smolts consumed by Caspian terns from this colony in 2008 were hatchery-reared, non-listed fall-run Chinook that were released from net pens in eastern San Pablo Bay. Caspian terns also nested at Eden Landing, Stevens Creek, and Agua Vista Park, but only periodic colony monitoring was conducted at the tern colonies at Agua Vista Park and Stevens Creek, while weekly colony monitoring was conducted at Eden Landing. The Eden Landing colony was more intensively monitored because of its proximity to Hayward Regional Shoreline and Don Edwards National Wildlife Refuge, two sites identified for future island construction/restoration for Caspian tern nesting in the FEIS and RODs. We estimated that 56 breeding pairs of Caspian terns nested at Eden Landing in 2008. In contrast to the diet of terns nesting on Brooks Island in 2008, terns nesting at Eden Landing had a much smaller percentage of juvenile salmonids in their diet (0.2% at Eden Landing versus 9% at Brooks Island). These and other previously reported results (Roby et al. 2003b, 2004, 2005) suggest that Caspian tern colonies located in the south Bay will likely have little impact on survival of juvenile salmonids compared to Caspian tern colonies in the north and central Bay. Tern nesting success at Eden Landing (0.81 young fledged per breeding pair) was higher than at Brooks Island (0.42 young fledged per breeding pair). All four Caspian tern colonies in the San Francisco Bay area appeared to be primarily limited both in size and productivity by the availability of suitable nesting habitat and/or the quality of nesting substrate. Other factors limiting nesting success for at least some of the colonies were mammalian nest predators, displacement by other colonial waterbirds, and human disturbance. Food availability may be a limiting factor for nesting success in some years, but it did not appear to be a significant constraint on productivity in 2008. The preliminary conclusions from this study of Caspian terns nesting in interior Oregon and the San Francisco Bay Area during 2008 are (1) Caspian terns can be recruited to new colony sites (i.e., Crump Lake) from existing breeding colonies (i.e., East Sand Island) over considerable distances, (2) Caspian terns are more easily recruited to nest at sites with a prior history of tern nesting (i.e., Crump Lake island), as compared to sites with no history of tern nesting (i.e., Fern Ridge island), (3) the diet of terns nesting at sites identified as alternative nesting locations in the FEIS (i.e., Brooks Island and Crump Lake) consisted mostly of forage fishes that are neither listed under the ESA nor of significant economic value for commercial, recreational, or subsistence fisheries, (4) availability of suitable sites for breeding colonies was the main factor limiting the number and size of tern colonies in both the San Francisco Bay area and interior Oregon, and (5) nesting success at existing colonies was limited by attributes of those colony sites as they influence (a) quality of nesting substrate, (b) vulnerability to mammalian and avian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance.

BRNW (Bird Research Northwest). (2010c). *Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon, 2009* (p. 78). http://www.birdresearchnw.org/09%20Draft%20SFB-Interior%20OR%20report.v2..pdf

The U.S. Army Corps of Engineers (USACE) implemented management actions for Caspian terns (Hydroprogne caspia) nesting in the Columbia River estuary beginning in 2008, management that was described in the January 2005 Final Environmental Impact Statement (FEIS) and November 2006 Records of Decision (RODs) for Caspian Tern Management to Reduce

Predation of Juvenile Salmonids in the Columbia River Estuary (USFWS 2005, 2006). This management plan, which was developed jointly by the USACE, the U.S. Fish and Wildlife Service, and NOAA Fisheries, seeks to redistribute a portion of the Caspian tern colony on East Sand Island in the Columbia River estuary to alternative colony sites in interior Oregon and the San Francisco Bay area by 2015. The goal of the plan is to reduce Caspian tern predation on out-migrating juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary, and thereby enhance recovery of salmonid stocks from throughout the Columbia River basin. Thirteen of 20 evolutionarily significant units (ESUs) of Columbia Basin salmonids are currently listed as either threatened or endangered under the U.S. Endangered Species Act (ESA). As part of this management plan the USACE completed construction of two 1-acre islands and two 0.5-acre islands at sites in interior Oregon. These specially-designed tern islands included a 1-acre island on Fern Ridge Reservoir near Eugene, Oregon (completed February 2008), a 1-acre island on Crump Lake in the Warner Valley, northeast of Lakeview, Oregon (completed March 2008), and two 0.5-acre islands at Summer Lake Wildlife Area in south-central Oregon near the town of Summer Lake (completed March 2009). Following the construction of these islands and before the arrival of Caspian terns from their wintering grounds, Caspian tern decoys and acoustic playback systems that broadcast Caspian tern calls were deployed on all the islands to attract nesting Caspian terns. Field crews monitored the islands on Crump Lake and in Summer Lake Wildlife Area throughout the nesting season because there was a prior history of Caspian terns nesting there. In 2009, Caspian terns quickly colonized the tern island on Crump Lake and both tern islands in Summer Lake Wildlife Area, where approximately 670 and 15 breeding pairs nested, respectively. Nesting terns at both locations were successful in rearing young to fledging; an average of 0.17 and 0.80 young were raised per breeding pair at Crump Lake and Summer Lake Wildlife Area, respectively. Prior to island construction in 2008 and 2009, the main factor limiting colony size and nesting success of Caspian terns at Crump and Summer lakes was fluctuating water levels that either inundated the available nesting habitat or land-bridged nesting islands to the mainland, allowing access by mammalian nest predators. In 2009, nest predation by gulls and food availability near the tern islands were apparently the most significant factors limiting tern colony size and nesting success. The diet composition of Caspian terns nesting on Crump Lake and in Summer Lake Wildlife Area consisted primarily of tui chub (Gala bicolor; 75.6% and 82.7% of the identifiable prey items, respectively). In 2009, one sucker (0.02% of identifiable prey items) was observed by researchers at the Crump Lake tern colony during the nesting season, but this juvenile sucker could not be positively identified as either an ESA-listed sucker (i.e., Warner sucker [Catostomus warnerensis]) or an unlisted sucker (i.e., Sacramento sucker [C. occidentalis]). A total of 46 rainbow trout (Salmo gairdneri; 13.1% of identifiable prey items) were observed at the Summer Lake tern colonies in 2009; these trout were likely hatchery-raised and released in nearby reservoirs and streams. A total of 63 Caspian terns that were previously banded were re-sighted at the tern islands on Crump Lake and in Summer Lake Wildlife Area during the 2009 nesting season. Of these, 24 had been banded at East Sand Island in the Columbia River estuary, over 500 km to the northwest. Based on the number of terns banded on East Sand Island relative to the size of that colony, we estimate that the majority of the Caspian terns that colonized the tern islands at Crump and Summer lakes had originated from the East Sand Island colony. These band re-sightings demonstrate that Caspian terns can be recruited to new colony sites from existing breeding colonies over considerable distances. Because there has been no prior history of Caspian terns nesting at Fern Ridge Reservoir or elsewhere in the Willamette Valley of Oregon, video cameras were used instead of direct observation by a field crew as the primary means to monitor the Fern Ridge tern island. Review of video footage and periodic site visits indicated that Caspian terns did not attempt to nest on the island in 2009, but did visit the island late in the breeding season and during the post-breeding season. Caspian terns were regularly observed on the Fern Ridge tern island from late June to late August (on 31 of 33 days when video footage was recorded), and as many as eight Caspian terns were observed on the island in amongst the tern decoys at one time. Video footage also revealed frequent visits to the Fern Ridge tern island by avian predators of Caspian terns (i.e., bald eagles, great horned owls, and peregrine falcons), and one instance of predation by an adult bald eagle on two hatch-year Caspian terns that were roosting on the island. Based on our review of video footage recorded at the Fern Ridge tern island, avian predators and possibly human disturbance may have precluded Caspian terns from nesting on the Fern Ridge tern island in 2009. Although no management action was undertaken to enhance Caspian tern nesting habitat in the San Francisco Bay area prior to the 2009 nesting season, we monitored existing Caspian tern colonies in the Bay area to gain a better understanding of current colony status, diet composition, and factors limiting both colony size and nesting success in preparation for potential colony expansion at Brooks Island in the Central Bay and island construction/restoration in the South Bay. There were six known breeding colonies of Caspian terns in the San Francisco Bay area during 2009, where a total of approximately 830 breeding pairs nested. This represents a 40% decline in the number of Caspian terns nesting in the Bay Area in 2009 relative to 2004, when the number of breeding pairs in the Bay Area peaked. This decline was largely driven by the decline in size of the breeding colony at Brooks Island, the largest Caspian tern colony in the Bay Area, where colony size was estimated at 681 breeding pairs in 2009, compared to 1,040 breeding pairs in 2004. Nesting success at tern colonies in the Bay Area declined 69% from 2003 to 2009, which again was driven by the decline in nesting success at the Brooks Island colony (0.62 and 0.14 fledglings produced per breeding pair in 2003 and 2009, respectively, a 77% decline). Factors affecting colony size and nesting success were related to attributes of those colony sites as they influenced (a) quality of nesting substrate, (b) susceptibility to mammalian and avian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance. Marine forage fishes, including silversides (Atheridae), surfperches (Embiotocidae), anchovies (Engraulidae), were the predominant component of Caspian tern diets at colonies in the San Francisco Bay area. Diet composition varied among colonies within the Bay Area, however, suggesting that fish assemblages near colony sites differed and nesting terns tended to forage near their nesting colony. In 2009, juvenile salmonids comprised 7.1% of prey items for terns nesting at Brooks Island in the Central Bay, and 0.1 - 0.2% of the diet of terns nesting at Eden Landing and Stevens Creek in the South Bay. A radio telemetry study of Caspian terns raising young at the Brooks Island colony, combined with recoveries of coded wire tags from smolts on the colony, revealed that the vast majority of salmonid smolts consumed by Brooks Island Caspian terns in 2009 were hatchery-reared, non-listed fall-run Chinook salmon smolts that had been released from net pens in eastern San Pablo Bay. Results indicate that the implementation of proposed tern management initiatives in the Central and South San Francisco Bay will not jeopardize ESA-listed salmonid stocks and will help restore the breeding population of Caspian terns in the region. Restoration of Caspian tern colonies in southern San Francisco Bay is very unlikely to have any appreciable impact on survival of juvenile salmonids, either from ESA-listed or unlisted stocks. The preliminary conclusions from this study of Caspian terns nesting in interior Oregon and the San Francisco Bay area during 2009 are (1) Caspian terns can be recruited to new colony sites (i.e., islands in

Crump Lake and Summer Lake Wildlife Area) from existing breeding colonies (i.e., East Sand Island) over considerable distances; (2) Caspian terns are more easily recruited to nest at sites with a prior history of tern nesting, as compared to sites with no history of tern nesting (i.e., Fern Ridge Reservoir); (3) the diet of Caspian terns nesting at alternative colony sites identified in the FEIS (i.e., Brooks Island, Crump Lake, and Summer Lake Wildlife Area) consisted mostly of forage fishes that are neither listed under the U.S. Endangered Species Act nor of significant economic value for commercial, recreational, or subsistence fisheries; (4) availability of suitable sites for breeding colonies was the main factor limiting the number and size of tern colonies in both the San Francisco Bay area and interior Oregon; (5) nesting success at existing colonies was limited by attributes of those colony sites as they influenced (a) quality of nesting substrate, (b) susceptibility to mammalian and avian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance.

BRNW (Bird Research Northwest). (2011a). *Impacts of Avian Predation on Salmonid Smolts from the Columbia and Snake Rivers: 2004-2009 Synthesis Report* (p. 207). http://www.birdresearchnw.org/Avian%20Predation%20Synthesis%20Report%202004-2009%20Final%20v2.pdf

Populations of anadromous salmonids (Oncorhynchus spp.) in the Columbia River basin are currently the subjects of intense conservation activity following decades of decline. In recent years, avian predation across the basin has been considered a factor limiting recovery of these imperiled fish populations. Caspian terns (Hydroprogne caspia), double-crested cormorants (Phalacrocorax auritus), American white pelicans (Pelecanus erythrorhynchos), California gulls (Larus californicus), and ring-billed gulls (L. delawarensis) are native piscivorous colonial waterbirds with a history of nesting in the Columbia Plateau region. We investigated the impact on survival of juvenile salmonids from predation by piscivorous colonial waterbirds nesting in the Columbia Plateau region during 2004-2009. Within the Columbia Plateau region, overall numbers of breeding Caspian terns remained relatively stable during the study period at between 800 and 1,000 breeding pairs at five colonies; the two largest breeding colonies were on Crescent Island in the mid-Columbia River and on Goose Island in Potholes Reservoir. Overall numbers of breeding double-crested cormorants in the Columbia Plateau region decreased during the study period, from about 1,500 breeding pairs to about 1,200 breeding pairs at four separate colonies; the largest breeding colony by far was at the north end of Potholes Reservoir. Numbers of breeding American white pelicans increased at the Badger Island colony on the mid-Columbia River, the sole breeding colony for the species in the State of Washington. Overall numbers of breeding gulls, the most numerous piscivorous colonial waterbirds in the region, declined during the study period. Potential limiting factors for piscivorous colonial waterbirds nesting in the Columbia Plateau region include human disturbance, mammalian predation, availability of suitable nesting habitat, inter-specific competition for limited nesting habitat, and food availability. Overall breeding numbers of Caspian terns and double-crested cormorants in the Columbia Plateau region are an order of magnitude less than the numbers of these two species nesting in the Columbia River estuary, whereas California gulls, ring-billed gulls, and American white pelicans are far more numerous in the Columbia Plateau region than in the estuary. We used bioenergetics methods to estimate prey consumption by Caspian terns nesting at Crescent Island and double-crested cormorants nesting at Foundation Island, both located in the mid-Columbia River just below the confluence with the Snake River. Taken together, the Crescent Island tern colony and the Foundation Island cormorant colony consumed approximately one

million juvenile salmonids annually during 2004 – 2009. Estimated annual consumption of smolts by Foundation Island cormorants ranged from 470,000 to 880,000, while that of Crescent Island terns ranged from 330,000 to 500,000. Consumption of salmon smolts by the Crescent Island tern colony declined during the study period, tracking a decline in colony size. Consumption of steelhead (O. mykiss) did not decline, however, perhaps reflecting greater steelhead availability in later years due to reduced transportation rates of Snake River steelhead. There was no apparent trend in smolt consumption by Foundation Island cormorants during the study period. Relative to salmonids, consumption of lamprey was minor, with fewer than 10,000 lamprey macropthalmia consumed per year by both colonies combined. We recovered passive integrated transponder (PIT) tags from salmonid smolts on nine different piscivorous waterbird colonies in the Columbia River basin to evaluate avian predation on juvenile salmonids during 2004-2009. These nine bird colonies had the highest numbers of smolt PIT tags of any in the Columbia Basin. Minimum estimates of predation rates based on PIT tag recoveries were used to determine which salmonid stocks were most affected by avian predation and which bird colonies had the greatest impact on smolt survival. This system-wide evaluation of avian predation indicated that Caspian terns and double-crested cormorants nesting on East Sand Island in the Columbia River estuary were consuming the highest proportions of available PIT-tagged smolts. However, Caspian terns and double-crested cormorants nesting at colonies in the Columbia Plateau region also had significant impacts on survival of specific salmonid stocks. Predation rates by Crescent Island terns on Snake River summer steelhead (7.7%) and by Goose Island terns on upper Columbia summer steelhead (10.0%) were substantial during the study period. Predation rates by Foundation Island cormorants on Snake River summer steelhead (2.0%) and Snake River sockeye (1.7%) were not as high, but notable. Predation rates by gulls and pelicans nesting in the Columbia Plateau region were minor (generally < 0.5% of available smolts) compared to smolt losses from inland tern and cormorant colonies. Hatchery smolts were often more susceptible to avian predation relative to their wild counterparts, although exceptions were numerous. Smolts out-migrating in June and July were often consumed at higher rates by birds than smolts of the same stock that out-migrated earlier (April or May). Predation rates on PIT-tagged smolts that were adjusted for colony size (i.e., smolt consumption per bird) were substantially higher for terns and cormorants nesting at colonies in the Columbia Plateau region compared to those nesting in the estuary. Thus, while inland colonies of terns and cormorants are much smaller than their counterparts in the estuary, inland colonies can be more reliant on salmonids as a food source. This greater reliance on salmonids, coupled with lower diversity of available salmonid stocks compared to the estuary, is responsible for the unexpectedly high impact of some inland tern and cormorant colonies on specific stocks of salmonids, particularly steelhead. Current management efforts to increase smolt survival through reductions in tern and cormorant predation in the estuary could result in some terns and cormorants from estuary colonies recruiting to inland colonies, potentially resulting in higher predation rates on certain ESA-listed salmonid stocks. Recruitment from estuary colonies may result in small, but significant increases in numbers of these two species nesting in the Columbia Plateau region. Nesting habitat and food supply appear to limit Caspian tern numbers on the Columbia Plateau and the demographic connectivity between the double-crested cormorant colony in the estuary and those on the Columbia Plateau appears limited. Although the number of Caspian terns that could relocate from estuary colonies to colonies on the Columbia Plateau is likely small relative to numbers nesting in the Columbia River estuary (< 1,000 adults), the impact on specific steelhead stocks could be substantial and warrants monitoring. We investigated factors that

influence susceptibility of juvenile salmonids to avian predation using juvenile steelhead from the threatened Snake River stock. Steelhead smolts (n = 25,909) were captured, externally examined, marked with PIT tags, and released to continue outmigration during 2007-2009. Recoveries of steelhead PIT tags on the Crescent Island Caspian tern colony indicated that steelhead susceptibility to tern predation increased significantly with declining steelhead external condition, decreased water discharge, decreased water clarity, and increased steelhead length up to 202 mm (fork length), but decreased for larger steelhead. Recoveries of PIT tags on the Foundation Island double-crested cormorant colony indicated that steelhead susceptibility to cormorant predation increased significantly with declining steelhead external condition, plus steelhead of hatchery origin were more susceptible compared to their wild counterparts. These results indicate that steelhead susceptibility to avian predation is condition- and size-dependent and is influenced by both river conditions and rearing environment (hatchery vs. wild). These findings unequivocally demonstrate that at least a portion of the smolt mortality caused by avian predation in the mid-Columbia River is compensatory. We also assessed the abundance, distribution, and diet of double-crested cormorants over-wintering on the lower Snake River in eastern Washington to investigate the potential for significant impacts from cormorant predation on survival of ESA-listed fall Chinook salmon that over-winter in the lower Snake River. A monthly average of 256 cormorants was observed on this reach of the lower Snake River. Overall diet composition of cormorants was highly variable and changed as winter progressed. The most prevalent prey types were centrarchids (34.3% by mass), followed by shad (15.0%). Fall Chinook salmon comprised an average of 3.4% by mass of the cormorant diet. Biomass consumption of all salmonids by overwintering cormorants was estimated at 3,100 to 11,000 kg, or about one third of the estimated salmonid biomass consumption by cormorants nesting at Foundation Island. The bulk of the diet of over-wintering cormorants, however, consisted of non-native fishes that compete with or depredate juvenile salmonids. Based on the results of this study, the greatest potential for increasing survival of smolts from ESA-listed salmonid stocks by managing inland avian predators would be realized by focusing management efforts on Caspian terns nesting at colonies on Crescent Island, Goose Island, and the Blalock Islands. Reductions in the size of these tern colonies would enhance survival of upper Columbia River and Snake River steelhead stocks in particular. More limited enhancement of smolt survival for Snake River steelhead and Snake River sockeye could be achieved by managing the double-crested cormorant colony at Foundation Island. Management of other inland piscivorous waterbird colonies in the Columbia Plateau region would provide relatively small and perhaps undetectable increases in stock-specific smolt survival. Further work is necessary, however, to translate smolt consumption and predation rate estimates into assessments of the potential benefits for threatened and endangered salmonid populations of reducing avian predation in the Columbia Plateau region. The analysis of potential benefits from management of piscivorous waterbirds for restoring ESA-listed stocks of salmonids is key to informed decision-making, as resource managers consider management of specific waterbird colonies on the Columbia Plateau, and identifying management objectives.

BRNW (Bird Research Northwest). (2011b). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2010* (p. 167). http://www.birdresearchnw.org/FINAL%202010%20Annual%20Report.pdf

We conducted field studies in 2010 to assess the impact of predation by Caspian terns (Hydroprogne caspia), double-crested cormorants (Phalacrocorax auritus), and other piscivorous colonial

waterbirds on juvenile salmonids (Oncorhynchus spp.) in the Columbia River basin. Additionally, we monitored the Caspian tern colonies located outside the Basin that were recently established on alternative nesting habitat for Caspian terns displaced from East Sand Island, as part of the Caspian Tern Management Plan for the Columbia River Estuary. The Caspian tern colony on East Sand Island, the largest of its kind in the world, consisted of about 8,283 breeding pairs in 2010, significantly less than in 2009 and the smallest the colony has been since it became fully established in 2001. Although the recent decline in size of the East Sand Island tern colony was coincident with a reduction in the amount of nesting habitat made available to terns on East Sand Island, nesting habitat did not appear to limit the size of the East Sand Island tern colony in 2010. Based on nesting densities observed at the East Sand Island tern colony over the past several years, plus poor nesting success during the 2010 El Niño, the reduction in available nesting habitat from five acres in previous years to 3.1 acres in 2010 was not the primary cause for the decline in colony size observed in 2010. Further reductions in the amount of Caspian tern nesting habitat provided on East Sand Island in future years will be necessary to realize the goal of relocating a majority of the East Sand Island tern colony to alternative sites, as prescribed in the Caspian Tern Management Plan. Juvenile salmonids continued to be a large part of the diet of Caspian terns nesting on East Sand Island, comprising 33% of the overall diet in 2010, slightly higher than the 10- year average during 2000-2009 (30%). As in previous years, marine forage fishes dominated the diet of Caspian terns nesting on East Sand Island, comprising 62% of all identified bill loads in 2010. Caspian terns nesting at the East Sand Island colony consumed about 5.3 million juvenile salmonids (95% c.i. = 4.5 – 6.1 million) in 2010, not significantly different than the smolt consumption estimates from the previous two years. Since 2000, the average number of smolts consumed by Caspian terns nesting on East Sand Island was 5.3 million smolts per year, less than half the annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary prior to 2000, when the breeding colony was located on Rice Island. Further reductions in smolt consumption by terns nesting on East Sand Island will require a significant reduction in the size of the tern colony; future management plans are designed to reduce the size of the East Sand Island tern colony to about one-third its pre-management size. Implementation of the federal management agencies' Caspian Tern Management Plan for the Columbia River Estuary continued outside the Columbia River basin, with the USACE-Portland District and its state and federal partners building four new Caspian tern nesting islands prior to the 2010 nesting season. Two of the four new islands are located in Lower Klamath National Wildlife Refuge, California (a 1-acre silt-core island in the Orems Unit and a 0.8-acre floating island on Sheepy Lake); one new island is located in Tule Lake National Wildlife Refuge, California (a 2-acre rock-core island in Sump 1B); and one new island is located at Summer Lake Wildlife Area, Oregon (a 0.5- acre rock-core island in Gold Dike impoundment). The severe drought in the Upper Klamath Basin and adjacent areas of interior Oregon, however, precluded allocating water to three of the four impoundments where new islands were built. Nevertheless, Caspian terns quickly colonized the new 0.8-acre floating island at Sheepy Lake in Lower Klamath National Wildlife Refuge, where 258 pairs raised 168 young. Nineteen terns that had been banded in the Columbia River estuary were re-sighted at the Sheepy Lake tern island. We continued to monitor four other alternative colony sites constructed by the USACE-Portland District in interior Oregon during 2008 and 2009: Fern Ridge Reservoir tern island, Crump Lake tern island, and East Link and Dutchy Lake tern islands in Summer Lake Wildlife Area. No Caspian terns successfully nested at three of these four islands and the fourth experienced very low nesting success, apparently due to adverse weather conditions and low forage fish availability associated with climate conditions prior to and during the 2010 nesting season. Diet composition and PIT tag recovery data from Caspian tern colonies in interior Oregon and northeastern California indicated these colonies were primarily consuming cyprinids (i.e., tui chub Gila bicolor), centrarchids (i.e., crappie Pomoxis spp.), and ictalurids (i.e., brown bullhead Ameiurus nebulosus) in 2010. Catostomids (suckers), several species of which are listed under the Endangered Species Act, were not identified in the diet of terns nesting at Crump Lake in 2010. One juvenile sucker (species unknown) was observed at the Summer Lake Caspian tern colony and four juvenile suckers (species unknown) were observed at the Sheepy Lake Caspian tern colony in 2010. Suckers represented a very small percentage (< 0.1%) of identifiable prey items at these two tern colonies. No sucker PIT tags were recovered from Caspian tern colonies in either interior Oregon or northeastern California in 2010. East Sand Island is also home to the largest double-crested cormorant colony in western North America, consisting of about 13,596 breeding pairs in 2010; 2010 was the second consecutive year where the colony grew by more than 10%. Juvenile salmonids represented about 16.4% of the diet of double-crested cormorants nesting on East Sand Island in 2010, compared with 9.2% in 2009. Double-crested cormorants nesting at this colony consumed approximately 19.2 million juvenile salmonids (95% c.i. = 14.6 – 23.8 million) in 2010, the highest annual smolt consumption ever estimated for the East Sand Island cormorant colony. In the past two years, smolt consumption by double-crested cormorants nesting on East Sand Island was significantly greater than smolt consumption by Caspian terns nesting on East Sand Island. Management options to reduce or limit smolt losses to the double-crested cormorant colony on East Sand Island are under consideration by federal, state, and tribal resource management agencies. In order to reduce predation on juvenile salmonids by double-crested cormorants in the Columbia River estuary, it will be necessary to reduce the size of the cormorant colony on East Sand Island. Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the Pacific coast, seem more appropriate in the context of the cormorant colony on East Sand Island, whose initial growth appears to have occurred largely at the expense of other colonies in the region. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses in the estuary will require analysis under the National Environmental Policy Act (NEPA), a process that is currently underway. Further up-river in the Columbia Plateau region, Caspian terns and double-crested cormorants are also the two bird species responsible for most of the smolt losses to avian predators. Management options to reduce the impacts of these two avian predators on smolt survival along the mid-Columbia and lower Snake rivers are currently being considered by resource managers. In 2010, the largest breeding colonies of Caspian terns in the Columbia Plateau region were on Crescent Island (in McNary Pool) and on Goose Island (Potholes Reservoir, WA), where 375 pairs and 416 pairs nested, respectively. Caspian tern nesting success at the Crescent Island colony averaged 0.52 young raised per nesting pair, higher than in recent years, while the Goose Island tern colony experienced almost complete nesting failure in 2010, due primarily to disturbance by avian and mammalian predators. Three other smaller Caspian tern colonies in the Columbia Plateau region also failed or nearly failed to produce any young. In 2010, salmonid smolts represented 71% of tern prey items at the Crescent Island colony and 21% of tern prey items at the Goose Island colony; estimated smolt consumption by terns nesting at these two colonies was 420,000 smolts and 122,000 smolts, respectively. The largest colony of double-crested cormorants on the mid-Columbia River was on Foundation Island (in McNary Pool), where 308 pairs nested in 2010. Diet sampling during 2005-2010 indicated that ca. 50%

(by mass) of the Foundation Island cormorant diet was juvenile salmonids during May (the peak of smolt out-migration), while less than 10% of the diet was salmonids during early April, June, and July. A total of 36,764 PIT tags from 2010 migration year smolts were recovered on bird colonies in the Columbia Plateau region. PIT tag recoveries indicated that smolt losses in 2010 were similar for Foundation Island cormorants (8,481 tags) and Crescent Island terns (8,255 tags). Substantial numbers of 2010 smolt PIT tags were also detected on the Caspian tern colony on Goose Island in Potholes Reservoir (8,512 tags) and on a mixed California gull (Larus californicus) and ring-billed gull (L. delawarensis) colony on Miller Rocks in The Dalles Pool (5,045 tags). PIT tags recovered from the Caspian tern colony in Potholes Reservoir were almost exclusively from upper Columbia River salmonid ESUs, while PIT tags recovered on other bird colonies in the Plateau region consisted of smolts from upper Columbia, Snake, and middle Columbia ESUs. Preliminary results indicate that Caspian terns from the Goose Island colony in Potholes Reservoir consumed an estimated 9.6% of the juvenile steelhead (Oncorhynchus mykiss) PIT-tagged and released at Rock Island Dam on the upper Columbia River in 2010. Predation rates by Crescent Island terns on Snake River steelhead (ca. 2.8%) and by Foundation Island cormorants on Snake River steelhead (ca. 1.3%) and Snake River sockeye (ca. 1.7%) were also notable in 2010, although lower compared to previous years (2004-2009). California and ring-billed gulls have nested in large numbers on islands on or near the mid- and upper Columbia River, but these gulls have generally consumed few fish and even fewer juvenile salmonids, with the exception of the gull colony on Miller Rocks in The Dalles Pool (see above). In 2010, the number of gulls counted on the Miller Rocks colony was 5,533, down from 6,016 gulls counted on colony during the 2009 breeding season. Despite this decline in the number of gulls counted on the Miller Rocks gull colony, the number of gulls utilizing Miller Rocks during the breeding season has increased by about 150% since 1998. Similarly, the American white pelican (Pelecanus erythrorhynchos) colony on Badger Island in McNary Pool has experienced significant growth since the late 1990's, increasing from 100 adults on colony in 1999 to 1,643 adults in 2010. Unlike the Miller Rocks gull colony, however, pelicans nesting at Badger Island are not consuming large numbers of juvenile salmonids, based on the relatively small numbers of smolt PIT tags detected on the colony. Continued monitoring of these and perhaps other incipient piscivorous waterbirds colonies in the Columbia River basin will be necessary to determine the magnitude and trend for total losses of juvenile salmonids to avian predators in the basin.

BRNW (Bird Research Northwest). (2012a). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2011* (p. 171). http://www.birdresearchnw.org/FINAL_2011_Annual_Report.pdf

We conducted field studies in 2011 to (1) assess the impact of avian predation on survival of juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary, (2) monitor the efficacy of on-going Caspian tern (Hydroprogne caspia) management actions designed to reduce their impact on salmonid smolt survival in the estuary, (3) test management strategies to limit nesting habitat availability for double-crested cormorants (Phalacrocorax auritus) at East Sand Island in the Columbia River estuary, and (4) evaluate the impacts on smolt survival of piscivorous colonial waterbirds (i.e., Caspian terns, double-crested cormorants, American white pelicans [Pelecanus erythrorhynchos], California gulls [Larus californicus], and ring-billed gulls [L. delawarensis]) that nest in the Columbia Plateau region. The Caspian tern colony on East Sand Island, the largest of its kind in the world, consisted of about 7,000 breeding pairs in 2011, a decline from 2010 (ca. 8,300 breeding pairs). The Caspian tern colony on East Sand Island did not produce a single fledgling in 2011, the first time that a complete breeding failure has been recorded at this colony. The proximal factors responsible for colony failure and the decline in colony size were intense disturbance by bald eagles (Haliaeetus leucocephalus) and associated gull predation on tern eggs and chicks. Climate conditions associated with a very strong La Niña and the resultant exceptionally high river flows also apparently contributed to the lack of nesting success through their effects on marine forage fish availability. Juvenile salmonids continued to be a large part of the diet of Caspian terns nesting on East Sand Island, comprising 36% of the diet (percent of prey items) in 2011, somewhat higher than the average during 2000-2010 (30%). Despite complete colony failure, Caspian terns nesting at the East Sand Island colony consumed about 4.8 million juvenile salmonids (95% c.i. = 4.0 – 5.6 million) in 2011, lower than the 11-year average but not significantly different than the smolt consumption estimates from the previous two years. Further reductions in smolt consumption by Caspian terns nesting on East Sand Island will require further reductions in the size of the tern colony; future management plans are designed to reduce the size of the East Sand Island tern colony to about one-third its pre-management size (ca. 9,500 breeding pairs). Management of Caspian tern nesting habitat at the East Sand Island colony continued in 2011, with the USACE further reducing the area of suitable tern nesting habitat on East Sand Island to 2.0 acres, 40% of the original area of managed tern nesting habitat on East Sand Island. This habitat restriction caused Caspian terns to nest at higher densities (0.85 nests/m2) than previously recorded in the Columbia River estuary. Since early 2008, the Portland District of the USACE has built a total of eight new islands as alternative Caspian tern nesting sites to compensate for reductions in Caspian tern nesting habitat on East Sand Island; five of these new tern islands are in interior Oregon and three are in the Upper Klamath Basin of northeastern California. Six of the eight new tern islands were surrounded by water throughout the 2011 nesting season, and thus suitable as tern nesting habitat. Four of these six suitable islands supported nesting Caspian terns, including the new 2-acre rock-core island at Tule Lake Sump 1B in Tule Lake National Wildlife Refuge, where 34 pairs nested. Adverse weather conditions (severe La Niña) and avian nest predators (gulls and great horned owls) limited Caspian tern nesting success and fledgling production at these alternative islands in 2011; however, a substantial number of terns banded at East Sand Island in the Columbia River estuary visited these sites, including 92 terns banded at East Sand Island that were seen at the Upper Klamath Basin tern islands during the 2011 breeding season. Data on diet composition of Caspian terns nesting at colonies in interior Oregon and northeastern California indicated that in 2011 these colonies were primarily consuming cyprinids (i.e., chub Gila spp.), centrarchids (i.e., crappie Pomoxis spp.), and ictalurids (i.e., bullhead Ameiurus spp.). Catostomids (suckers), several species of which are listed under the Endangered Species Act, were not identified in the diet of terns nesting in interior Oregon (i.e., Crump Lake and Summer Lake) during 2011. Two juvenile suckers (species unknown) were observed at two Caspian tern colonies in northeastern California (i.e., Sheepy Lake and Tule Lake Sump 1B) during 2011. Suckers represented a very small percentage (< 0.1%) of identifiable prey items at these two tern colonies. No sucker PIT tags were recovered from Caspian tern colonies in either interior Oregon or northeastern California during 2011. East Sand Island in the Columbia River estuary is also home to the largest double-crested cormorant colony in western North America, which consisted of about 13,000 breeding pairs in 2011, very similar to 2010 (ca. 13,600 breeding pairs). Juvenile salmonids represented about 19% of the diet (percent biomass) of double-crested cormorants nesting on East Sand Island in 2011, the highest percentage observed since 1999 (24.6% of the diet). Double-crested cormorants nesting at the East Sand Island colony consumed approximately

20.5 million juvenile salmonids (95% c.i. = 15.2 – 25.9 million) in 2011, the highest annual point estimate of smolt consumption for the East Sand Island cormorant colony so far recorded. During the past two years, smolt consumption by double-crested cormorants nesting on East Sand Island has been significantly greater than smolt consumption by Caspian terns nesting on East Sand Island. In 2011, a pilot study was conducted to test the feasibility of a management strategy to limit the amount of nesting habitat available to double-crested cormorants at East Sand Island. An eight-foot-tall privacy fence was built to bisect the colony and visually separate 15% of the nesting area used by cormorants in 2010 from the remainder of the colony. Using human disturbance to haze cormorants during the nest initiation period (late April to mid-May), double-crested cormorants were successfully dissuaded from using this 15% of their former nesting area. Cormorants on the other side of the fence nested normally, apparently unaffected by the hazing activities. No detrimental effects of hazing activities were observed on non-target species that also use this portion of the island, including nesting Brandt's cormorants, nesting glaucous-winged/western gulls, and roosting California brown pelicans. Further up-river in the Columbia Plateau region, Caspian terns and double-crested cormorants are also the two bird species responsible for most of the smolt losses to avian predators. Management options to reduce the impacts of these two avian predators on smolt survival along the mid-Columbia River and lower Snake River are currently being considered by resource managers. In 2011, the largest breeding colonies of Caspian terns in the Columbia Plateau region were at Crescent Island on the mid-Columbia River (in McNary Pool) and on Goose Island on Potholes Reservoir (near Othello, WA), where nearly equal numbers of breeding pairs (ca. 420) nested in 2011. Caspian tern nesting success at both colonies in 2011 was also similar (ca. 0.3 young raised per nesting pair). During the 2011 breeding season, salmonid smolts represented 84% of tern prey items at the Crescent Island colony, the highest percentage ever recorded at that colony, and 24% of tern prey items at the Goose Island/Potholes colony. Estimated consumption of juvenile salmonids by Caspian terns nesting at these two colonies was 440,000 smolts and 111,000 smolts, respectively. The largest colony of double-crested cormorants on the mid-Columbia River was on Foundation Island in McNary Pool, where about 318 pairs nested in 2011. Diet sampling during 2005-2010 indicated that ca. 50% (by mass) of the diet of Foundation Island cormorants was juvenile salmonids during May (the peak of smolt out-migration), while less than 10% of the cormorant diet was salmonids during early April, June, and July. Using diet data collected during 2005-2010, and data on colony size and productivity in 2011, we estimated that Foundation Island cormorants consumed 24,700 kg of juvenile salmonids (95% c.i. = 19,100 – 30,300 kg) in 2011. As in previous years, this was significantly greater than salmonid consumption by the Crescent Island Caspian tern colony (14,700 kg in 2011; 95% c.i. = 12,200 – 17,200 kg). An estimated 36,918 PIT tags from 2011 migration year salmonid smolts were deposited by birds on their nesting colonies in the Columbia Plateau region. PIT tag recoveries indicated that smolt losses in 2011 were highest due to Crescent Island Caspian terns (11,734 PIT tags), followed by Foundation Island double-crested cormorants (8,376 PIT tags) and Goose Island Caspian terns (6,387 PIT tags). PIT tags recovered from the Caspian tern colony on Goose Island in Potholes Reservoir were almost exclusively from upper Columbia River salmonid evolutionarily significant units (ESUs) or distinct population segments (DPSs), while PIT tags recovered on other bird colonies in the Columbia Plateau region consisted of smolts from Upper Columbia, Snake, and Middle Columbia ESUs or DPSs. PIT tag recovery results indicate that Caspian terns from the Goose Island colony in Potholes Reservoir consumed an estimated 8.9% of the ESA-listed steelhead (O. mykiss) smolts that were PIT-tagged and detected/released at Rock Island

Dam on the upper Columbia River, the highest ESU-specific predation rate measured in 2011 for birds nesting at a colony in the Columbia Plateau region. Predation rates by Crescent Island terns on Snake River steelhead (ca. 1.9%) and by Foundation Island cormorants on Snake River steelhead (ca. 1.8%) were also notable in 2011 and comparable to those reported in previous years (2007-2010). Predation on salmonid smolts by American white pelicans nesting on Badger Island and California and ring-billed gulls nesting on Crescent Island and Miller Rocks during 2011 were relatively minor (generally < 0.5% per ESU or DPS) in comparison to that of Caspian terns and double-crested cormorant nesting at colonies in the Columbia Plateau region. California and ring-billed gulls nest in large numbers on islands on or near the mid- and upper Columbia River, but these gulls have generally consumed few fish and even fewer juvenile salmonids compared to Caspian terns or double-crested cormorants nesting along the mid-Columbia River. In 2011, the number of gulls counted on the Miller Rocks colony was 5,750, up slightly from the 5,533 gulls counted on the colony during the 2010 breeding season. The number of gulls nesting on Miller Rocks has apparently increased by about 160% since 1998. Similarly, the American white pelican colony on Badger Island in McNary Pool has undergone dramatic growth since the late 1990's, increasing from ca. 100 adults on-colony in 1999 to ca. 2,200 adults on-colony in 2011. The numbers of smolt PIT tags recovered from both the Miller Rocks gull colony and the Badger Island pelican colony have increased commensurate with increases in colony size.

BRNW (Bird Research Northwest). (2012b). *Caspian Tern Colony Site Assessment: Management Opportunities in Western North America* (p. 97). http://www.birdresearchnw.org/IAPMP_site_assessment_report%20v18.pdf

We compiled existing information on biological factors throughout the breeding range of Caspian terns (Hydroprogne caspia) in western North America to assess potential locations as alternative nesting sites for Caspian terns currently nesting at certain colonies in the Columbia Plateau region of Washington. This work provides an update and expansion upon the previous review of Caspian tern nesting habitat in western North America by the U.S. Fish and Wildlife (Seto et al. 2003). This report presents information for consideration with regard to the possible relocation of Caspian terns nesting at colonies on Crescent Island (in McNary Pool on the mid- Columbia River near Wallula, WA) and on Goose Island (in Potholes Reservoir near Othello, WA) to alternative colony sites as part of a prospective management plan for Caspian terns in the Columbia Plateau region (i.e., Inland Avian Predation Management Plan [IAPMP]). A total of 145 current, former, or potential Caspian tern colony sites were identified in western North America (Alaska to northwestern Mexico, west of the Continental Divide). Movement data from Caspian terns banded at Crescent Island or Goose Island-Potholes during 2005-2011 indicated some connectivity across an extensive array of sites throughout coastal and interior western North America. Specifically, Caspian terns banded at Crescent Island or Goose Island- Potholes were re-sighted at nesting or roosting locations in Alaska, British Columbia, Washington, Oregon, California, Idaho, Utah, and northwestern Mexico. Evaluations of the 145 potential alternative nesting sites for Caspian terns identified by this study were conducted via literature review, colonial waterbird atlases, online databases, and extensive discussions with academic, federal, state, non-governmental, and provincial biologists across western North America. Our results suggested that 41 of these sites (28%) have management potential, 82 sites (57%) were considered to not have management potential, and there was insufficient information available to evaluate 22 sites (15%); 17 of the 22 sites with insufficient information are in Mexico or

Canada. The efficacy of initiatives developed as part of the IAPMP to increase salmonid smolt survival through reductions in the number of nesting Caspian terns at certain colonies in the Columbia Plateau region depends not only on the successful reduction in numbers of nesting Caspian terns at Crescent Island and/or Goose Island-Potholes, but also on adaptive management to prevent terns from forming new colonies that would negate those reductions. Prospective tern colony sites located on the Columbia or Snake rivers were therefore considered to not have management potential due to the likelihood of continued conflicts with ESA-listed salmonids from the Columbia River basin. Similarly, potential colony sites on the Columbia or Snake rivers where suitable tern nesting habitat is currently available may require some level of adaptive management to prevent Caspian terns from relocating to these sites. Biological characteristics for the 41 sites with apparent management potential were then used to assess the suitability of each site to attract Caspian terns to nest, the potential constraints at the site for sustaining a Caspian tern colony, and considerations for enhancing the site to accommodate a Caspian tern breeding colony. Of the 41 sites that were considered to have management potential, 13 were considered to have high overall suitability as alternative Caspian tern colony sites, based on 15 suitability criteria and additional site information. Of the 13 sites considered to have high overall suitability as alternative Caspian tern colony sites, all are in either Washington or California; 4 are in coastal Washington, 3 are in interior Washington, 3 are in coastal northern California, 1 is in interior northern California, and 2 are in coastal southern California. Each of these 13 sites, however, ranked poorly in at least one suitability criterion, indicating that some biological conflicts or constraints exist at even the most suitable management sites. For instance, at some of the 13 highly-suitable sites, there is potential geographic overlap between a new or expanded Caspian tern breeding colony and threatened or endangered fish species protected by the U.S. Endangered Species Act (ESA). Caspian tern diet data were generally lacking at the majority of these potential colony sites; thus, potential conflicts were evaluated based on spatial overlap alone. Actual site-specific impacts, therefore, are difficult to predict because the availability of alternative prey and factors influencing the susceptibility of ESA-listed fish species to Caspian tern predation are not known for all sites. Further investigation of this and other biological conflicts or constraints (e.g., factors limiting tern colony size and nesting success) may be prudent prior to or as part of the final site selection conducted by the resource management agencies in order to avoid conflicts with other fish species of conservation concern and effectively manage those factors that might prevent colony establishment or long-term colony viability. Overall, this colony site assessment evaluated biological factors influencing establishment of a suite of potential sites that could be restored, created, or enhanced to attract nesting Caspian terns. Assessments of social, political, and economic factors that could legitimately influence the selection of alternative colony sites for Caspian terns were outside the scope of this report. Additionally, potential conflicts were limited to federally protected fish and wildlife species and did not include foreign (Canada, Mexico), state, or local species or populations of conservation, economic, or cultural concern. Consideration of these possible conflicts, public input, and long-term strategies to evaluate the effectiveness of this plan will be necessary to assess the success of Caspian tern management to increase survival of juvenile salmonids from the Columbia River basin.

BRNW (Bird Research Northwest). (2013a). *Implementation and Effects of Double-crested Cormorant Dissuasion Research at East Sand Island, Columbia River Estuary: 2008-2012* (p. 17) [Technical Memorandum]. http://www.birdresearchnw.org/Dissausion%202008-2012.pdf

This Technical Memorandum provides a summary of the research activities related to testing the feasibility of several techniques for dissuading double-crested cormorants (Phalacrocorax auritus) from nesting on parts of their breeding colony on East Sand Island. These studies were conducted during 2008-2012. Descriptions of each dissuasion method, the efficacy of each dissuasion method (i.e., effects on breeding double-crested cormorants), and the effects of each dissuasion method on non-target waterbird species are included. A feasibility assessment is provided for each dissuasion method that was tested. Standards used to evaluate the feasibility of the different dissuasion methods include: (1) effectiveness at dissuading double-crested cormorants from nesting, (2) degree of disturbance to non- target species, (3) expense, and (4) ease of implementing the dissuasion method. Table 1 compares the cost estimates for each dissuasion method by year. An appendix describing the history of scientific collection of double-crested cormorants related to research at East Sand Island and elsewhere in the Columbia River estuary during 1997-2012 is also provided.

BRNW (Bird Research Northwest). (2013b). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2012* (p. 239). http://www.birdresearchnw.org/FINAL_2012_Annual_Report_v9.pdf

We conducted field studies in 2012 to (1) assess the impact of avian predation on survival of juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary, (2) monitor the efficacy of on-going management actions designed to reduce the impact of Caspian terns (Hydroprogne caspia) on salmonid smolt survival in the estuary, (3) test management strategies for limiting the availability of nesting habit for double-crested cormorants (Phalacrocorax auritus) at East Sand Island in the Columbia River estuary, and (4) evaluate the impacts on smolt survival of piscivorous colonial waterbirds (i.e., Caspian terns, double-crested cormorants, American white pelicans Pelecanus erythrorhynchos, California gulls Larus californicus, and ring-billed gulls L. delawarensis) that nest in the Columbia Plateau region. The Caspian tern breeding colony on East Sand Island, the largest of its kind in the world, consisted of about 6,400 breeding pairs in 2012, continuing the downward trend in colony size from the peak of about 10,000 pairs in 2008. The Caspian tern colony on East Sand Island produced a total of about 410 fledglings in 2012, compared to complete breeding failure at this colony in 2011. The proximal factor responsible for colony failure in 2011 and very poor nesting success in 2012 (an average of only 0.06 young raised per breeding pair) was intense disturbance by bald eagles (Haliaeetus leucocephalus) and associated predation on tern eggs and chicks by glaucous- winged/western gulls (L. glaucescens/occidentalis). The average proportion of juvenile salmonids in the diet of Caspian tern diets during the 2012 nesting season was 34%, similar to 2009-2011. The estimated total smolt consumption by Caspian terns nesting at East Sand Island in 2012 was 4.9 million (95% c.i. = 3.9 - 5.8 million), similar to 2011. Recoveries of smolt passive integrated transponder (PIT) tags on the Caspian tern colony at East Sand Island indicated that tern predation rates in 2012 were highest on steelhead populations (7.4 – 10.0%, depending on the population), followed by salmon populations (0.7 – 2.2%, depending on the population), based on ESA-listed PIT-tagged smolts last interrogated passing Bonneville Dam on the Columbia River or Sullivan Dam on the Willamette River; there were indications that predation rates on some ESA-listed salmonid populations were trending lower in 2012 compared to 2010 and 2011. To further reduce the impacts of predation by Caspian terns nesting at East Sand Island on salmonid stocks from the Columbia River basin, more terns will need to be relocated to colonies outside the basin; the management objective is to reduce the size of the East Sand Island tern colony to 4,000 breeding pairs or less, < 40% its pre-management size (ca. 10,000 breeding pairs), while attracting the displaced Caspian terns to alternative colony sites built for terns elsewhere. Caspian tern management actions continued in 2012, with the U.S. Army Corps of Engineers, Portland District (Corps) further reducing the area of suitable tern nesting habitat on East Sand Island to 1.58 acres, 32% of its former area. This habitat restriction caused Caspian terns to nest at higher densities (average of 1.06 nests/m2) than previously seen in the Columbia River estuary. The Corps has built a total of nine new islands as alternative Caspian tern nesting habitat since early 2008, six in interior Oregon and three in the Upper Klamath Basin region of northeastern California. Six of these nine new islands supported nesting Caspian terns in 2012, including the 1-acre rock-core island built early in 2012 on Malheur Lake in Malheur National Wildlife Refuge, where 232 pairs nested. Nest predators, both mammalian and avian, and apparent low forage fish availability at some sites (Crump Lake and Summer Lake Wildlife Area), limited Caspian tern colony size and nesting success at five of the six tern colonies that formed on the Corps' new islands in 2012. Substantial numbers of Caspian terns from the colony on East Sand Island in the Columbia River estuary, however, are visiting these new islands; 64 terns originally banded in the Columbia River estuary were re-sighted on the Corps' new Malheur Lake tern island and 83 were re-sighted on the Corps' Upper Klamath Basin tern islands in 2012. Data on diet composition of Caspian terns nesting on Corps-constructed tern islands in interior Oregon and northeastern California indicated that in 2012 terns from these colonies primarily consumed cyprinids (i.e., chub Gila spp., fathead minnows Pimephales promelas, and common carp Cyprinus carpio), centrarchids (i.e., crappie Pomoxis spp.), and ictalurids (i.e., bullhead Ameiurus spp.). Catostomids (suckers), several species of which are listed under the Endangered Species Act, were not identified in the diet of Caspian terns nesting on Corps-constructed tern islands at Sheepy Lake, Tule Lake Sump 1B, and Summer Lake during 2012. One juvenile sucker (species unknown) was observed at the Caspian tern colony on the Corps-constructed tern island in Crump Lake during 2012; suckers represented a very small percentage (< 0.1%) of identifiable prey items at this Caspian tern colony. No sucker PIT tags were recovered from Caspian tern colonies on the Corps-constructed tern islands in either interior Oregon or northeastern California during 2012. The double-crested cormorant colony on East Sand Island in the Columbia River estuary consisted of about 12,300 breeding pairs in 2012, the largest colony of its kind in western North America and similar in size to 2011 (ca. 13,000 breeding pairs). Juvenile salmonids represented about 20% (by biomass) of the double-crested cormorant diet in 2012, compared to about 19% in 2011. Our estimate of total smolt consumption by double-crested cormorants nesting on East Sand Island in 2012 was 18.9 million smolts (95% c.i. = 14.0 – 23.8 million), not significantly different from the number of smolts consumed by cormorants from this colony in 2011. Annual smolt consumption by double-crested cormorants nesting on East Sand Island has been trending upward since 2003, until 2012 when estimated consumption leveled off. As in other recent years, estimates of total smolt consumption by East Sand Island cormorants were significantly higher than that of Caspian terns nesting on East Sand Island in 2012. Recoveries of smolt PIT tags on the East Sand Island cormorant colony in 2012 indicated that population-specific predation rates ranged from 0.6% to 7.2% for populations originating upstream of Bonneville Dam on the Columbia River or upstream of Sullivan Dam on the Willamette River. Compared to predation rates on salmon populations by Caspian terns nesting on East Sand Island, predation rates by double-crested cormorants nesting on East Sand Island (2% – 4%) were generally higher; however, the highest estimate of population-specific predation rates for East Sand Island cormorants was on steelhead from the upper Columbia River

(7.2%), less than the maximum population- specific predation rate by East Sand Island terns (10.0%). Using both bioenergetics-based estimates of smolt consumption at the level of the salmonid species and PIT tag-based estimates of population-specific predation rates on salmonids, it is possible to develop a more comprehensive understanding of the impacts of avian predators on survival of juvenile salmonids from across the basin. Population- specific predation rates based on PIT tag recoveries indicated that the impacts of Caspian terns and double-crested cormorants nesting on East Sand Island are substantial for several salmonid populations originating upstream of Bonneville Dam. Bioenergetics-based estimates of smolts consumed indicated that other salmonid populations from across the basin are also negatively affected, and some significantly so. Genetic identification of smolts in the diet of Caspian terns and double-crested cormorants indicated that salmonid populations from the basin that are infrequently PIT-tagged, but ESA-listed (e.g., Upper Willamette River steelhead, Lower Columbia River Chinook salmon), are also consumed in significant numbers by terns and cormorants nesting at East Sand Island. Overall smolt consumption by East Sand Island cormorants has been higher during 2010-2012 compared to the previous decade, while predation rates on ESA-listed populations originating upstream of Bonneville Dam have not shown this same trend. Impacts of double-crested cormorant predation on sub- yearling Chinook smolts originating downstream of Bonneville Dam, however, have been substantial during 2010-2012. In 2012, the Corps expanded a pilot study initiated in 2011 to test possible strategies for limiting the size of the double-crested cormorant colony on East Sand Island. An eight- foot-high privacy fence was built to bisect the colony and visually separate 62% of the nesting area used by the colony in 2010 from the remainder of the colony. Using human disturbance to haze cormorants during the nest initiation period, cormorants were successfully dissuaded from using this 62% of their former nesting area. Some hazed cormorants were satellite-tagged or radio-tagged to follow their movements to prospective new nesting sites. About 55% of these tagged cormorants dispersed from the East Sand Island colony after tagging, but nearly all eventually returned to the Columbia River estuary and attempted to nest on East Sand Island. Tagged cormorants dispersing from East Sand Island were detected at colonies and roost sites (1) on the lower Columbia River below Bonneville Dam, (2) the outer Washington coast (Willapa Bay and Grays Harbor), (3) Puget Sound, and (4) northern Salish Sea (San Juan Islands; Strait of Georgia; Vancouver, BC area). Only one tagged cormorant was detected on the north coast of Oregon (Cannon Beach). Caspian terns, double-crested cormorants, American white pelicans, California gulls, and ring-billed gulls are native piscivorous colonial waterbirds that nest in the Columbia Plateau region. The total number of Caspian terns nesting in the Columbia Plateau region was about 1,000 breeding pairs at six colonies in 2012, as high as or higher than any other year during 2005-2011. The two largest Caspian tern breeding colonies were at Goose Island (463 pairs) in Potholes Reservoir, WA and at Crescent Island (422 pairs) on the mid-Columbia River. The third largest breeding colony was recently formed at Badger Island (60 pairs) on the mid-Columbia River. A small number of Caspian terns (n = 8) that were originally banded as adults on East Sand Island in the Columbia River estuary – where management actions to reduce the size of the colony are being implemented – were re-sighted at colonies in the Columbia Plateau region during 2011 and 2012; some of these banded terns (n = 4) were confirmed to be nesting at colonies in the Columbia Plateau region. The movement of banded Caspian terns that had previously nested on East Sand Island to colonies in the Columbia Plateau region was not seen during 2006-2010, before tern management intensified at East Sand Island. Natal dispersal of terns banded as chicks at East Sand Island to the colonies in the Columbia Plateau region has also been confirmed. Caspian tern movements from East Sand Island to colonies in the Columbia Plateau region, if substantial, could off-set benefits to salmonids of tern management in the estuary because per bird impacts on smolt survival are higher for terns nesting in the Columbia Plateau region compared to those nesting in the estuary, where marine forage fishes (anchovy, smelt, surfperch, etc.) tend to dominate the diet. Total numbers of double-crested cormorants nesting in the Columbia Plateau region increased slightly in 2012, from an average of about 1,350 breeding pairs during 2005- 2011 to about 1,550 breeding pairs at four colonies in 2012; the largest colonies were in the North Potholes Reserve (992 nesting pairs) and on Foundation Island in the mid- Columbia River (390 nesting pairs). Numbers of American white pelicans nesting on Badger Island in the mid-Columbia River, a colony that experienced rapid growth during 2004-2010, appear to have stabilized at about 2,100 adults. The numbers of gulls nesting on Miller Rocks, a colony located just downstream of John Day Dam on the Columbia River, were similar to those observed in recent years (ca. 4,500 adults). Following the abandonment of the large California gull colony on Three Mile Canyon Island (ca. 6,200 adults were counted on-colony in 2009), there was a commensurate increase in the number of California gulls nesting on islands in the Blalock Islands complex in 2012; in 2012 ca. 7,300 nesting California gulls were counted on one island in the Blalock Islands, whereas in 2009 no gulls nested there. Salmonid smolts represented 83% of Caspian tern prey items at the Crescent Island colony and 30% of prey items at the Goose Island colony, resulting in an estimated 730,000 juvenile salmonids consumed by Caspian terns nesting at these two colonies combined in 2012. Estimates of predation rates based on PIT tag recoveries on Caspian tern colonies indicate that impacts were highest on survival of Upper Columbia River steelhead (estimated predation rate of 17.3% by Goose Island terns), Snake River steelhead (estimated predation rate of 2.8% by Crescent Island terns), and Upper Columbia River spring Chinook (estimated predation rate of 2.5% by Goose Island terns). Smolt PIT tag recoveries on Caspian tern colonies located at Twining Island on Banks Lake (> 45 km from the Columbia River) and at Harper Island on Sprague Lake (> 65 km from the Snake River) indicated that Caspian terns from those two colonies commuted long distances to the mainstem rivers to consume ESA-listed juvenile salmonids. Studies to refine estimates of avian predation rates based on smolt PIT tags recovered on colonies of double-crested cormorants, California gulls, and ring-billed gulls were conducted in 2012. These studies resulted in correction factors for PIT tag deposition rates, the proportion of PIT tags consumed by birds that were subsequently deposited on-colony, as opposed to off-colony. These correction factors are needed to more accurately measure predation rates on juvenile salmonids by these three species of piscivorous colonial waterbirds. Previously, estimates of PIT tag deposition rates were only available for Caspian terns. Deposition corrected results from 2012 indicated that predation rates on steelhead populations by gulls nesting at certain colonies in the Columbia Plateau region were as great or greater than those of nearby Caspian tern and double-crested cormorant colonies. For example, predation rate estimates indicate that ca. 4% of the available Snake River steelhead and Upper Columbia River steelhead were consumed by gulls nesting on Crescent Island in 2012; ca. 4% of available Snake River steelhead and ca. 6% of available Upper Columbia River steelhead were consumed by gulls nesting on Miller Rocks in 2012. Predation rates on most populations of salmon by gulls nesting at the Crescent Island and Miller Rocks colonies were, however, generally less than 1.0%, with the exception of the predation rate on Snake River sockeye salmon by gulls nesting on Miller Rocks (ca. 5%). PIT tag-derived predation rates by double- crested cormorants nesting on Foundation Island, corrected for PIT tag deposition rate, indicated that predation rates were highest on Snake River

sockeye salmon (2.5%) and Snake River steelhead (2.4%). Data on PIT tag deposition rates for American white pelicans nesting at the colony on Badger Island are not currently available. Minimum predation rate estimates (not corrected for PIT tag deposition rates) indicate that American white pelicans consumed less than 0.3% of the available smolts in 2012, regardless of salmonid population. Resource management agencies are currently developing a management plan aimed at reducing avian predation rates on ESA-listed salmonids in the Columbia Plateau region, especially on steelhead smolts from the Upper Columbia River and Lower Snake River populations. Previous and future research efforts will help inform this process so that the resultant management initiatives are science-based, defensible, cost-effective, and have a high probability of success.

BRNW (Bird Research Northwest). (2014a). *East Sand Island Biological Assessment: 2010-2012* (p. 36) [Final Technical Memorandum]. http://www.birdresearchnw.org/Final%20Biological%20Assessment.v4.pdf

BRNW (Bird Research Northwest). (2014b). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2013* (p. 251). http://www.birdresearchnw.org/FINAL_2013_Annual_Report.pdf

The primary objectives of this project in 2013 were to (1) evaluate management initiatives implemented to reduce predation on juvenile salmonids (Oncorhynchus spp.) by Caspian terns (Hydroprogne caspia) nesting on East Sand Island in the Columbia River estuary, including the monitoring of alternative Caspian tern nesting islands built by the Corps outside the Columbia River basin; (2) collect, compile, and analyze data needed to assist in completion of the NEPA analysis required for management of (a) double- crested cormorants (Phalacrocorax auritus) nesting on East Sand Island and (b) Caspian terns nesting at colonies in the Columbia Plateau region; (3) investigate the numbers of other piscivorous colonial waterbirds (i.e., Brandt's cormorants P. penicillatus, California brown pelicans Pelecanus occidentalis californicus, American white pelicans P. erythrorhynchos, and gulls Larus spp.) that use the Columbia River to nest or roost and assess their potential impacts on smolt survival; and (4) assist resource managers as technical advisors in the development of plans for long-term management of avian predation on juvenile salmonids from the Columbia River basin, as warranted. The Caspian tern colony on East Sand Island, the largest for the species in the world, consisted of about 7,400 breeding pairs in 2013. This is an increase from the estimate of 6,400 pairs in 2012, and the first increase since the initiation of habitat reduction on East Sand Island in 2008, when the colony numbered about 10,000 breeding pairs. In addition to the increase in colony size, Caspian terns at this colony were more resilient to disturbances by bald eagles and associated gull depredation on tern eggs and chicks compared to during 2010-2012. The Caspian tern colony on East Sand Island produced about 1,480 fledglings in 2013 (average of 0.20 young raised/breeding pair), a significant increase from 2010-2012 (average of 0 - 0.06 young raised/breeding pair), but lower than in other years during 2001-2009. The average proportion of juvenile salmonids in the diet of Caspian terns during the 2013 nesting season was 32%, similar to 2009-2012. The estimated total smolt consumption by Caspian terns nesting at East Sand Island in 2013 was 4.6 million (95% c.i. = 3.9 - 5.3 million), similar to 2012. Recoveries of smolt passive integrated transponder (PIT) tags on the Caspian tern colony at East Sand Island indicated that tern predation rates on salmonid smolts that were interrogated passing Bonneville Dam on the Columbia River or Sullivan Dam on the Willamette River were similar in 2013 and 2012. Also similar to previous

years, tern predation rates were significantly higher on steelhead populations (8.6 – 12.5%, depending on the population) compared with salmon populations (0.6 – 1.4%, depending on the population). Despite the increase in the size of the tern colony in 2013 compared to 2012, predation rates on ESA-listed steelhead and salmon populations have trended lower since tern habitat reductions were initiated in 2008. Caspian tern management actions in the Columbia River estuary continued in 2013. The U.S. Army Corps of Engineers, Portland District (Corps) maintained 1.58 acres of suitable nesting habitat for Caspian terns on East Sand Island, the same area of habitat as in 2012, and 32% of the area of nesting habitat provided during 2001-2007. The restriction in available tern nesting habitat on East Sand Island to 1.58 acres caused Caspian terns to nest at an average density of 1.17 nests/m2 , an increase from 1.06 nests/m2 in 2012, and the highest tern nesting density so far observed in the Columbia River estuary. In addition, several hundred pairs of Caspian terns attempted to nest in three discrete satellite colonies on the upper beach of East Sand Island, adjacent to the 1.58-acre area of designated tern nesting habitat; however, no young were successfully raised in these satellite colonies. Passive deterrence measures (stakes, ropes, and flagging) installed by the Corps to dissuade Caspian terns from nesting on areas of the upper beach near the main colony along with tidal inundations of some nest sites were effective in limiting the formation and size of satellite colonies. The Corps has constructed nine islands as alternative Caspian tern nesting colony sites since early 2008, six in interior Oregon and three in the Upper Klamath Basin region of northeastern California. Two of these islands were not available for tern nesting in 2013, and one is no longer being monitored for Caspian tern nesting activity. Of the six islands that were monitored for Caspian tern nesting activity, five supported nesting Caspian terns. A combined total of over 1,100 breeding pairs of Caspian terns nested at these five alternative colony sites in 2013, a 50% increase from 2012. Estimated productivity was low among the five sites, however, ranging from an average of 0 to 0.37 young raised/breeding pair, depending on the site. In 2013, mammalian and avian nest predators, displacement by other colonial waterbird species (i.e., California gulls L. californicus, American white pelicans), drought, adverse weather condition, and likely low forage fish availability (due to drought), limited Caspian tern colony formation, colony size, and nesting success at one or more of the alternative colony sites. A substantial number of Caspian terns that were banded at the colony on East Sand Island in the Columbia River estuary, however, did use the alternative colony sites created by the Corps; 57 terns banded in the Columbia River estuary were seen at the alternative colony sites in interior Oregon and 110 were seen at the alternative colony sites in the Upper Klamath Basin during the 2013 nesting season. Based on estimated movement rates (5.3%) calculated from Caspian terns banded as adults, 684 Caspian terns (including both banded and unbanded terns) were estimated to have moved from East Sand Island to alternative colony sites in 2013. To further reduce the impacts of predation by Caspian terns nesting at East Sand Island on salmonid stocks from the Columbia River basin, more terns will need to be relocated to colonies outside the basin; the management objective is to reduce the size of the East Sand Island tern colony to 3,125 - 4,375 breeding pairs, less than 45% of its pre- management size (ca. 10,000 breeding pairs), while attracting the displaced Caspian terns to alternative colony sites. The double-crested cormorant colony on East Sand Island consisted of about 14,900 breeding pairs in 2013. This is the largest double-crested cormorant colony ever recorded on East Sand Island, and is about 15% larger than it was during 2011-2012. This one colony likely includes more than 40% of the breeding population of double-crested cormorants in western North America, and is the largest known breeding colony of the species anywhere. In addition to double-crested cormorants, an estimated 1,550 pairs of Brandt's cormorants nested in the cormorant colony on East Sand Island in 2013. Brandt's cormorants first nested in this mixed-species colony in 2006, and numbers increased each year through 2012, when 1,680 breeding pairs were counted. Juvenile salmonids represented about 11% (by biomass) of the double-crested cormorant diet in 2013, compared to about 20% in 2012. Our estimate of total smolt consumption by double-crested cormorants nesting on East Sand Island in 2013 is 16.3 million smolts (95% c.i. = 11.4 – 21.1 million), not significantly different from the number of smolts consumed by cormorants from this colony in 2012. The majority of these consumed smolts (about 11.4 million or 70%) were sub-yearling Chinook salmon (O. tshawytscha) smolts consumed predominantly in the latter portion of the cormorants breeding season (June – August), as was the case in 2012. Estimated consumption of spring migrating smolts (coho [O. kisutch], yearling Chinook, and sockeye [O. nerka] salmon along with steelhead [O. mykiss]), however, was 4.8 million smolts (95% c.i. = 3.8 – 5.8 million), significantly less than consumption of spring migrants in 2012 (8.1 million smolts [95% c.i. = 6.2 – 9.9 million smolts]). This approximately 41% reduction in consumption of spring migrants occurred despite a 21% increase in peak cormorant colony size, suggesting a pronounced decline in proportion of spring migrants in the diet of double-crested cormorants during the 2013 nesting season. As in other recent years, estimates of total smolt consumption by double-crested cormorants nesting on East Sand Island in 2013 were significantly higher than that of Caspian terns nesting on East Sand Island. During 2004 – 2013, estimates of total annual smolt consumption by the East Sand Island double-crested cormorant colony have varied widely, from a low of 2.4 million smolts to a high of 20.5 million smolts (mean = 12.3 million). This large inter-annual variability in smolt consumption (coefficient of variation {CV} = 49%) has occurred over a period of relatively stable colony size (10,950 – 14,900 breeding pairs; CV = 9%) and has closely tracked the proportion of the cormorant diet that was salmonid smolts (2 – 20% of biomass consumed; CV = 47%); the proportion of smolts in the cormorant diet is an important input parameter in the bioenergetics calculations. During 2004 - 2013, the type of salmonid consumed in the largest numbers by double- crested cormorants nesting at East Sand Island was sub-yearling Chinook salmon (ca. 7.8 million smolts/year), followed by coho salmon, steelhead, and yearling Chinook salmon (ca. 2.4, 1.1, and 1.0 million smolts/year, respectively). Recoveries of smolt PIT tags on the East Sand Island cormorant colony in 2013 indicated that population- or ESU-specific predation rates ranged from 0.7% to 2.9% for populations originating upstream of Bonneville Dam on the Columbia River or upstream of Sullivan Dam on the Willamette River. Despite the increase in the size of the cormorant colony in 2013, the ESU-specific predation rates measured in 2013 were some of the lowest recorded since 2007. Similar to consumption estimates (number of fish consumed based on bioenergetics calculations), cormorant predation rates on particular populations or ESUs of salmonids based on smolt PIT tag recoveries have been highly variable among salmonid populations and among years. As demonstrated by the data collected in 2013, variability in the impacts on salmonids from cormorant predation cannot be explained by differences in colony size alone. Factors driving the large inter-annual variation in impacts of cormorant predation (smolt consumption and predation rates) are poorly understood, but may include environmental conditions in the estuary, the abundance and arrival timing of marine forage fish in the estuary, differences in cormorant nesting chronology and success, and/or other biotic and abiotic factors that influence cormorant feeding behavior. In 2013, the USACE expanded a pilot study initiated in 2011 to test possible strategies for limiting the size of the East Sand Island cormorant colony. Prior to the nesting season, two 8-foot-high privacy fences were built to bisect the colony. These fences visually separated 4.0 acres (25%) of the ca. 16 acres of available cormorant nesting area at the west end of East Sand Island. We used human disturbance to haze cormorants during the nest initiation period, and were successful in dissuaded them from using areas outside the 4.0-acre designated area in 2013. Some double-crested cormorants were satellite-tagged (n = 83) to follow their post-hazing movements to prospective new nesting sites. About 96% of these tagged cormorants (80/83) dispersed from the East Sand Island colony after tagging, and of these about 96% eventually returned to East Sand Island (73/76) and attempted to nest there. Tagged cormorants dispersing from East Sand Island during the nesting season were detected at colonies and roost sites (1) elsewhere in the Columbia River estuary (n = 76), (2) on the lower Columbia River below Bonneville Dam (n = 27), (3) on the outer Washington coast (including Willapa Bay and Grays Harbor; n = 21), and (4) in Puget Sound (n = 1). No double-crested cormorants satellite-tagged on East Sand Island early in the 2013 nesting season were detected along the coast of Oregon during the nesting season. Native piscivorous colonial waterbirds that nest in the Columbia Plateau region include Caspian terns, double-crested cormorants, American white pelicans, California gulls, and ring-billed gulls (L. delawarensis). Of these, Caspian terns have been identified as the single most significant avian predator (per capita) in the Columbia Plateau region on salmonid smolts, particularly ESA-listed steelhead populations from the Upper Columbia River and Snake River. Total numbers of Caspian terns nesting in the Columbia Plateau region declined from ca. 870 breeding pairs during 2005-2012 to ca. 775 breeding pairs in 2013, distributed among five breeding colonies. In 2013, the two largest Caspian tern colonies in the Columbia Plateau region were at Crescent Island (395 breeding pairs) on the mid-Columbia River and at Goose Island (340 breeding pairs) on Potholes Reservoir, WA. The size of both of these Caspian tern colonies declined from 2012 to 2013, but nesting success at both colonies increased in 2013. A small number of Caspian terns (about 26 breeding pairs) established nests at the Blalock Islands in the mid-Columbia River, but nesting success was quite limited. We observed a small number of banded Caspian terns that were originally banded as adults on East Sand Island in the Columbia River estuary, where management actions have been implemented, at the Goose Island (n = 1) and Crescent Island (n = 4) colonies in 2013. Prior to 2011, when tern management intensified at East Sand Island, movement to the Columbia Plateau region by banded adult Caspian terns that previously nested on East Sand Island had not been documented. Estimates of Caspian tern predation rates on salmonids based on smolt PIT tag recoveries on tern colonies in the Columbia Plateau region indicated that impacts were greatest on the upper Columbia River steelhead population (14.9% depredated by terns from the Goose Island colony) and on the Snake River steelhead population (2.8% depredated by terns from the Crescent Island colony). Predation rates by Goose Island terns on upper Columbia River yearling Chinook were also notable (2.1%), but significantly lower than predation rates on steelhead. Predation rates by Caspian terns nesting at the small colony in the Blalock Islands were an order of magnitude less than those of terns nesting at Goose and Crescent islands, but steelhead were still highly susceptible to predation by terns from this colony. A total of 23 adult Caspian terns nesting at Goose Island were marked with GPS tags and tracked during foraging trips over several days. Nearly half of the GPS-tagged terns (n = 11) made foraging trips to the mid-Columbia River, including Wanapum Reservoir, Priest Rapids Reservoir, and Hanford Reach. Of note, four GPS-tagged terns made foraging trips to the lower Snake River, including one tern that exhibited the greatest foraging range ever documented in a breeding Caspian tern: 93 km straight-line distance from the colony. Management of the Caspian tern colonies at Goose and Crescent islands to reduce their impacts on ESA-listed salmonids is currently under

consideration by regional managers. Band re-sighting data indicate high connectivity among Caspian tern colonies in the Columbia Plateau region and colonies elsewhere in western North America from Mexico to Alaska, both inland and along the coast. This suggests that Caspian terns displaced from these two Columbia Plateau colonies may re-nest at existing or newly-created colony sites outside the Columbia River basin. Total numbers of double-crested cormorants nesting in the Columbia Plateau region decreased slightly in 2013, from about 1,570 breeding pairs during 2012 to about 1,400 breeding pairs at four colonies in 2013; the largest colonies were in the North Potholes Reserve (ca. 800 nesting pairs) and on Foundation Island in the mid-Columbia River (ca. 390 nesting pairs). Numbers of American white pelicans nesting on Badger Island in the mid-Columbia River, a colony that experienced rapid growth during 2004-2011, appear to have stabilized at about 2,100 adults. The numbers of California gulls nesting on Miller Rocks, a colony located just downstream of John Day Dam on the Columbia River, were similar to those observed in recent years (ca. 4,800 adults). Following the abandonment of the large California gull colony on Three Mile Canyon Island (ca. 6,200 adults were counted on-colony in 2009), there was a commensurate increase in the number of California gulls nesting on islands in the Blalock Islands complex during 2012- 2013; in 2013 ca. 8,100 nesting gulls (mostly California gulls) were counted on two islands in the Blalock Islands, whereas in 2009 no gulls nested there. Currently there are no plans to manage colonies of cormorants, gulls, or white pelicans in the Columbia Plateau region based on previous research investigating their relative impacts on survival of juvenile salmonids. Recently-collected smolt PIT tag data, however, casts new light on the impacts of certain gull colonies on smolt survival, in particular the California gull colonies on Miller Rocks and Crescent Island. Deposition rates of smolt PIT tags on nesting colonies (percentage of smolt PIT tags that were consumed by gulls and subsequently deposited by the gull on-colony and used to estimate predation rates) by California gulls were significantly lower than those of Caspian terns and double-crested cormorants. Average on-colony PIT tag deposition rates by California gulls was just 17% (95% c.i. = 14% - 19%) in 2012 and 2013. Incorporation of on-colony deposition rates into predation rate models increased the estimates of colony-wide predation rates on juvenile salmonids by a factor of about 6 for California gulls, compared to previously published estimates. After adjusting for on- colony deposition rates, colony-wide predation rates on juvenile salmonids varied significantly by salmonid ESU and gull colony (range: < 0.1% to 8.5%); the California gull colonies on Miller Rocks and Crescent Island had a much greater impact on smolt survival compared to the California gull or ring-billed gull colonies on Island 20 (on the mid-Columbia River near Richland, WA) and the Blalock Islands. These results suggest that smolt predation rates by gulls nesting at some colonies in the Columbia Plateau region are comparable to, if not higher than, those of Caspian terns and double-crested cormorants nesting at colonies in the Columbia Plateau region.

BRNW (Bird Research Northwest). (2015a). *Implementation of the Inland Avian Predation Management Plan, 2014* (p. 93). http://www.birdresearchnw.org/2014_IAPMP_Final_Report_v2.pdf

In 2014, the U.S. Army Corps of Engineers - Walla Walla District and U.S. Bureau of Reclamation began implementation of the Inland Avian Predation Management Plan (IAPMP) as means to reduce predation by Caspian terns on U.S. Endangered Species Act (ESA) listed salmon stocks in the Columbia River basin (USACE 2014). The primary management objective in 2014 was to reduce the size of the Caspian tern colony on Goose Island in Potholes Reservoir to less than 40

breeding pairs. To accomplish this task, extensive passive dissuasion (stakes, ropes, and flagging) was erected in potentially suitable Caspian tern nesting habitat on Goose Island prior to the 2014 nesting season. Ultimately, about 2.4 acres, or over half of the upland area of Goose Island, was covered by passive dissuasion. An effort was also made to prevent any nesting by California and ring-billed gulls on Goose Island, on the theory that nesting gulls would be an attractant for prospecting Caspian terns and could limit abilities to dissuade Caspian terns. Once Caspian terns and gulls arrived on Goose Island to initiate nesting, human hazing was used to actively dissuade both terns and gulls from nesting anywhere on Goose Island. California gulls and, especially, ring-billed gulls quickly adapted and acclimated to the passive and active dissuasion, and initiated nesting (laid eggs) despite our efforts. Once gulls laid eggs, hazing gulls that were attending eggs was precluded due to the risk of gull nest failure. As the area on Goose Island with active gull nests expanded, the opportunities to actively haze Caspian terns that were prospecting for nest sites on Goose Island declined. Nevertheless, between the passive dissuasion deployed on preferred Caspian tern nesting habitat at Goose Island, and active dissuasion (hazing) using a green laser, only three pairs of Caspian terns laid eggs on Goose Island and all three eggs were collected under permit soon after they were laid. Consequently, despite having little effect on the number of gulls nesting on Goose Island, passive dissuasion and active hazing succeeded in preventing any successful nesting by Caspian terns on Goose Island in Potholes Reservoir. However, some Caspian terns that were precluded from nesting on Goose Island were highly motivated to nest in the area, and a small satellite colony of Caspian terns formed on a rocky islet near Goose Island where no Caspian tern nesting activity had previously been recorded. This islet, dubbed "Northwest Rocks," eventually attracted as many as 156 breeding pairs of Caspian terns, which nested at high density (1.67 nests/m2) amongst earlier-nesting gulls. The Northwest Rocks had not been considered potential nesting habitat for the Goose Island Caspian tern colony, and as such passive dissuasion and active hazing of Caspian terns attempting to nest on Northwest Rocks were not planned for the 2014 nesting season as part of implementing initial Phase 1 components of the IAPMP. Consequently, managers decided not to attempt to dissuade Caspian terns from nesting on Northwest Rocks in 2014, and the new satellite colony ultimately produced about 46 young Caspian terns. Caspian terns attempted to nest at four other previously used colony sites in 2014, and perhaps a fifth site where nesting Caspian terns had not previously been recorded. Extensive aerial and ground searches throughout the region failed to detect any additional Caspian tern nesting activity. The four previously used active colony sites were: (1) Crescent Island in McNary Pool in the Columbia River, (2) the Blalock Islands in John Day Pool in the Columbia River, (3) Twinning Island in Banks Lake, and (4) Harper Island in Sprague Lake. The potential new Caspian tern breeding site was on a small island in Lenore Lake, where a small gull colony exists. Of these five sites, only the colonies at Crescent Island and the Blalock Islands succeeded in raising any young. Crescent Island was the site of by far the largest Caspian tern breeding colony in the Columbia Plateau region during 2014. A total of about 474 breeding pairs of Caspian terns attempted to nest on Crescent Island in 2014, nearly identical to the average colony size during 2000-2013 (461 breeding pairs). Average nesting success at the Crescent Island Caspian tern colony was about 0.33 young raised per breeding pair, slightly below the long-term average (0.52 young raised per breeding pair in 2000-2013). Resighting of banded Caspian terns on the Crescent Island tern colony suggested that much of the increase in colony size at Crescent Island was related to management actions at Goose Island to reduce colony size there, causing some Caspian terns to immigrate to the Crescent Island colony. Despite the increase in the size of the

Crescent Island Caspian tern colony in 2014, the overall size of the Caspian tern breeding population in the Columbia Plateau region did not increase, and may have declined slightly from about 773 breeding pairs in 2013 to about 755 breeding pairs in 2014. Based on average per capita predation rates by Caspian terns nesting at various colonies in the Columbia Plateau region during 2007-2013, predicted predation rates were less than 2% (the goal of the IAPMP) on most, but not all, ESA-listed salmonid populations in 2014. Specifically, predicted predation rates on ESA-listed Upper Columbia River steelhead remained above 2% (7.0%, 95% PI: 4.1-12.4) for Caspian terns nesting at Potholes Reservoir because of the new satellite colony of Caspian terns that formed on Northwest Rocks adjacent to Goose Island. Also, predicted predation rates on ESA-listed Snake River steelhead (5.1%, 95% PI: 2.8-8.8) and Upper Columbia River steelhead (2.8%, 95% PI: 1.2-4.7) by Caspian terns nesting on Crescent Island exceeded 2%. Because of the small size (< 100 pairs) of other Caspian tern breeding colonies in the Columbia Plateau region, including at the Blalock Islands where 45 pairs attempted to nest in 2014, predicted predation rates on ESA-listed salmonid ESUs/DPSs by Caspian terns nesting at other colonies were negligible (< 0.5% per ESU/DPSs).

BRNW (Bird Research Northwest). (2015b). *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River, 2014* (p. 222).

The primary objectives of this study in 2014 were to (1) evaluate management initiatives implemented to reduce predation on juvenile salmonids by Caspian terns nesting on East Sand Island in the Columbia River estuary, including the monitoring of alternative Caspian tern nesting islands built by the Corps outside the Columbia River basin; (2) evaluate management implemented to reduce predation on juvenile salmonids by Caspian terns nesting on Goose Island in Potholes Reservoir by (a) collecting PIT-tags from piscivorous waterbird colonies to estimate smolt predation rates and (b) monitoring Caspian tern dispersal patterns associated with activities to dissuade nesting on the Goose Island colony; (3) monitor and evaluate colony size and juvenile salmon consumption by double-crested cormorants (Phalacrocorax auritus) nesting on East Sand Island and other sites in the lower Columbia River estuary; and (4) provide technical assistance to resource managers on the topic of avian predation on ESA-listed juvenile salmonids, as warranted. The management plan entitled, Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary was first implemented in 2008 and continued in 2014. As part of this plan, the U.S. Army Corps of Engineers – Portland District (Corps) maintained 1.55 acres of suitable nesting habitat for Caspian terns on East Sand Island in 2014, slightly less than the area of nesting habitat provided during 2012-2013 (1.58 acres), and a 69% reduction in area of tern nesting habitat on East Sand Island compared to what was provided during 2001-2007, prior to implementation of the management plan. In 2014, Caspian terns nested on the East Sand Island colony at an average density of 1.06 nests/m2, a decrease from the average nesting density recorded in 2013 (1.17 nests/m2), but still a higher nesting density compared to pre- management (average of 0.55 nests/m2). Passive nest deterrence measures (stakes, ropes, and flagging) installed by the Corps to dissuade Caspian terns from nesting on the upper beach near the main tern colony and elsewhere on East Sand Island were successful in preventing Caspian terns from forming satellite colonies anywhere on East Sand Island in 2014. The Caspian tern colony on East Sand Island, the largest for the species in the world, consisted of about 6,270 breeding pairs in 2014. This is a decrease from the estimate of 7,400 pairs in 2013 and the smallest Caspian tern colony size recorded at East Sand Island since the initiation of reductions in tern nesting habitat on the island in 2008, as part of the Caspian Tern

Management Plan. This represents a decline of about 41% in the size of the Caspian tern colony on East Sand Island from its peak in 2008 (ca. 10,670 breeding pairs). As was the case in 2013, Caspian terns at this colony were relatively resilient to disturbances by bald eagles (Haliaeetus leucocephalus) and associated gull (Larus spp.) depredation of tern eggs and chicks, limiting factors that caused the Caspian tern colony to fail or nearly fail during 2010-2012. The Caspian tern colony on East Sand Island produced roughly 1,700 fledglings in 2014 (average of about 0.28 young raised/breeding pair), an increase compared to 2010-2012 when productivity averaged 0 – 0.06 young raised/breeding pair, but still lower than the average during the previous decade (2000-2009). The average proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during the 2014 nesting season was 33%, similar to the average observed over the previous eight nesting seasons. The estimated total smolt consumption by Caspian terns nesting at East Sand Island in 2014 was 4.5 million (95% c.i. = 3.9 - 5.1 million), not significantly different from total annual smolt consumption during 2011, 2012, and 2013, but significantly less than pre-management. Predation rates on specific populations of salmonids (ESUs/DPSs) by Caspian terns in 2014 were similar to those observed during 2011-2013, but were generally lower than those observed during the period 2007-2010. Reductions in tern predation rates following the implementation of management coincided with comparable reductions in tern colony size, suggesting that Caspian tern management initiatives to reduce tern nesting habitat on East Sand Island are resulting in lower predation rates on particular ESUs/DPSs of salmonids in the Columbia River estuary. Similar to previous years, Caspian tern predation rates were significantly higher on populations of steelhead (O. mykiss) smolts (8.6 – 11.4%, depending on DPS) compared with populations of salmon (0.9 – 1.6%, depending on ESU). Since 2008, the Corps has constructed nine islands as alternative colony sites for Caspian terns displaced from East Sand Island, six in interior Oregon and three in the Upper Klamath Basin region of northeastern California. Two of these islands were not available for tern nesting in 2014, and one is no longer being monitored for Caspian tern nesting activity. The other six Corps-constructed islands were monitored for Caspian tern nesting activity in 2014, and nesting attempts by Caspian terns were recorded at five of these islands. A combined total of 786 breeding pairs of Caspian terns attempted to nest at Corps-constructed tern islands in 2014, a 27% increase from the average number of breeding pairs that nested on Corp-constructed tern islands in 2008-2013 (618 breeding pairs). Estimated average productivity among the five Corps-constructed islands, however, was somewhat higher in 2014 (0.27 young raised/breeding pair) compared to 2013 (0.18 young raised/breeding pair). The increase in average nesting success by Caspian terns at the Corps-constructed islands from 2013 to 2014 was in large part due to increased predator control efforts at these sites. Regardless, nest predation by mammalian and avian predators, displacement by other colonial waterbird species (i.e., California gulls [L. californicus] and American white pelicans [Pelecanus erythrorhynchos]), drought, adverse weather conditions, and apparent low availability of preferred forage fish (due to drought) continued to limit Caspian tern colony formation, colony size, and nesting success at the Corps-constructed islands. Nevertheless, a substantial number of Caspian terns that were banded at the colony on East Sand Island in the Columbia River estuary used the Corps-constructed islands as alternative colony sites; a total of 84 Caspian terns banded in the Columbia River estuary were resighted at one or more of the Corps-constructed islands in interior Oregon and northeastern California during the 2014 nesting season. Based on the estimated movement rate of Caspian terns from East Sand Island to the Corps-constructed islands (3.1%; calculated using Program MARK on mark-resighting data of banded adult Caspian terns), about 461 Caspian terns (3.1%

of breeding individuals at the East Sand Island colony in 2013, including both banded and unbanded birds) moved from East Sand Island to the Corps-constructed islands in 2014. This high number of Caspian terns moving from East Sand Island to the Corps-constructed islands in a single year (461 individuals) demonstrates the connectivity of the East Sand Island colony with the colonies that have formed on the Corps-constructed islands in interior Oregon and northeastern California. To further reduce the impacts of predation by Caspian terns nesting at East Sand Island on survival of salmonid smolts in the Columbia River estuary, more Caspian terns (1,895- 3,145 breeding pairs) will need to be relocated to colonies outside the basin based on the size of the colony in 2014 (6,270 breeding pairs) relative to the target colony size for Caspian terns nesting on East Sand Island identified in the management plan (3,125 - 4,375 breeding pairs). This will likely require a further reduction in area of suitable Caspian tern nesting habitat on East Sand Island by at least one third, or down to about 1 acre of nesting habitat. In 2014, efforts to monitor of the double-crested cormorant colony on East Sand Island in the Columbia River estuary were reduced from previous years, awaiting the completion and release of the Double-crested Cormorant Management Plan to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary, with management actions scheduled for implementation as early as the spring of 2015. Objectives for monitoring the double-crested cormorant colony on East Sand Island in 2014 were to (1) estimate colony size and (2) estimate stock-specific predation rates on juvenile salmonids. The double-crested cormorant colony on East Sand Island consisted of about 13,600 breeding pairs in 2014, about 26% more than the average number of double-crested cormorants that nested on East Sand Island in 1997-2013 (ca. 10,775 breeding pairs). This one colony includes at least 40% of the breeding population of double-crested cormorants in western North America, and is the largest known breeding colony of the species anywhere. In addition to double-crested cormorants, ca. 1,630 pairs of Brandt's cormorants (P. penicillatus) nested in the cormorant colony on East Sand Island in 2014. Brandt's cormorants first nested in this mixed-species colony in 2006, and numbers increased each year through 2012, when 1,680 breeding pairs were counted. Despite a smaller colony in 2014, recoveries of smolt PIT tags on the East Sand Island cormorant colony in 2014 indicated that ESU/DPS-specific predation rates were up substantially compared with 2013 and were some of the highest recorded since the colony was first scanned for PIT tags in 1999. Predation rates on salmon ESUs were especially high relative to previous years, with an estimated 8.5% (95% c.i. = 6.1 - 13.2%) and 6.1% (95% c.i. = 3.9 - 10.1%) of Snake River spring/summer Chinook (O. tshawytscha) and Upper Columbia River spring Chinook, respectively, consumed by cormorants in 2014. Predation on steelhead DPSs ranged from 6.4% (95% c.i. = 3.7 - 10.7%) on Middle Columbia River steelhead to 10.4% (95% c.i. = 7.3 - 16.3%) on Upper Columbia River steelhead. As demonstrated by smolt PIT tag data collected in 2014 and previous years, inter-annual variation in the impact of cormorant predation on survival of salmonid smolts in the Columbia River estuary was poorly explained by differences in colony size alone. Factors that have been linked to high inter-annual variation in cormorant predation (smolt consumption and predation rates) include river discharge into the estuary and ocean conditions (i.e., the North Pacific Gyre Oscillation) as they influence the abundance and availability of alternative prey (marine and estuarine forage fishes). Native piscivorous colonial waterbirds that nest in the Columbia Plateau region include Caspian terns, double-crested cormorants, American white pelicans, California gulls, and ring-billed gulls (L. delawarensis). Of these, Caspian terns have been identified as having the greatest impact on ESA-listed juvenile salmonids in the Columbia Plateau region. The impacts of Caspian tern predation in the Columbia Plateau region on survival of ESA- listed steelhead populations from the Upper Columbia River and Snake River have been especially high. In January 2014, the U.S Army Corps of Engineers – Walla Walla District completed the Inland Avian Predation Management Plan (IAPMP). The goal of the IAPMP is to reduce Caspian tern predation rates on ESA-listed Columbia Basin salmonids to less than 2% (per colony and per ESA-listed population) by redistributing Caspian terns from the two largest nesting sites in the Columbia Plateau region (i.e., colonies on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River) to sites outside the Columbia River Basin. In 2014, the Corps and the Bureau of Reclamation (BOR) implemented Phase I of the IAPMP by reducing nesting habitat on Goose Island and actively discouraging Caspian terns from nesting there. In 2014, as part of a separately study funded by the U.S. Army Corps of Engineers – Walla Walla District and the U.S. Bureau of Reclamation (see separate report; BRNW 2014b), we monitored Caspian tern nesting activity throughout the Columbia Plateau region to help evaluate the effectiveness of the nest dissuasion actions implemented at Goose Island in dispersing Caspian terns to alternative colony sites outside the basin. These nest dissuasion actions were successful in preventing all but three breeding pairs of Caspian terns from nesting on Goose Island proper in 2014 (340 breeding pairs nested there the previous year). The three breeding pairs that nested on Goose Island each laid a single egg that was collected under permit soon after it was laid. Formation of a Caspian tern breeding colony on Goose Island was prevented in 2014 without causing any apparent disruption of breeding California and ring-billed gulls on the island. Surveys throughout the Columbia Plateau region in 2014 indicated that Caspian terns attempted to nest at four additional sites where they had previously nested and two new sites not previously used by nesting Caspian terns. The four previously used Caspian tern colony sites that were also active in 2014 were: Crescent Island on the mid- Columbia River (474 breeding pairs); Twinning Island in Banks Lake (67 breeding pairs); the Blalock Islands on the mid-Columbia River (45 breeding pairs); and Harper Island in Sprague Lake (8 breeding pairs). The new Caspian tern breeding sites were on a small islet adjacent to Goose Island in Potholes Reservoir (dubbed "Northwest Rocks"; 156 breeding pairs) and amongst a small colony of gulls on a small island in Lenore Lake (2 breeding pairs). Of these seven sites, only the colonies at Crescent Island, the Blalock Islands, and Northwest Rocks succeeded in raising any young. Recoveries of smolt PIT tags on the colony at Northwest Rocks indicated that Caspian terns nesting there consumed 2.9% (95% c.i. = 1.9 - 5.1%) and 0.3% (95% c.i. = 0.1 - 0.7%) of Upper Columbia River steelhead and yearling Chinook salmon, respectively. Estimated predation rates by Caspian terns nesting at Northwest Rocks in 2014 were the lowest recorded for Caspian terns nesting at Potholes Reservoir to date, and significantly lower than pre-management estimates during 2007-2013. These results indicate that efforts to dissuade Caspian terns from nesting on Goose Island in Potholes Reservoir were successful at reducing smolt consumption by Caspian terns in the Columbia Plateau region in 2014. The reduction in Caspian tern predation rate on steelhead smolts, however, was not below the 2% threshold target established by the IAPMP. In conjunction with the efforts to dissuade Caspian terns from nesting on Goose Island in 2014, we evaluated the individual responses of 28 Caspian terns that were captured on Goose Island prior to egg-laying and fitted with solar-powered satellite telemetry tags. We observed three types of initial response by tagged Caspian terns to elimination of tern nesting habitat on Goose Island: (1) stay in the area and compete for reduced available nesting habitat (i.e. Northwest Rocks), (2) move to one of several nearby colonies (70 – 125 km away) and attempt to nest there, returning to the Goose Island area if nesting fails, and (3) nomadic wandering throughout the region, without a sustained association with any colony.

Tern foraging activity was reduced in areas of the mid-Columbia River where terns have previously had substantial impacts on Upper Columbia River steelhead (i.e. the Wanapum and Priest Rapids pools). Displaced terns did not leave the larger Columbia Plateau region at an appreciable rate during the primary smolt outmigration period, however. Consequently, some predation may have been shifted to other locations and/or other Columbia Basin salmonid populations. Additional IAPMP actions to be implemented in 2015, including an expansion of nest dissuasion from Goose Island to the nearby adjacent islets, initiation of nest dissuasion at Crescent Island, and enhancement of nesting habitat for Caspian terns in San Francisco Bay, appear poised to address several of the factors limiting the displacement of terns from the Columbia Plateau. Marginal nesting habitat at Banks Lake, Sprague Lake, or in the Blalock Islands in the Columbia River (John Day Pool) may be a continued draw for displaced Caspian terns, however. The inability of tagged terns to nest successfully anywhere away from the rocky islet adjacent to Goose Island in 2014 suggests that the long-term goal of reducing tern predation on Columbia Basin salmonids by encouraging fidelity to nest sites outside the Columbia Basin will likely require a sustained, multi-year effort. The largest Caspian tern breeding colony in the Columbia Plateau region during 2014 was on Crescent Island in the mid-Columbia River. A total of about 474 breeding pairs of Caspian terns attempted to nest on Crescent Island in 2014, a 21% increase in colony size compared to 2013. Resighting of banded Caspian terns on the Crescent Island tern colony suggested that much of the increase in colony size at Crescent Island was related to management actions at Goose Island to reduce colony size there, causing some Caspian terns to immigrate to the Crescent Island colony, about 100 km away. Despite increases in colony size at both Crescent Island and other Caspian tern colonies in the Columbia Plateau region in 2014, the overall size of the Caspian tern breeding population in the region did not increase, and apparently declined slightly in 2014 (758 breeding pairs) compared to 2013 (773 breeding pairs). Predation rates on steelhead populations by Caspian terns nesting on Crescent Island were higher in 2014 compared to previous years (2007-2013). In 2014, predation rates on Upper Columbia River steelhead (3.4%; 95% c.i. = 2.5 - 4.9%) and Snake River steelhead (4.7%; 95% c.i. = 3.7 - 6.9%) and were the first and second highest predation rates recorded since 2007, respectively. Impacts on survival of salmonid smolts, both steelhead and salmon, from Caspian terns nesting on Twinning Island and the Blalock Islands in 2014 were lower than for Caspian terns nesting on Crescent Island, due in part to the much larger size of the Crescent Island tern colony (474 pairs), compared with the Caspian tern colonies on Twinning Island (66 pairs) or the Blalock Islands (45 pairs). Over-all (all Caspian tern colonies combined) predation rate estimates indicate that actions to dissuade Caspian terns from nesting in Potholes Reservoir in 2014 resulted in lower impacts on upper Columbia River ESUs/DPSs compared to previous years, suggesting that management actions in 2014 benefited fish survival, particular survival of Upper Columbia River steelhead.

Broadbooks, H. E. (1961). Ring-Billed Gulls Nesting on Columbia River Islands. *The Murrelet*, *42*(1), 7–8. JSTOR. https://doi.org/10.2307/3535670

Brown, D. E. (1926). Birds Observed at Moses Lake, Grant County, Washington. *The Murrelet*, *7*(3), 48–51. JSTOR. https://doi.org/10.2307/3535643

Brugger, K. E. (1993). Digestibility of Three Fish Species by Double-Crested Cormorants. *The Condor*, *95*(1), 25–32. https://doi.org/10.2307/1369383

I determined daily energy requirements of captive Double-crested Cormorants (Phalacrocorax auritus) and their metabolizable energy coefficients (MECs) for three fish species: channel catfish (Ictalurus punctatus), gizzard-shad (Dorosoma cepedianum), and bluegill (Lepomis macrochirus). Ad libitum intake ranged from 264 to 503 g*bird-1*day-1 among tests, resulting in metabolizable energy values of 6 16 to 1,334 kJ*kg-1*day-1. Ninety percent of the marker carmine red was recovered in 48 hr, suggesting that collection periods should be ca. three days to determine digestion efficiencies. Estimated MECs ranged from 77.9% to 89.2% among fish diets, with bluegill < channel catfish = gizzard shad. No seasonal differences were found for MECs of catfish. Nitrogen corrections reduced MECs to approximately 75% for bluegill, 78% for gizzard shad, and 79% for channel catfish.

Budy, P., Thiede, G. P., Bouwes, N., Petrosky, C. E., & Schaller, H. (2002). Evidence Linking Delayed Mortality of Snake River Salmon to Their Earlier Hydrosystem Experience. *North American Journal of Fisheries Management*, *22*, 35–51.
The numbers of Snake River salmon and steelhead Oncorhynchus spp. have substantially declined since the completion of the Columbia River hydrosystem. We used analytical approaches to identify management options for halting the decline of these stocks, such as removal of Snake River dams and improvements to the existing hydrosystem. The benefits these actions are predicted to have in terms of salmon recovery hinge on whether the mortality that takes place in the estuary and early in their ocean residence is related to earlier hydrosystem experience during downstream migration. Evidence from the literature demonstrates numerous mechanisms that would explain this delayed mortality in relation to a fish's experience passing through the hydrosystem. Spatial and temporal comparisons of stock performance provide indirect evidence of delayed mortality and evidence that delayed mortality is linked to hydrosystem experience. Recent mark–recapture data also provide evidence of differences in delayed mortality by route of passage through the hydrosystem. The different types of evidence discussed here suggest that the delayed mortality of Snake River fish is related to the hydrosystem.

Bullock, I. D., & Gomersall, C. H. (1981). The breeding populations of terns in Orkney and Shetland in 1980. *Bird Study*, *28*(3), 187–200. https://doi.org/10.1080/00063658109476723
The northern islands of Scotland hold the bulk of British and Irish Arctic Terns. It had been feared that this population was in decline, and in 1980 a survey was held to establish the facts.

Carter, H. R., Sowls, A. L., Rodway, M. S., Wilson, U. W., Lowe, R. W., McChesney, G. J., Gress, F., & Anderson, D. W. (1995). Population Size, Trends, and Conservation Problems of the Double-Crested Cormorant on the Pacific Coast of North America. *Colonial Waterbirds*, *18*, 189–215. JSTOR. https://doi.org/10.2307/1521540
Population size, trends and conservation problems of the Double-crested Cormorant (Phalacrocorax auritus) were collated for the Pacific coast of North America using available data up to 1992. About 54,942 birds currently breed there, including roughly 5,848 (5,622 at 90 coastal colonies and at least 226 at 5 interior colonies) and 49,094 (43,358 at 126 coastal colonies and at least 5,736 at 22 interior colonies) for subspecies P. a. cincinatus in Alaska and P. a. albociliatus, from British Columbia to Sinaloa (Mexico), respectively. In addition, 51 and 22 inactive colonies have been documented in coastal and interior regions, respectively. Major historical declines (in the 1800s and early 1900s) occurred in much of Alaska, California, and Mexico, followed by increases in British Columbia, Washington, Oregon and California from the 1920s to 1980s.

Recent declines are occurring in British Columbia, Washington, and Baja California. Trends are affected by apparent movements of nesting birds during El Niño oceanographic conditions and due to habitat loss at interior colonies, as well as recent use of artificial nesting habitats in some areas. Conservation problems have included various forms of human disturbance and persecution, marine pollutants, and high levels of predation owing to introduced and natural predators.

Castro, G., Stoyan, N., & Myers, J. P. (1989). Assimilation efficiency in birds: A function of taxon or food type? *Comparative Biochemistry and Physiology Part A: Physiology*, *92*(3), 271–278. https://doi.org/10.1016/0300-9629(89)90563-X
1. We review the available measurements of assimilation efficiency in birds and find a strong dependence upon food ingested, regardless of bird taxa. 2. Assimilation efficiency in birds is about 75% for most food types, except plants (36.9%) and fruits (41%).

Chatwin, T. A., Mather, M. H., & Giesbrecht, T. D. (2002). Changes in Pelagic and Double-Crested Cormorant Nesting Populations in the Strait of Georgia, British Columbia. *Northwestern Naturalist*, *83*(3), 109–117. JSTOR. https://doi.org/10.2307/3536609
This study was initiated in 2000, as previous studies in the 1990s suggested that nesting populations of pelagic cormorant (Phalacrocorax pelagicus) and double-crested cormorant (P. auritus) were declining in the Strait of Georgia. We conducted a complete count in 2000 and compared population estimates from counts completed in various years since the mid 1950s. We surveyed 34 pelagic and 17 double-crested cormorant historic and current colonies. Our analyses showed that overall counts of pelagic cormorants were down by half and double-crested cormorants had declined by two-thirds since 1987. Pelagic cormorants had significantly fewer nests in 2000 compared with 1987, although during that period an increase in the population at 1 colony was noted. Significant increasing trends were noted at 2 of 17 double-crested cormorant colonies. However, these increases did not offset the dramatic declines in overall population size. We suggest that the causes of declines are possibly related to a combination of bald eagle (Haliaeetus leucocephalus) disturbance, change in prey availability, and human disturbance.

Chavez, F. P., Ryan, J., Lluch-Cota, S. E., & C, M. Ñ. (2003). From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean. *Science*, *299*(5604), 217–221. https://doi.org/10.1126/science.1075880
In the Pacific Ocean, air and ocean temperatures, atmospheric carbon dioxide, landings of anchovies and sardines, and the productivity of coastal and open ocean ecosystems have varied over periods of about 50 years. In the mid-1970s, the Pacific changed from a cool "anchovy regime" to a warm "sardine regime." A shift back to an anchovy regime occurred in the middle to late 1990s. These large-scale, naturally occurring variations must be taken into account when considering human-induced climate change and the management of ocean living resources.

Chiaramonte, L. V., Meyer, K. A., & Lamansky, J. A. (2019). Colonial Waterbird Predation and Angler Catch of Hatchery Rainbow Trout Stocked in Southern Idaho Fisheries. *Transactions of the American Fisheries Society*, *148*(6), 1088–1101. https://doi.org/10.1002/tafs.10198
The abundance of piscivorous colonial waterbirds such as double-crested cormorants Phalacrocorax auritus and American white pelicans Pelecanus erythrorhynchos has increased dramatically in recent decades in North America, resulting in increased conflict between these birds and fisheries

resources, which raises the need to quantify the effects of waterbird predation on fisheries. We estimated avian predation and angler use of two sizes of hatchery-reared Rainbow Trout Oncorhynchus mykiss (250 mm and 300 mm on average; termed standard catchables and magnum catchables) at 15 Idaho waters with known cormorant and pelican presence. Fish were tagged with passive integrated transponder (PIT), radio, and T-bar anchor tags prior to release; the tags were subsequently recovered from bird nesting, roosting, and loafing sites. Estimated angler use, which included fish harvested as well as those that were catch-and-release, averaged 17%, while avian predation averaged 35%. Angler catch at study waters declined exponentially as avian predation increased. Predation specifically attributed to double-crested cormorants and American white pelicans was related to their relative abundance at the waterbodies where the fish were stocked. Avian predation rates were similar for standard and magnum catchables, suggesting that larger fish were not able to escape predation any better than smaller ones. Our results add to existing evidence indicating that in some southern Idaho fisheries, piscivorous birds, rather than anglers, are the dominant consumers of hatchery trout. This study further contributes to the larger issue of competition between humans, wildlife, and fisheries populations.

Clark, A. C., Kollasch, T. M., & Williamson, D. A. (2006). Movements of Double-Crested Cormorants Fledged on the Columbia River Estuary. *Northwestern Naturalist*, *87*(2), 150–152. JSTOR.

Clements, S., Stahl, T., & Schreck, C. B. (2012). A comparison of the behavior and survival of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (O. mykiss) in a small estuary system. *Aquaculture*, *362–363*, 148–157. https://doi.org/10.1016/j.aquaculture.2011.11.029
We used radio and acoustic telemetry to study the behavior and survival of wild steelhead trout (Oncorhynchus mykiss) and hatchery coho salmon (Oncorhynchus kisutch) and steelhead outmigrants in a small coastal estuary during two years. Survival was generally low for hatchery fish but more variable, both within and between years, for wild steelhead. The rate of downstream movement in the river varied both within and between species and was generally not correlated with flow. Both hatchery and wild steelhead tended to spend less than a day in the estuary, and tended to move downstream on outgoing tides. In contrast, hatchery coho salmon spent a longer period of time in the estuary (~8d). On several occasions, coho salmon were observed moving both upstream and downstream between the upper (freshwater) and lower (saline) zones of the estuary. We also documented a high incidence of predation by avian and mammalian predators on coho outmigrants.

Coleman, J. T. H., Richmond, M. E., Rudstam, L. G., & Mattison, P. M. (2005). Foraging Location and Site Fidelity of the Double-crested Cormorant on Oneida Lake, New York. *Waterbirds*, *28*(4), 498–510. https://doi.org/10.1675/1524-4695(2005)28[498:FLASFO]2.0.CO;2
We studied the foraging behavior of the Double-crested Cormorant (Phalacrocorax auritus) on Oneida Lake, New York, by monitoring the activities of 27 radio-tagged birds in July and August of 1999 and 2000. A total of 224 locations were obtained of cormorants actively diving, and presumed foraging, at the time of detection. A geographic information system was used to examine foraging distances from the nesting island, the water depth and type of substrate at preferred foraging sites, and to estimate kernel home ranges for analysis of individual foraging site fidelity. An explanatory model was developed to determine parameters affecting the distance

to cormorant foraging sites. The mean distance to foraging locations of tagged cormorants from the colony site was 2,920 m (SE ± 180 m, max = 14,190 m), and 52% of the locations were within 2,000 m of the nesting island. No cormorant was observed making daily foraging trips to outside water bodies. Mean foraging distance was greater during morning than in the afternoon, and there was a significant effect of the time of day on distance. There was no significant effect of sex date, a seasonal measure on distance to foraging location. Individual cormorants exhibited fidelity to specific foraging sites. Most cormorants foraged in close proximity to the nesting island much of the time, while those detected further from the island tended to return repeatedly to the same locations. Ninety percent of the foraging locations were in water depths ≤7.5 m, and most were in water 2.5-5 m deep. Compositional analysis of habitat use revealed a preference for these depths, along with substrates of cobble with rubble, and silt with clay.

Collar, S. (2013). *Site Fidelity and Colony Dynamics of Caspian Terns Nesting at East Sand Island, Columbia River Estuary, Oregon, USA* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/fb494c738

Fidelity to breeding sites in colonial birds is an adaptive trait thought to have evolved to enhance reproductive success by reducing search time for breeding habitat, allowing earlier nest initiation, facilitating mate retention, and reducing uncertainty of predator presence and food availability. Studying a seabird that has evolved relatively low colony fidelity, such as the Caspian tern, allowed me to explore the influence of stable nesting habitat on fidelity and nest site selection. The Caspian tern (Hydroprogne caspia) breeding colony on East Sand Island (ESI) in the Columbia River estuary is the largest colony of its kind in the world. This colony has experienced a decade of declining nesting success, culminating with the failure of the colony to produce any young in 2011. The objective of my study was to understand the dynamics of this Caspian tern super-colony by investigating the actions of breeding individuals over two seasons, as well as the behavior of the colony as a whole from 2001-2011. I was interested in (1) the degree of nest site fidelity exhibited by breeding terns in successive years and its relationship to reproductive success, and (2) how the interaction of top-down and bottom-up forces influenced average nesting success across the entire colony, and caused the observed trends in nesting success at the East Sand Island colony from 2001 to 2011. My study investigated the potential influence of bottom-up and top-down drivers for the declining productivity at this once thriving colony of Caspian terns. I used sophisticated surveying equipment to test for nest site fidelity and group adherence between two consecutive breeding seasons for 80 Caspian terns marked with field readable leg bands. Available bare sand nesting habitat at this colony site declined by 33% between the two years, displacing some focal individuals from their previously held nest territories. Terns whose former nest site was no longer in suitable habitat had twice the inter-annual distance between nest sites when compared with terns whose former nest site was still in suitable habitat. There was a negative association between inter-annual distance between nests and the number of neighbors retained from the previous year. Displaced terns retained few, if any, neighbors, indicating that group adherence by nesting terns was largely a result of individual philopatry to nesting areas within the colony, rather than adherence to neighboring nesting pairs. There was a tendency for displaced terns to nest in closer proximity to the edge of the colony, and to have nesting attempts that ended earlier compared to non-displaced terns. After all nesting attempts failed during year 2 of the study, terns displaced from year 1 nest sites paradoxically exhibited higher fidelity to the colony site after colony failure in year 2 than terns that retained their year 1 nesting area. Failure of the previous nesting attempt and the novelty of the nest site and its neighbors, factors that should have resulted in low philopatry, were apparently out-weighed by the scarcity of suitable alternative nesting habitat for Caspian terns within the region. I also investigated the potential influence of bottom-up and top-down drivers for the declining productivity at this once thriving colony of Caspian terns. Since 2001 the decline in reproductive success of Caspian terns at ESI has been associated with a significant increase in average river discharge during May and June. I also found a significant increase in kleptoparasitism rates of terns by glaucous-winged/western gulls (Larus glaucescens x L. occidentalis) since 2001, and a significant negative relationship between average annual rates of gull kleptoparasitism and Caspian tern nesting success at ESI. There was also a significant increase in disturbance rates by bald eagles (Haliaeetus leucocephalus) during June for terns nesting at the ESI colony, and eagle disturbance rates were positively associated with May river discharge. The abundance of forage fish for terns in the estuary was inversely related to river discharge, which also apparently influenced the reliance of tern nest predators on the tern colony as a food source, resulting in increased disturbance to and decreased reproductive success at the tern colony. Although correlational, our results support the hypothesis that the decline in Caspian tern nesting success at this large estuarine colony was primarily driven by bottom-up factors, both as they directly affect tern productivity through the food supply, and indirectly as they affect the alternative food supply of potential predators of Caspian tern nest contents.

Collar, S., Roby, D. D., & Lyons, D. E. (2017). Top-Down and Bottom-Up Interactions Influence Fledging Success at North America’s Largest Colony of Caspian Terns (Hydroprogne caspia). *Estuaries and Coasts*, *40*(6), 1808–1818. https://doi.org/10.1007/s12237-017-0238-x

Our study investigated the influence of bottom-up and top-down drivers on the declining fledging success at a once thriving breeding colony of Caspian terns (Hydroprogne caspia). Situated at the mouth of the Columbia River, OR, East Sand Island (ESI) is home to the largest Caspian tern breeding colony in North America. Since 2001, the decline in fledging success of Caspian terns at ESI has been associated with a significant increase in average river discharge during May and June. During the years 2001–2011, the abundance of forage fish available to terns in the estuary was inversely related to river discharge. This relationship also apparently affected the reliance of nest predators on the tern colony as a food source, resulting in increased disturbance and decreased fledging success at the tern colony in years of higher river discharge. There was a significant longitudinal increase in disturbance rates by bald eagles (Haliaeetus leucocephalus) during June for terns nesting at the ESI colony, and eagle disturbance rates were positively associated with May river discharge. We also found a significant increase in kleptoparasitism rates of terns by hybrid glaucous-winged/western gulls (Larus glaucescens x Larus occidentalis) since 2001, and Caspian tern fledging success at ESI decreased with increasing average annual rates of gull kleptoparasitism. Our results support the hypothesis that the decline in Caspian tern fledging success at this large estuarine colony was primarily driven by the interaction of bottom-up and top-down factors, influencing tern fledging success through the food supply and triggering potential predators to identify the tern breeding colony as an alternative source of prey.

Collins, C. T. (2006). Banding Studies of Caspian Terns in Southern California. *North American Bird Bander*, *31*(1), 10–17.

Caspian Terns currently breed at three anthropocentric sites in southern California. Observations of banded birds and band recoveries from 1986 to 2006 indicate low nesting colony philopatry and substantial inter-colony movements from year to year. Several terns banded as chicks dispersed northward to colonies in San Francisco Bay and the Columbia River. Only two immigrant individuals were identified in the southern California colonies. The oldest recovery was of an 18-yearold individual. Most of the local breeding population migrates and appears to winter in coastal western Mexico. These data closely agree with a recent regional analysis of Pacific coast colonies.

Collis, K., Evans, A., Cramer, B., Turecek, A., Payton, Q., Bhatt, R., Kaufman, T., Gibson, M., & Lawes, T. (2019). *Implementation of the Inland Avian Predation Management Plan, 2018* (p. 99). http://www.birdresearchnw.org/2018%20IAPMP%20Final%20Report_v5.pdf

In 2018, the U.S. Army Corps of Engineers - Walla Walla District and the U.S. Bureau of Reclamation (BOR) completed implementation of the Inland Avian Predation Management Plan (IAPMP) to reduce predation by Caspian terns (Hydroprogne caspia) on U.S. Endangered Species Act (ESA)-listed salmonid (Oncorhynchus spp.) populations from the Columbia River basin (USACE 2014). The primary objective of management in the fifth year of implementation of the plan was to limit the numbers of Caspian terns breeding at Goose Island and surrounding islands in Potholes Reservoir and on Crescent Island in McNary Reservoir to less than 40 breeding pairs each to reduce predation impacts of terns on ESA-listed juvenile salmonids in the Columbia Plateau region. To accomplish this task, the availability of suitable Caspian tern nesting habitat was nearly eliminated at these sites by installing a variety of passive nest dissuasion materials prior to the 2018 nesting season, materials that were designed to preclude tern nesting at both locations. In addition, on Crescent Island, willows had been planted over extensive areas of the island to preclude tern nesting over the long-term. On both Goose and Crescent islands, passive dissuasion was placed over all the area where Caspian terns have previously nested, as well as all areas of open, sparsely-vegetated habitat that might be used by ground-nesting Caspian terns or gulls (Larus spp.). Ultimately, 4.1 acres, or more than 85% of the upland area of Goose Island were covered with passive nest dissuasion materials consisting of stakes, rope, and flagging. On Crescent Island, about 2.4 acres of potential Caspian tern nesting habitat were covered with passive nest dissuasion materials consisting of fences rows of privacy fabric, as well as stakes, rope, flagging, and woody debris in 2018; additionally, all open areas on Crescent Island had been planted with willows and other native vegetation prior to the 2016 nesting season. Finally, an island in northeastern Potholes Reservoir that was used by Caspian terns for nesting in 2016 (0.15 acre) and one additional nearby island where terns were observed prospecting in 2018 (0.10 acre) were covered in passive dissuasion to prevent terns from nesting at those sites. Once Caspian terns arrived to initiate nesting, active nest dissuasion (i.e. human hazing) was used to try to dissuade terns from nesting on Goose Island and other islands in Potholes Reservoir. No hazing has been required to prevent Caspian terns from nesting on Crescent Island since the onset of management in 2015. As was the case in 2015-2017, passive and active nest dissuasion techniques were successful in preventing all nesting and roosting by both Caspian terns and gulls in upland areas on Crescent Island during the 2018 nesting season. Prior to management (2005-2013), an average of 403 breeding pairs of Caspian terns nested on Crescent Island. The complete abandonment of Crescent Island by nesting terns beginning in the first year of management was somewhat unexpected because Caspian terns and gulls had nested consistently on Crescent Island for nearly three decades prior to management. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the use of closely-spaced fence rows of privacy fabric and willow plantings as passive nest dissuasion measures in all the suitable Caspian tern nesting habitat; fencing and willow plantings were not deployed at Goose Island due to shallow rocky soils. Another factor was the successful dissuasion of gulls from nesting on Crescent Island during 2015-2018; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active nest dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to the nest dissuasion techniques implemented there. Instead, gulls abandoned Crescent Island as a nesting site and some, if not most, of these birds likely established a new colony on Badger Island located on the Columbia River just one kilometer upriver from Crescent Island in 2015-2018. Similarly, many Caspian terns displaced from Crescent Island relocated to unmanaged colony sites on the Columbia River, including the Blalock Islands in John Day Reservoir (70 river kilometers downriver from Crescent Island) in 2015-2018 and Badger Island in 2017-2018, where Caspian terns have nested in small numbers intermittently over the last decade. Despite the use of passive and active nest dissuasion techniques on Goose Island and elsewhere in Potholes Reservoir in 2018, some Caspian terns continued to display high fidelity to Potholes Reservoir as a nesting area in 2018, the fifth year of management at this site. This fidelity is likely due to Caspian terns nesting on Goose Island since 2004 and the persistence of a large gull colony on the island, both before and after management, which continues to attract prospecting Caspian terns to the site. Another factor that might explain the strong fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. As was the case in 2015-2017, Caspian tern use of Goose Island for roosting and nesting in 2018 was largely limited to areas near the island's shoreline that became exposed during the nesting season as reservoir levels receded. Despite high fidelity of terns to the area, active nest dissuasion (hazing) and collection (under permit) of any Caspian tern eggs discovered were factors in preventing the formation of a Caspian tern colony in Potholes Reservoir in 2018. This is the third consecutive year that nest dissuasion activities initiated at Goose Island were successful in preventing Caspian terns from successfully nesting there; in 2014, 159 breeding pairs nested on a small rocky islet (i.e., Northwest Rocks) immediately adjacent to Goose Island, and in 2015 two breeding pairs of Caspian terns nested under the passive dissuasion near the former colony location on Goose Island. Prior to management (2005-2013), an average of 367 breeding pairs of Caspian terns nested on Goose Island. In 2018, egg laying by Caspian terns on Goose Island and elsewhere in Potholes Reservoir occurred between 30 April and 16 July. During this period, a total of 11 Caspian tern eggs were discovered at two different locations in Potholes Reservoir; 10 tern eggs were discovered on Goose Island and one tern egg was discovered on a previously unused island in northern Potholes Reservoir. All 11 tern eggs discovered were collected under permit. By comparison, a total of 20 Caspian tern eggs were found on Goose Island and other islands in northeastern Potholes Reservoir in 2017. Aerial, ground, and boat-based surveys were conducted in the Columbia Plateau region to determine where Caspian terns displaced from the managed colonies in Potholes Reservoir and at Crescent Island might attempt to re-nest. In 2018, Caspian terns attempted to nest at four extant colony sites in the Columbia Plateau region that are currently unmanaged. All four of these sites have been used for breeding by Caspian terns previously, including the Blalock Islands complex in John Day Reservoir (313 breeding pairs in 2018; up from the premanagement average [59 breeding pairs] and down from the average during the management period [393 breeding pairs]), Badger Island in McNary Reservoir (8 breeding pairs in 2018; down from the pre-management average [10 breeding pairs] and down from the average during the management period [10 breeding pairs]), Harper Island in Sprague Lake (79 breeding pairs in 2018; up from the pre-management average [8 breeding pairs] and up from the average during the management period [38 breeding pairs]), and an unnamed island in Lenore Lake (91 breeding pairs in 2018; up from the pre-management average [0 breeding pairs] and up from the average during the management period [54 breeding pairs]). The former Caspian tern colony site at Twinning Island in Banks Lake was not active in 2017-2018, with the average colony size during the pre-management and management periods both totaling 27 breeding pairs. As was the case in 2015-2017, the largest Caspian tern colony in the Columbia Plateau region was on the Blalock Islands, where 64% of all the Caspian terns in the region nested during 2018. Compared to the average size of the Caspian tern colony on the Blalock Islands prior to management (2005-2013; 59 breeding pairs), the colony was 8-11 times larger during 2015-2018. The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2018 was 491 breeding pairs at four separate colonies. This represents a 44% decline in the regional breeding population size for Caspian terns compared pre-management average (873 breeding pairs), and a 28% decline when compared to the average during the management period (679 breeding pairs). Although nest dissuasion actions implemented on Goose and Crescent islands in 2018 were effective in preventing all Caspian terns from nesting at these two colonies, formerly the two largest tern colonies in the region, it did not result in a commensurate reduction in the total number of Caspian terns breeding in the region. This was due to the continued use and increase in the colony size at unmanaged sites (i.e., Blalock Islands, Lenore Lake, and Harper island) when compared to pre-management averages. While smaller in 2018, the average Blalock Islands colony size during 2015-2018 (480 breeding pairs) was similar in size to the largest Caspian tern colonies recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2005. The overall goal of the IAPMP is to reduce predation on juvenile salmonids in the Columbia Plateau region at Goose and Crescent Islands while implementing adaptive management actions to limit the formation of incipient colonies within the basin, where feasible. The target metric is for a predation rate of less than 2% on any ESA-listed salmonid stock (hereafter ESA/DPS), per colony, per year. Recoveries of smolt PIT tags on Caspian tern colonies in 2018 were used to estimate predation rates and to compare smolt losses prior to and following tern management actions associated with the IAPMP. To ensure adequate numbers of ESA-listed Upper Columbia River steelhead – a population that is highly susceptible to tern predation and therefore a suitable population to evaluate the efficacy of management actions – were available for predation rate analyses, we intentionally PIT-tagged and released (n=7,366) steelhead smolts into the tailrace of Rock Island Dam as part of this study in 2018. Predation rates indicated that the goal of achieving rates of less than 2% were met for most, but not all, Caspian tern colonies and ESA-listed salmonid ESUs/DPSs in 2018. Predation rates were zero or close to zero for terns nesting in Potholes Reservoir (Goose and surrounding islands) and Crescent Island due to the complete (Crescent Island) or nearly complete (Potholes Reservoir) abandonment of these colony sites in 2018. Predation rates per ESU/DPS at unmanaged Caspian tern colonies varies due to colony location as it relates to the availability of juvenile salmonids and alternative prey sources. Predation rates at the unmanaged Lenore Lake tern colony were also less than 2% per ESU/DPS, with the highest rate observed on Upper Columbia River steelhead at 0.8% (95% credible interval [CRI] = 0.4–1.7). Predation rates for the large unmanaged tern colony in the Blalock Islands, however, exceed the 2% threshold for three ESA-listed ESUs/DPSs in 2018; (1) Upper Columbia River steelhead at 2.9% (95% CRI = 1.5– 5.2), (2) Snake River steelhead at 2.5% (95% CRI = 1.4–4.5), and (3) Snake River sockeye at 2.0%

(95% CRI = 0.4–6.1). Due to a lack of access to the colony site following the nesting season, predation rate estimates were not available for Caspian terns nesting on Harper Island in Sprague Lake in 2018. Based on limited data from years past, Caspian terns nesting on Harper Island forage on juvenile salmonids in lower Snake River but impacts by the colony in 2018 were presumably less than 2% per ESA-listed salmonid population based on the relatively small number of terns (79 breeding pairs) that nested on Harper Island in 2018. Predation rate estimates at the Badger Island tern colony were also not available in 2018, but impacts were presumably close to zero given the small number (8 pairs) and brief (approximately one week) existence of a colony on Badger Island in 2018. Based on a comparison to historic predation rates by Caspian terns nesting in the Columbia Plateau region during 2007–2017, impacts were amongst the lowest ever recorded in 2018. This was particularly true for predation on Upper Columbia River steelhead, where average premanagement predation rates of 15.7% (95% CRI = 14.1–18.9) by Goose Island terns in Potholes Reservoir were reduced to < 0.1% in 2018. Adaptive management at incipient colony sites in northern Potholes Reservoir also reduced or eliminated predation on Upper Columbia River steelhead from 4.1% (95% CRI = 2.9–6.3) in 2016 to < 0.1% in 2018. Historic predation rates at the unmanaged Lenore Lake tern colony were also low (≤ 1.0% per ESU/DPS), suggesting that at its current size (16 to 91 nesting pairs, per year), the colony poses only a minor threat to Upper Columbia River steelhead survival. Impacts by terns nesting at the unmanaged Blalock Island colony in 2018, however, remained above the 2% minimum goal or threshold for numerous ESUs/DPSs, as was the case during 2015–2017. Due to continued high rates of predation by Blalock Island terns, impacts to some ESA-listed ESUs/DPSs, particularly those originating from Snake River, remain as high or higher than those observed prior to implementation of management actions as part of the IAPMP. In summary, management aimed at eliminating breeding colonies of Caspian terns on Goose Island in Potholes Reservoir and on Crescent Island in McNary Reservoir, formerly the largest breeding colonies for the species in the Columbia Plateau region, were successful in 2018. Consequently, predation on juvenile salmonids by Caspian terns nesting at these two colony sites was effectively eliminated. Numbers of breeding Caspian terns in the Columbia Plateau region have declined from pre-management levels due to the management of colonies on Goose and Crescent islands, with the regional population size declining by 44% in 2018, the most appreciable decline since the onset of management in 2014. However, based on opportunistic resightings of banded Caspian terns in previous years, many terns that were displaced from colonies on Goose and Crescent islands have remained in the region, and have attempted to nest at unmanaged colony sites. Most notable has been the post-management increase in the size of the formerly small breeding colony in the Blalock Islands. Caspian terns nesting in the Blalock Islands during 2015-2018 have consumed sufficient numbers of juvenile salmonids to at least partially off-set reductions in smolt consumption due to tern management at Goose and Crescent islands. Nesting habitat for Caspian terns at the Blalock Islands remains heavily dependent on water levels, with tern nesting habitat typically only being available when reservoir levels are below full reservoir levels. Changes in water levels due to weather related events (e.g., high spring flows and/or high wind events) have occurred that limit colony size and productivity at this site. Based on results collected during this five-year study (2014-2018), the IAPMP objective of preventing Caspian terns from nesting on Goose and Crescent islands, thereby reducing predation rates by terns nesting at these two sites on ESA-listed salmonid stocks to less than 2%, has been achieved. The adaptive management objective of the IAPMP, to limit predation on ESA-listed salmonid stocks at other colonies in the Columbia Plateau region to less than 2%, will not be realized until the size of the Caspian tern colony at the Blalock Islands is reduced from its current size and there are no further substantive increases in the colony size at other tern colonies in the Columbia Plateau region.

Collis, K., Evans, A., Cramer, B., Turecek, A., Payton, Q., Kelly, K., Stetler, F., Fitzmaurice, S., & Loschl, P. J. (2018). *Implementation of the Inland Avian Predation Management Plan, 2017* (p. 99). http://www.birdresearchnw.org/2017%20IAPMP%20Final%20Report.pdf

In 2017, the U.S. Army Corps of Engineers - Walla Walla District and the U.S. Bureau of Reclamation (BOR) continued implementation of the Inland Avian Predation Management Plan (IAPMP) to reduce predation by Caspian terns (Hydroprogne caspia) on U.S. Endangered Species Act (ESA)-listed populations of salmonids (Oncorhynchus spp.) from the Columbia River basin (USACE 2014). The primary objective of management in the fourth year of implementation was to limit the numbers of Caspian terns breeding at colonies in Potholes Reservoir and on Crescent Island in McNary Reservoir to less than 40 breeding pairs each. To accomplish this task, the availability of suitable Caspian tern nesting habitat was nearly eliminated at these sites by installing a variety of “passive nest dissuasion” materials prior to the 2017 nesting season, materials that were designed to preclude tern nesting at both locations. In addition, on Crescent Island, willows had been planted over extensive areas of the island to preclude tern nesting over the long-term. On both Goose and Crescent islands, passive dissuasion was placed over all the area where Caspian terns have previously nested, as well as all areas of open, sparsely-vegetated habitat that might be used by ground-nesting Caspian terns or gulls (Larus spp.). Ultimately, 4.3 acres, or more than 85% of the upland area of Goose Island were covered with passive nest dissuasion materials consisting of stakes, rope, and flagging. On Crescent Island, about 2.4 acres of potential Caspian tern nesting habitat were covered with passive nest dissuasion materials consisting of fences rows of privacy fabric, as well as stakes, rope, flagging, and woody debris in 2016; additionally, all open areas on Crescent Island had been planted with willows and other native vegetation prior to the 2016 nesting season. Finally, the island in northeastern Potholes Reservoir that was used by Caspian terns for nesting in 2016 (0.15 acre) and four nearby islands where terns were observed prospecting in 2017 (0.3 acre) were covered in passive dissuasion to prevent terns from nesting at those sites. An effort was also made to prevent nesting by the two species of gulls (California gulls [L. californicus] and ring-billed gulls [L. delawarensis]) that have nested at Goose and Crescent islands, on the theory that nesting gulls would attract prospecting Caspian terns and could limit the efficacy of efforts to dissuade Caspian terns from nesting at these managed sites. Once Caspian terns and gulls arrived to initiate nesting, active nest dissuasion (i.e. human hazing) was used to try to dissuade both Caspian terns and gulls from nesting on Goose and Crescent islands, as well as on other islands in the northern portion of Potholes Reservoir. As was the case in 2015-2016, passive and active nest dissuasion techniques were successful in preventing all nesting and roosting by both Caspian terns and gulls in upland areas on Crescent Island during the 2017 nesting season, the third year of management at this site. Prior to management (2005-2013), an average of 403 breeding pairs of Caspian terns nested on Crescent Island. The complete abandonment of Crescent Island by nesting terns beginning in the first year of management was somewhat unexpected because Caspian terns and gulls had nested consistently on Crescent Island for nearly three decades prior to management. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the use of closely-spaced fence rows of privacy fabric and willow plantings as passive nest dissuasion measures in all the suitable Caspian tern nesting habitat on Crescent Island, including the former colony area; fencing and willow plantings were not deployed at Goose Island due to shallow rocky soils. Another factor was the successful dissuasion of gulls from nesting on Crescent Island in 2015-2017; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active nest dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to the nest dissuasion techniques implemented there. Instead, gulls abandoned Crescent Island as a nesting site and established a new colony on Badger Island located on the Columbia River just one kilometer upriver from Crescent Island in 2015-2017. Similarly, many Caspian terns displaced from Crescent Island relocated to unmanaged colony sites on the Columbia River, including the Blalock Islands in John Day Reservoir (70 river kilometers downriver from Crescent Island) in 2015-2017 and Badger Island in 2017, where Caspian terns have nested in small numbers intermittently over the last decade. Despite the use of passive and active nest dissuasion techniques on Goose Island and elsewhere in Potholes Reservoir, some Caspian terns continued to display high fidelity to Potholes Reservoir as a nesting area in 2017, the fourth year of management at this site. This fidelity is likely due to Caspian terns nesting on Goose Island since 2004 and the persistence of a large gull colony on the island, both before and after management, which continues to attract prospecting Caspian terns to the site. Another factor that might explain the strong fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. As was the case in 2015-2016, Caspian tern use of Goose Island for roosting and nesting in 2017 was largely limited to areas near the island's shoreline, areas that became exposed during the nesting season as reservoir levels receded. Despite high fidelity of terns to the area, active nest dissuasion (hazing), collection (under permit) of any Caspian tern eggs discovered, and high rates of gull depredation on newly-laid Caspian tern eggs were factors in preventing the formation of a Caspian tern colony on Goose Island and elsewhere in Potholes Reservoir in 2017. This is the second consecutive year that nest dissuasion activities initiated at Goose Island were successful in preventing Caspian terns from successfully nesting there; in 2014, 159 breeding pairs nested on Northwest Rocks near Goose Island, and in 2015 two breeding pairs of Caspian terns nested under the passive dissuasion near the former colony location on Goose Island. Prior to management (2005-2013), an average of 367 breeding pairs of Caspian terns nested on Goose Island. In 2017, egg laying by Caspian terns on Goose Island and elsewhere in Potholes Reservoir occurred between 29 April and 7 July. During this period, a total of 20 Caspian tern eggs were discovered at three different locations in Potholes Reservoir; 18 tern eggs were discovered on Goose Island and one tern egg was discovered on two different islands in northern Potholes Reservoir. Of the 20 tern eggs that were discovered, 18 were collected under permit and two were depredated by gulls soon after they were laid. By comparison, a total of 282 Caspian tern eggs were found on Goose Island and an incipient colony in northeastern Potholes Reservoir in 2016; 6 tern eggs were discovered and collected under permit on Goose Island and 276 tern eggs were discovered on an incipient colony in northeastern Potholes Reservoir after the colony was completely abandoned due to predation and disturbance caused by a mink early June. The eggs laid on the incipient colony in northeastern Potholes Reservoir were not collected. Aerial, ground, and boat-based surveys were conducted in the Columbia Plateau region to determine where Caspian terns displaced from the managed colonies in Potholes Reservoir and at Crescent Island might attempt to re-nest. In 2017, Caspian terns attempted to nest at four different unmanaged colony sites in the Columbia Plateau region. Three of these colony sites had been used in previous years, and one site was new in

2017. The formerly occupied colony sites included the Blalock Islands complex in John Day Reservoir (449 breeding pairs in 2017, down from 483 breeding pairs in 2016), Harper Island in Sprague Lake (92 breeding pairs in 2017, up from three breeding pairs in 2016), and Badger Island in McNary Reservoir (41 breeding pairs in 2017, down from 60 breeding pairs in 2012; site not occupied by nesting terns in 2013-2016). The incipient colony site included a new island in Lenore Lake (123 breeding pairs in 2017) located approximately 0.4 km NNE from the former Lenore Lake colony site used by terns in 2014-2016. The former Caspian tern colony sites at Twinning Island in Banks Lake (6 breeding pairs in 2016) and an unnamed island in Lenore Lake (39 breeding pairs in 2016; see above) were not active in 2017. As was the case in 2015-2016, the largest Caspian tern colony in the Columbia Plateau region was on the Blalock Islands, where 64% of all the Caspian terns in the region nested during 2017. Compared to the average size of the Caspian tern colony on the Blalock Islands prior to management (2005-2013; 59 breeding pairs), the colony was 8-11 times larger during 2015-2017. The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2017 was 705 breeding pairs at four separate colonies. This represents a 19% decline in the total number of Caspian terns breeding in the Columbia Plateau region compared to the pre-management average during 2005-2013 (873 breeding pairs), but was a slightly higher (4%) than the regional breeding population size for Caspian terns in 2016 (675 breeding pairs). Although nest dissuasion actions implemented on Goose and Crescent islands in 2017 were effective in preventing all Caspian terns from nesting at these two colonies, formerly the two largest tern colonies in the region, it did not result in a commensurate reduction in the total number of Caspian terns breeding in the region. This was due to the more than 8-fold increase in the number of Caspian terns nesting in the Blalock Islands and increases in colony size at three other colony sites (i.e. on an unnamed island in Lenore Lake, on Harper Island in Sprague Lake, and on Badger Island in the mid-Columbia River) in 2017, compared to the pre-management average for those colonies. The Blalock Islands colony during 2015-2017 was similar in size to the largest Caspian tern colonies recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2005. The over-all goal of the IAPMP is to reduce predation rates (percentage of available fish consumed) on juvenile salmonids by Caspian terns to less than 2% of each Endangered Species Act (ESA)-listed salmonid population (hereafter ESU/DPS), per colony, per year. Recoveries of smolt PIT tags on Caspian tern colonies were used to estimate predation rates and to compare smolt losses prior to and following tern management actions. To ensure adequate numbers of ESA-listed upper Columbia River steelhead – a population that is highly susceptible to tern predation and therefore a suitable population to evaluate the efficacy of management – were available for predation rate analyses, we intentionally PIT-tagged and released (n= 7,437) steelhead smolts into the tailrace of Rock Island Dam as part of this study in 2017. Estimated predation rates indicated that the management goal of achieving rates of less than 2% were met for most, but not all, Caspian tern colonies and ESA-listed salmonid ESUs/DPSs in 2017. Predation rates were zero or close to zero for terns nesting in Potholes Reservoir (Goose and surrounding islands) and Crescent Island due to the complete (Crescent) or nearly complete (Potholes Reservoir) abandonment of these colony sites in 2017. Predation rates at the unmanaged Lenore Lake and Badger Island colonies were also less than 2% per colony and ESU/DPS, with the highest rate observed by Lenore Lake terns on upper Columbia River steelhead at 1.0% (95% credible interval [CRI] = 0.6-2.0). For the third consecutive year, predation rates for the large unmanaged colony in the Blalock Islands exceed the 2% threshold for Snake River and Upper Columbia River steelhead at 3.4% (95% CRI = 2.4-5.1) and 4.2%

(95% CRI = 2.7-6.5), respectively. Rates were below the 2% threshold, however, for all other ESA-listed ESUs/DPSs evaluated. Due to lack of access to the colony site following the nesting season, predation rate estimates were not available for terns nesting on Harper Island in Sprague Lake in 2017. Based on a comparison to historic predation rates by Caspian terns nesting in the Columbia Plateau region during 2007-2016, impacts were amongst the lowest ever recorded at managed colony sites in 2017. This was particularly true for predation on Upper Columbia River steelhead, where average pre-management predation rates of 15.7% (95% CRI = 14.1-18.9) by Goose Island terns were reduced to < 0.1% in 2017. Rates at the unmanaged Lenore Lake and Badger Island colonies were also low (≤ 1.0% per ESU/DPS and colony) in 2017. Impacts by terns nesting at the unmanaged Blalock Island colony, however, remained above the 2% goal for steelhead DPSs in 2017. Due to continued predation by Blalock Island terns, impacts to Snake River steelhead remain as high or higher than those observed prior to management due to the relocation of terns from Crescent Island to the Blalock Islands following implementation of IAPMP in 2015. Adaptive management actions at the Blalock Islands nesting sites may be needed before the over-all goal of reducing predation rates to less 2% per colony, ESU/DPS, and year can be achieved. In summary, management to eliminate breeding colonies of Caspian terns on Goose Island in Potholes Reservoir and on Crescent Island in McNary Reservoir, formerly the largest breeding colonies for the species in the Columbia Plateau region, was fully successful in 2017, the fourth year of implementation of the IAPMP. Consequently, predation on juvenile salmonids by Caspian terns nesting at these two colony sites was effectively eliminated. Numbers of breeding Caspian terns in the Columbia Plateau region have declined from pre-management levels due to the management of colonies on Goose and Crescent islands, with the regional population size declining by 19%. Based on opportunistic resightings of banded Caspian terns in previous years, most terns that were displaced from colonies on Goose and Crescent islands have remained in the region, and many have attempted to nest at unmanaged colony sites. Most notable has been the post-management increase in the size of the formerly small breeding colony in the Blalock Islands. Caspian terns nesting in the Blalock Islands during 2015-2017 have consumed sufficient numbers of juvenile salmonids to at least partially off-set reductions in smolt consumption due to tern management at Goose and Crescent islands. Nesting habitat for Caspian terns in the Blalock Islands is dependent on reservoir level; quality tern nesting habitat is only available when reservoir levels are below full pool. Based on results during the first four years of implementation of the IAPMP, the over-all goal of the Plan to reduce predation rates to less than 2% per tern colony, ESA-listed ESU/DPS, and year will not be fully realized until alternative nesting habitat is further reduced at unmanaged colony sites, especially in the Blalock Islands, the lone tern colony where predation rates exceeded management goals in 2017.

Collis, K., Evans, A., Tennyson, J., Turecek, A., & Bhatt, R. (2020). *Avian Predation in the Columbia Plateau Region: Management, Monitoring, and Evaluation in 2019* (p. 73). http://www.birdresearchnw.org/2019%20GPUD%20Final%20Report.pdf

From 2014-2018, the U.S. Army Corps of Engineers – Walla Walla District (Corps) and the Bureau of Reclamation (Reclamation) funded efforts to implement and evaluate the Inland Avian Predation Management Plan (IAPMP). The goal of the management plan was to reduce predation on Endangered Species Act (ESA)-listed juvenile salmonids (Oncorhynchus spp.) by Caspian terns (Hydroprogne caspia) nesting at colonies in the Columbia Plateau region (CPR), namely Crescent Island on the Columbia River and Goose Island in Potholes Reservoir, the two largest tern colonies in the region. The objectives of the plan were to use passive nest dissuasion techniques (i.e. fencing, stakes, rope, flagging, woody debris, and vegetation plantings) to eliminate tern nesting habitat on both islands and to use active nest dissuasion techniques as an adaptive management tool to insure terns were not able to establish colonies at either site. Concomitant with management implemented as part of the IAPMP, the plan called for monitoring and evaluating the efficacy of those management components and actions at both the colony- and system-level, including measuring changes in Caspian tern nesting distribution and colony sizes in the CPR, as well as tern impacts on ESA-listed juvenile salmonids originating from the Snake and Columbia rivers. In 2019, the Grant County Public Utility District (GPUD) and the Priest Rapids Coordinating Committee (PRCC) supported continued implementation and monitoring of the IAPMP, so that advances made in reaching the goals of the plan during 2014-2018 were not lost and further reductions in smolt losses to tern predation could be achieved. Additionally, the GPUD and PRCC funded efforts to determine the impacts of unmanaged piscivorous colonial waterbirds (i.e. California gulls [Larus californicus], ring-billed gulls [L. delawarensis], double-crested cormorants [Phalacrocorax auratus], and American white pelicans [Pelecanus erythrorhynchos]) on smolt survival and to assess the system-wide, cumulative impacts of avian predation on smolt survival. In total, this study will inform adaptive management actions that could be carried out to maximize the benefits to ESA-listed juvenile salmonids by managing avian predation in the CPR. The primary objective of the sixth year of implementation of the IAPMP was to limit the numbers of Caspian terns breeding at Goose Island and surrounding islands in Potholes Reservoir, and on Crescent Island in McNary Reservoir, to less than 40 breeding pairs each to reduce predation impacts of terns on ESA-listed juvenile salmonids in the CPR. To accomplish this task, the availability of suitable Caspian tern nesting habitat was nearly eliminated at these sites by installing a variety of passive nest dissuasion materials on Goose Island and elsewhere in Potholes Reservoir, and vegetation growth (planted in 2016) on Crescent Island prior to the 2019 nesting season. On both Goose and Crescent islands, passive nest dissuasion materials and/or vegetation covered all areas where Caspian terns have previously nested, as well as all areas of open, sparsely vegetated habitat that might be used by ground-nesting Caspian terns or gulls (Larus spp.). Finally, an island in northeastern Potholes Reservoir that was used by Caspian terns for nesting in 2016, and one additional nearby island where terns were observed prospecting in 2018, were covered in passive dissuasion to prevent terns from nesting at those sites in 2019. Once Caspian terns arrived to initiate nesting in 2019, active nest dissuasion (i.e. human hazing) was used to dissuade terns from nesting on Goose Island and other islands in Potholes Reservoir. No hazing has been required to prevent Caspian terns from nesting on Crescent Island since the onset of management in 2015. Despite the use of passive and active nest dissuasion techniques on Goose Island and elsewhere in Potholes Reservoir, some Caspian terns continued to display high fidelity to Potholes Reservoir as a nesting area in 2019, the sixth year of management at this site. This fidelity is likely due to Caspian terns, a relatively long-lived species (i.e. some individuals having of life span of more than 20 years), having first nested on Goose Island in 2004 and the persistence of a large gull colony on the island, both before and after management, which continues to attract prospecting Caspian terns to the site. Another factor that might explain the strong fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. As was the case in 2015-2018, Caspian tern use of Goose Island for roosting and nesting in 2019 was largely limited to areas near the island's shoreline that became exposed during the nesting season as reservoir levels receded. Despite high fidelity of terns to the area, active nest dissuasion (hazing) and collection of any tern eggs laid (under permit) were factors in preventing the formation of a Caspian tern colony in Potholes Reservoir in 2019. This is the fourth consecutive year that nest dissuasion activities initiated at Goose Island were successful in preventing Caspian terns from nesting there; in 2014, 159 breeding pairs nested on a small rocky islet (i.e. Northwest Rocks) immediately adjacent to Goose Island, and in 2015 two breeding pairs of Caspian terns nested under the passive dissuasion near the former colony location on Goose Island. Prior to management (2005-2013), an average of 367 breeding pairs of Caspian terns nested on Goose Island. In 2019, egg laying by Caspian terns on Goose Island and elsewhere in Potholes Reservoir occurred between 29 April and 5 July. During this period, a total of 20 Caspian tern eggs were discovered at two different locations in Potholes Reservoir; 19 tern eggs were discovered on Goose Island and the surrounding islets and one tern egg was discovered on the colony site used by terns in 2016 in northern Potholes Reservoir. Eight tern eggs discovered were collected under permit, and the remainder were depredated by gulls prior to collection. As was the case in 2015-2018, passive nest dissuasion techniques (i.e. revegetation) alone were successful in preventing all nesting and roosting by both Caspian terns and gulls in upland areas on Crescent Island during the 2019 nesting season. Prior to management (2005-2013), an average of 403 breeding pairs of Caspian terns nested on Crescent Island. The complete abandonment of Crescent Island by nesting terns beginning in the first year of management was somewhat unexpected because Caspian terns and gulls had nested consistently on Crescent Island for nearly three decades prior to management. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the successful dissuasion of gulls from nesting on Crescent Island during 2015-2019; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active nest dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to the nest dissuasion techniques implemented there. Instead, gulls abandoned Crescent Island as a nesting site and some, if not most, of these birds established a new colony on Badger Island located on the Columbia River just one kilometer upriver from Crescent Island in 2015-2019. Similarly, many Caspian terns displaced from Crescent Island relocated to unmanaged colony sites on the Columbia River, including the Blalock Islands in John Day Reservoir (70 river kilometers downriver from Crescent Island) in 2015-2019, where Caspian terns have nested in small numbers intermittently over the last decade. Aerial, ground, and boat-based surveys were conducted in the CPR to determine where Caspian terns displaced from the managed colonies in Potholes Reservoir and at Crescent Island might attempt to re-nest. In 2019, Caspian terns attempted to nest at three extant colony sites in the CPR that are currently unmanaged. All three of these sites have been used for breeding by Caspian terns previously, including the Blalock Islands complex in John Day Reservoir (379 breeding pairs in 2019; up from the pre-management average [59 breeding pairs] and down from the average during the management period [391 breeding pairs]), Harper Island in Sprague Lake (18 breeding pairs in 2019; up from the pre-management average [8 breeding pairs] and down from the average during the management period [35 breeding pairs]), and on North Rock in Lenore Lake (48 breeding pairs in 2019; up from the pre-management average [0 breeding pairs] and down from the average during the management period [52 breeding pairs]). The former Caspian tern colony sites at Twinning Island in Banks Lake and Badger Island on the Columbia River in McNary Reservoir were not active in 2019. As was the case in 2015- 2018, the largest Caspian tern colony in the CPR was on the Blalock Islands, where 87% of all the Caspian terns in the region nested during 2019. Compared to the average size of the Caspian tern colony on the Blalock Islands prior to management (2005-2013; 59 breeding pairs), the colony was 5-11 times larger during 2015-2019. The total estimated breeding population of Caspian terns in the CPR during 2019 was 445 breeding pairs at three separate colonies. This represents a 49% decline in the regional breeding population size for Caspian terns compared to the pre-management average (873 breeding pairs), and a 30% decline when compared to the average during the management period (640 breeding pairs). Although nest dissuasion actions implemented on Goose and Crescent islands in 2019 were effective in preventing all Caspian terns from nesting at these two colonies, it did not result in a commensurate reduction in the total number of Caspian terns breeding in the region. This was due to the continued use and increase in the colony size at unmanaged sites (i.e. Blalock Islands, North Rock, and Harper island) when compared to premanagement averages. While smaller in 2018-2019, the average Blalock Islands colony size during the management period (2015-2019; 391 breeding pairs) was similar in size to the largest Caspian tern colonies recorded anywhere in the CPR since intensive monitoring began in 2000. A primary goal of the IAPMP is to reduce predation rates (proportion of available fish consumed) on ESA-listed juvenile salmonids by Caspian terns to less than 2% per salmonid population, per colony. Recoveries of smolt passive integrated transponder (PIT) tags on Caspian tern colonies in 2019 were used to estimate salmonid population-specific (hereafter ESU/DPS) predation rates and to compare predation rates prior to and during tern management actions associated with the IAPMP. To help ensure that ESA-listed Upper Columbia River steelhead – a population that is highly susceptible to tern predation and therefore a suitable population to evaluate the efficacy of management actions – were available for predation rate analyses, 3,784 steelhead smolts were intentionally PIT-tagged and released into the tailrace of Rock Island Dam (RIS) by Chelan County Public Utility District employees in 2019. Numbers of steelhead tagged at RIS in 2019 were less than that of years past but provided a representative sample of the run-at-large for predation analyses in 2019. Caspian tern predation rate estimates indicated that the goal of achieving rates of less than 2% were met for most, but not all, tern colonies and ESA-listed salmonid ESUs/DPSs in 2019. For the fifth consecutive year, predation rates were zero or close to zero for terns nesting on Goose Island and Crescent Island due to the complete (Crescent Island), or nearly complete (Goose Island and other islands in northern Potholes Reservoir), abandonment of these colony sites. Predation rates at the unmanaged tern colony in Lenore Lake (North Rock) were also less than 2% per ESU/DPS, with the highest rate observed on Upper Columbia River steelhead at 1.0% (95% credible interval [CRI] = 0.6–1.7). Predation rates for the large unmanaged tern colony in the Columbia River on the Blalock Islands, however, exceed the 2% threshold for two ESA-listed ESUs/DPSs, with predation rates of 5.9% (95% CRI = 3.4–10.0) and 3.0% (95% CRI = 1.9–4.7) for Upper Columbia River steelhead and Snake River steelhead, respectively. Predation rate estimates were not available for Caspian terns nesting on Harper Island in Sprague Lake (i.e. we were not granted access to the privately-owned island to recover PIT tags), but just 18 pairs nested on Harper Island in 2019. Based on limited data from years past, Caspian terns nesting on Harper Island are capable of foraging on juvenile salmonids in the lower Snake River, but impacts have been low (< 0.3% for all ESU/DPS), presumably due to the small size of the colony and it's distance from the lower Snake River (> 60 km). Comparisons of Caspian tern predation rates on juvenile salmonids prior to and during implementation of the IAPMP indicate there have been benefits to Upper Columbia River steelhead, with predation rates by Goose Island and Crescent Island Caspian terns eliminated during implementation of the IAPMP. There is also evidence that Upper Columbia River steelhead smolt survival has increased in the river reach where Goose and Crescent Island terns forage (Rock Island Dam to McNary Dam). Due to continued high rates of predation by Blalock Island terns, however, impacts to some ESA-listed ESUs/DPSs, particularly those originating from the Snake River, remain as high or higher than those observed prior to implementation of management actions as part of the IAPMP. As such, adaptive management actions will likely be necessary to achieve the over-all goals of the IAPMP in the future. An investigation of predation rates by other piscivorous colonial waterbird species (California and ring-billed gulls [hereafter "gulls"], American white pelicans, and double-crested cormorants) and colonies indicated that several gull colonies posed a risk to smolt survival in 2019. Predation rates by gulls nesting on Island 20, Badger Island, and Miller Rocks Island were amongst the highest of any colony evaluated in 2019, with predation rates on Upper Columbia River steelhead, Snake River steelhead, and Snake River sockeye greater than 5% of available fish, depending on the colony and ESU/DPS. For instance, predation rate estimates as high as 10.9% (95% CRI = 6.7-17.7) of Upper Columbia River steelhead and 5.9% (95% CRI = 2.6-11.8) of Snake River sockeye were observed by gulls nesting on Badger Island and Miller Rocks Island, respectively. Conversely, predation rate estimates by double-crested cormorants nesting in Lenore Lake were < 0.1% of available fish and minimum estimates of predation of < 0.2% of available fish were observed by American white pelicans nesting on Badger Island, indicating that not all piscivorous colonial waterbird species and colonies posed a risk to smolt survival in the CPR. To investigate the cumulative effects of avian predation (predation by all colonies combined) on smolts and to determine what proportion of all sources of smolt mortality (1-survival) were due to bird predation, we conducted a mark-recapture-recovery analysis on Upper Columbia River steelhead that were PIT-tagged and released at Rock Island Dam in 2019. We used previously published methods to jointly estimate predation and survival rates during smolt passage through multiple river reaches and we compared results from 2019 to those in years past (2008-2018). Results indicated that avian predation was often the single greatest source of mortality for steelhead during out-migration from Rock Island Dam to Bonneville Dam, with bird predation accounting for more than 50% of all mortality sources in 10 of the last 12 years (2008-2019), including in 2019. Estimated steelhead smolt losses to piscivorous colonial waterbirds were greater than direct losses associated with dam passage, predation from piscivorous fish, mortality from disease, and all other remaining mortality factors combined. Even after passage through the impounded sections of the middle and lower Columbia River upstream of Bonneville Dam, the impact of piscivorous colonial waterbirds on survival of steelhead smolts in the free-flowing section of the Columbia River downstream of Bonneville Dam was substantial, with Caspian terns and double-crested cormorants nesting on East Sand Island annually consuming upwards of 28% of available steelhead smolts in the estuary. Results indicate that although progress has been made to increase steelhead smolt survival by decreasing Caspian tern predation between Rock Island Dam and McNary Dam, avian predation continues to be a dominate source of smolt mortality in the Columbia River basin.

Collis, K., Roby, D. D., Baird, C., Lawes, T., Wilson, A., Congdon, C., & Evans, A. F. (2015). *Monitoring and Predator Control at the Corps-Constructed Caspian Tern Islands in Southeastern Oregon and Northeastern California, 2015* (p. 38). http://www.birdresearchnw.org/2015%20Predator%20Control%20Final%20Report_v12.pdf

The primary goal of this study was to monitor and evaluate the efficacy of providing alternative Caspian tern nesting habitat in southeastern Oregon and northeastern California as part of the Caspian Tern Management Plan for the Columbia River estuary (USFWS 2005, 2006), and to actively manage those factors (e.g., predators) that might limit Caspian tern colony size and nesting success at four of the tern islands constructed by the Corps as alternative nesting habitat in these regions. We monitored and evaluated the effects of Caspian tern management actions at the four Corps-constructed tern islands that were deemed suitable for Caspian tern nesting in southeastern Oregon and northeastern California during the 2015 breeding season (see below). In general, colony preparations (e.g., removal of emergent vegetation) and social attraction techniques (i.e., Caspian tern decoys and audio playback of vocalizations) were used to entice Caspian terns to initiate nesting at each site. Predators, both avian and mammalian, were actively managed under permit to help ensure the success of Caspian terns attempting to nest at these sites. Also, Caspian tern nesting ecology and factors limiting colony size and nesting success were investigated. Furthermore, predation rates by Caspian terns on fishes of conservation concern were evaluated at each of the colonies monitored as part of this study. Specifically, there were three project objectives in 2015, which are outlined below. Objective 1. Implement predator control measures and evaluate their effectiveness at the Corps-constructed Caspian tern islands: Major limiting factors on Caspian tern colony size and nesting success at the Corps-constructed islands are (1) colony disturbance and depredation of Caspian tern eggs, chicks, and adults by terrestrial mammalian predators (i.e. raccoons, coyotes, mink), (2) colony disturbance and depredation of Caspian tern adults and chicks by avian predators (i.e. great horned owls), and (3) inter-specific competition for nest sites and depredation of Caspian tern eggs and chicks by California and ring-billed gulls (Collis et al. 2002, BRNW 2015a) Impacts from these predators can not only reduce colony size and nesting success, but may also cause entire Caspian tern colonies to be abandoned. We implemented various measures (see below) at the Corps-constructed tern islands to reduce or eliminate these limiting factors and carefully monitored their effectiveness. Objective 2. Attract, monitor, and evaluate Caspian terns nesting at Corps-constructed islands: Habitat enhancement and social attraction techniques were used to attract Caspian terns to nest at the Corps-constructed tern islands. Once a colony was established, we monitored colony occupancy/attendance, nesting chronology, and factors limiting colony size and nesting success. Objective 3. Evaluate predation rates on fish populations of conservation concern by Caspian terns nesting at Corps-constructed tern islands: To identify potential conflicts with fish species of conservation concern from Caspian terns nesting at the Corps-constructed tern islands, we recovered (electronically detected) PIT tags placed in juvenile fishes that were consumed by Caspian terns and later deposited at their nesting colonies. These data were used to estimate predation rates by Caspian terns on ESA-listed suckers (Warner sucker [Catostomus warnerensis], Lost River sucker [Deltistes luxatus], and shortnose sucker [Chasmistes brevirostris]) by terns nesting on a Corps-constructed island in the Upper Klamath Basin, and on redband trout (O. mykiss gairdneri) by terns nesting on a Corps-constructed island in Malheur Lake.

Collis, K., Roby, D. D., Craig, D. P., Adamany, S., Adkins, J. Y., & Lyons, D. E. (2002). Colony Size and Diet Composition of Piscivorous Waterbirds on the Lower Columbia River: Implications for Losses of Juvenile Salmonids to Avian Predation. *Transactions of the American Fisheries Society*, *131*(3), 537–550. https://doi.org/10.1577/1548-8659(2002)131<0537:CSADCO>2.0.CO;2

We investigated colony size and diet composition of piscivorous waterbirds (gulls, terns, and cormorants) nesting on the lower Columbia River from the mouth (river km 0) to the head of McNary Pool (river km 553) in 1997 and 1998. The study was prompted by concern that avian predation might constitute a significant source of mortality to juvenile salmonids Oncorhynchus spp. during out-migration. The diet of California gulls Larus californicus and ring-billed gulls L. delawarensis nesting in colonies above The Dalles Dam (river km 308) included few fish and very few juvenile salmonids. The sole exception was a small colony of California gulls in which salmonids accounted for 15% (by mass) of the diet.

Collis, K., Roby, D. D., Craig, D. P., Ryan, B. A., & Ledgerwood, R. D. (2001). Colonial Waterbird Predation on Juvenile Salmonids Tagged with Passive Integrated Transponders in the Columbia River Estuary: Vulnerability of Different Salmonid Species, Stocks, and Rearing Types. *Transactions of the American Fisheries Society*, *130*(3), 385–396. https://doi.org/10.1577/1548-8659(2001)130<0385:CWPOJS>2.0.CO;2

Passive integrated transponder (PIT) tags implanted in Columbia River basin juvenile salmonids Oncorhyncus spp. were recovered from breeding colonies of Caspian terns Sterna caspia and double-crested cormorants Phalacrocorax auritus on Rice Island, a dredge spoil island in the Columbia River estuary. Tags were recovered to assess the relative vulnerability of different salmonid species, stocks, and rearing types to avian predators. We detected 50,221 PIT tags at the two bird colonies, mostly from juvenile chinook salmon O. tshawytscha and steelhead O. mykiss raised in hatcheries; 72% of the total tags were from the tern colony and 28% from the cormorant colony. Tagged steelhead smolts were more vulnerable to predation by both bird species than were yearling chinook salmon. More than 15% of PIT tags from steelhead smolts that were available in the estuary in 1998 were detected at the bird colonies compared with 2% of PIT tags from yearling chinook salmon. The greater vulnerability of steelhead may reflect size-dependent selection by avian predators. Salmonids listed under the Endangered Species Act and unlisted salmonids were equally vulnerable to predation by both terns and cormorants. Hatchery-raised yearling chinook salmon were more vulnerable than their wild counterparts to predation by terns, a surfacefeeding species; however, hatchery-raised and wild yearling chinook salmon were equally vulnerable to predation by cormorants, a diving species. These results suggest that hatchery-raised yearling chinook salmon, and hatchery-raised steelhead in some years, are more vulnerable to tern predation than wild fish because they have a greater tendency to reside near the water surface where terns forage.

Collis, K., Roby, D. D., Larson, K. W., Adrean, L. J., Nelson, S. K., Evans, A. F., Hostetter, N., Battaglia, D., Lyons, D. E., Marcella, T., & Patterson, A. (2012). Trends in Caspian Tern Nesting and Diet in San Francisco Bay: Conservation Implications for Terns and Salmonids. *Waterbirds*, *35*(1), 25–34. https://doi.org/10.1675/063.035.0103

Colony size, nesting ecology and diet of Caspian Terns (Hydroprogne caspia) were investigated in the San Francisco Bay area (SFBA) during 2003–2009 to assess the potential for conservation of the tern breeding population and possible negative effects of predation on survival of juvenile salmonids (Oncorhynchus spp.). Numbers of breeding Caspian Terns declined 36% from 2003 to 2009, mostly due to abandonment of the Knight Island colony and decline of the Brooks Island colony, the two largest colonies in the SFBA. Concurrently, nesting success declined 69% associated with colony site characteristics such as (a) quality and quantity of nesting substrate, (b) vulnerability to nest predators, (c) displacement by other colonial waterbirds and (d) human disturbance. Marine fishes were the predominant prey in tern diets from the SFBA; however, diet composition varied among colonies. Juvenile salmonids comprised 22.9% of the diet of terns nesting in the North Bay, 5.3% of diet of terns nesting in the Central Bay, and 0.1% in the South Bay. Construction or restoration of nesting islands in the South Bay may help maintain and

restore breeding Caspian Terns without enhancing mortality of salmonid stocks of conservation concern.

Collis, K., Roby, D. D., Loschl, L., Peter J., Suzuki, Y., Kelly, K., Schniedermeyer, E., Evans, A. F., Cramer, B., Turecek, A., & Payton, Q. (2017). *Implementation of the Inland Avian Predation Management Plan, 2016* (p. 104). http://www.birdresearchnw.org/2016%20IAPMP%20Final%20Report.pdf
In 2016, the U.S. Army Corps of Engineers - Walla Walla District and the U.S. Bureau of Reclamation (BOR) continued implementation of the Inland Avian Predation Management Plan (IAPMP) to reduce predation by Caspian terns (Hydroprogne caspia) on U.S. Endangered Species Act (ESA)-listed populations of salmonids (Oncorhynchus spp.) from the Columbia River basin (USACE 2014). The primary objective of management in the third year of implementation was to reduce the numbers of Caspian terns breeding at colonies on Goose Island in Potholes Reservoir and on Crescent Island in McNary Reservoir to less than 40 breeding pairs each. To accomplish this task, the availability of suitable Caspian tern nesting habitat was nearly eliminated on both islands by installing a variety of "passive nest dissuasion" materials prior to the 2016 nesting season, materials that were designed to preclude tern nesting on both islands. In addition, on Crescent Island willows had been planted over extensive areas to preclude tern nesting over the long-term. Ultimately, 4.3 acres, or more than 85% of the upland area of Goose Island and nearby islets, were covered with passive nest dissuasion materials consisting of stakes, rope, and flagging. On Crescent Island, about 2.4 acres of potential Caspian tern nesting habitat were covered with passive nest dissuasion materials consisting of fences rows of privacy fabric, as well as stakes, rope, flagging, and woody debris; any remaining open areas on Crescent Island had been planted with willows prior to the 2016 nesting season. On both islands, passive dissuasion was placed over all the area where Caspian terns have previously nested, as well as all areas of open, sparsely-vegetated habitat that might be used by ground-nesting Caspian terns or gulls (Larus spp.). An effort was also made to prevent nesting by the two species of gulls that nest abundantly on both islands (California gulls [L. californicus] and ring-billed gulls [L. delawarensis]), on the theory that nesting gulls would attract prospecting Caspian terns and could limit the efficacy of efforts to dissuade Caspian terns from nesting on the two islands. Once Caspian terns and gulls arrived on Goose and Crescent islands to initiate nesting, active nest dissuasion (i.e. human hazing) was used to try to dissuade both Caspian terns and gulls from nesting anywhere on either island. Both California and ring-billed gulls quickly acclimated to both the passive and active dissuasion employed at Goose Island and, as in 2014 and 2015, gulls initiated nesting and laid eggs despite dissuasion efforts. Once gulls laid eggs, hazing gulls that were attending eggs was precluded due to the risk of causing gull nests to failure. As the area on Goose Island with active gull nests expanded, the opportunities to actively haze Caspian terns that were prospecting for nest sites on Goose Island declined. Nevertheless, between the passive dissuasion deployed on potential Caspian tern nesting habitat and active dissuasion (hazing, including use of a green laser) to deter prospecting terns, nesting by Caspian terns on Goose Island and nearby islets was prevented in 2016. This is the first year since nest dissuasion activities were initiated at Goose Island that efforts were successful in preventing Caspian terns from successfully nesting on Goose Island; in 2014, 159 breeding pairs nested on Northwest Rocks near Goose Island, and in 2015 two breeding pairs of Caspian terns nested on the main island under the passive dissuasion near the site of the former colony. Prior to management (2004-2013), an average of 343 breeding pairs of Caspian terns nested on Goose Island each

year. Despite the use of a combination of passive and active dissuasion on suitable Caspian tern nesting habitat on Goose Island during the 2014-2016 breeding seasons, some Caspian terns have continued to display high fidelity to Potholes Reservoir as a nesting area. This fidelity is likely due to Caspian terns nesting on Goose Island since 2004 and the persistence of a large gull colony on the island, which attracts prospecting Caspian terns to the site. Another factor that might explain the strong fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. As was the case in 2015, Caspian tern use of Goose Island for roosting and nesting in 2016 was largely limited to areas near the island's shoreline, which gradually were exposed during the nesting season as reservoir levels receded. Active nest dissuasion (hazing), collection of any Caspian tern eggs discovered, and high rates of gull predation on newly-laid Caspian tern eggs were factors in preventing the formation of a Caspian tern colony on Goose Island in 2016. Only six Caspian tern eggs were discovered in five different nests on Goose Island during the 2016 nesting season. Of those six tern eggs, four were collected under permit and two were depredated by gulls soon after they were laid. By comparison, a total of 43 Caspian tern eggs were found on Goose Island and nearby islets in 2015. Passive and active nest dissuasion techniques were successful in preventing all nesting and roosting by both Caspian terns and gulls on Crescent Island during the 2016 nesting season, as was the case in 2015. The results during the 2015 and 2016 nesting seasons were somewhat unexpected because Caspian terns and gulls had nested consistently on Crescent Island for nearly three decades prior to 2015. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the use of closely-spaced fence rows of privacy fabric as passive dissuasion in much of the suitable Caspian tern nesting habitat on Crescent Island, including the former colony area; similar fencing was not deployed at Goose Island due to shallow rocky soils. Another factor was the successful dissuasion of all gulls from nesting on Crescent Island in both 2015 and 2016; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to the passive and active dissuasion techniques. Instead, gulls abandoned Crescent Island as a nesting site and established a new colony on Badger Island (located on the Columbia River just one kilometer upriver from Crescent Island) in both 2015 and 2016. Similarly, Caspian terns displaced from Crescent Island relocated to an alternative colony site on the Columbia River, the Blalock Islands in John Day Reservoir (70 river kilometers downriver from Crescent Island), where Caspian terns have nested in small numbers over the last decade. Resightings of Caspian terns that were previously color-banded on Crescent Island confirmed that there was a large influx of terns to the Blalock Islands colony from the colony on Crescent Island in 2015, and many of these same color-banded terns renested at the Blalock Islands colony in 2016. System-wide action effectiveness monitoring determined that Caspian terns attempted to nest at five different colonies in the Columbia Plateau region in 2016. Four of these occupied colony sites had been used in previous years, and one site was new in 2016. The formerly occupied sites included the Blalock Islands on the Columbia River (483 breeding pairs in 2016, down from 677 breeding pairs in 2015), Twinning Island in Banks Lake (6 breeding pairs in 2016, down from 64 breeding pairs in 2015), Harper Island in Sprague Lake (3 breeding pairs in 2016, down from 10 breeding pairs in 2015), and an unnamed island in Lenore Lake (39 breeding pairs in 2016, up from 16 breeding pairs in 2015). In 2016, an incipient Caspian tern colony became established on a small, low-lying island in northeastern Potholes Reservoir, where 144 breeding pairs of Caspian terns attempted to nest before the colony was abandoned in early June. As was the case in 2015, the largest Caspian tern colony in the Columbia Plateau region was on the Blalock Islands, where 72% of all the Caspian terns in the region nested during 2016. Compared to the average historical size of the Caspian tern colony on the Blalock Islands during 2005-2014 (58 breeding pairs), the colony was 11 times larger in 2015 and eight times larger in 2016. The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2016 was 675 breeding pairs at five separate colonies. This represents a 23% decline in the total number of Caspian terns breeding in the Columbia Plateau region compared to the pre-management average during 2005-2013 (873 breeding pairs). Although nest dissuasion actions implemented on Goose and Crescent islands in 2016 were effective in preventing all Caspian terns from nesting at these two colonies, formerly the two largest tern colonies in the region, it did not result in a commensurate reduction in the total number of Caspian terns breeding in the region. This was primarily due to the more than 8-fold increase in the number of Caspian terns nesting in the Blalock Islands in 2016 compared to the pre-management average for that colony. The Blalock Islands colony during 2015-2016 was similar in size to the largest Caspian tern colony recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2000. Resightings of Caspian terns that were previously color-banded indicated strong site fidelity to the Potholes Reservoir area, despite the third year of efforts to dissuade Caspian terns from nesting at Goose Island and nearby islets. The Blalock Islands experienced a large influx of nesting Caspian terns in 2015, both from the colony on Crescent Island and the colony on Goose Island, but most immigrants came from Crescent Island. Many of the terns that immigrated to the Blalock Islands in 2015 returned to that colony in 2016. Although most Caspian terns dissuaded from Goose and Crescent islands remained in the Columbia Plateau region during the 2015 and 2016 nesting seasons, some terns dispersed to breeding or nonbreeding sites along the coasts of Washington and Oregon, as well as to colonies on Corps-constructed islands in interior Oregon and northeastern California. Results from a more robust analysis to estimate inter-annual movement rates and the number of terns that moved among colonies are also included this report. The goal of the IAPMP is to reduce Caspian tern predation rates (percentage of available fish consumed by terns) on ESA-listed salmonid populations to less than 2% per tern colony per year (USACE 2014). Based on an analysis of former predation rates by Caspian terns nesting in the Columbia Plateau region during 2007-2015 and data on the size of breeding colonies (number of breeding pairs) in 2016, we predicted that predation rate goals would be achieved for many, but not all, tern colonies and salmonid populations in 2016. Predicted predation rates on listed salmonid populations were close to zero (≤ 0.2% per ESA-listed population) for Caspian terns nesting at Goose Island due to the near complete abandonment of the colony in 2016. Predicted predation rates on ESA-listed salmonid populations by Caspian terns nesting on Crescent Island were even closer to zero (< 0.1% per ESA-listed population), due to the complete abandonment of the colony in 2016. Because of the large size of the Caspian tern colony at the Blalock Islands in 2016 (483 breeding pairs), however, predicted predation rates were above the 2% threshold for Upper Columbia River steelhead (4.9%; 95% prediction interval [PI] = 3.8 - 6.4%), Snake River steelhead (4.6%; 95% PI = 4.0 - 5.6%), Snake River sockeye salmon (2.6%; 95% PI = 1.6 - 5.0%), and Snake River spring/summer Chinook salmon (2.0%; 95% PI = 1.8 - 2.3%). There is a lack of sufficient data to estimate former predation rates, or predict current predation rates, on ESA-listed salmonid populations by Caspian terns nesting on (1) Twinning Island in Banks Lake, (2) the small unnamed island in Lenore Lake, and (3) the incipient colony in northeastern Potholes Reservoir. Salmonid PIT tags were recovered, however, from these three nesting sites following the 2016 breeding season and actual (as opposed to predicted) estimates of predation rates are pending further analysis; results will be presented as part of a report to the Grant County Public Utility District and the Priest Rapids Coordinating Committee in January 2017. Actual predation rate estimates based on smolt PIT tag recoveries will also be available for terns that nested on the Blalock Islands in 2016. Due to the small numbers of Caspian terns that were present on Goose Island and the complete abandonment of the Crescent Island tern colony, PIT tag recovery was not conducted at either of these sites and, consequently, predicted predation rates represent the best estimate of predation rates in 2016. In summary, management to eliminate breeding colonies of Caspian terns on Goose Island in Potholes Reservoir and on Crescent Island in McNary Reservoir, formerly the largest breeding colonies for the species in the Columbia Plateau region, was fully successful in 2016, the third year of implementation of the IAPMP. Consequently, predation on juvenile salmonids by Caspian terns nesting at these two colony sites was effectively eliminated. Numbers of breeding Caspian terns in the Columbia Plateau region have declined from pre-management levels due to the management of colonies on Goose and Crescent islands, with the regional population size declining by 23%. Based on resightings of banded Caspian terns, most terns that were displaced from colonies on Goose and Crescent islands have remained in the region, and many have attempted to nest at alternative colony sites in the region. Most notable was the post-management increase in the size of the formerly small breeding colony in the Blalock Islands. Caspian terns nesting in the Blalock Islands during 2015-2016 have consumed sufficient numbers of juvenile salmonids to at least partially compensate for reductions in smolt consumption due to tern management at Goose and Crescent islands. Nesting habitat for Caspian terns in the Blalock Islands is dependent on reservoir level; quality tern nesting habitat is only available when reservoir levels are below full pool. A new tern colony also appeared on a small island in northeastern Potholes Reservoir, but this colony failed before any chicks were fledged due to predators reaching the island as reservoir levels dropped. Based on results during the first three years of implementation of the IAPMP, the goal of the Plan to reduce predation rates on ESA-listed salmonid populations below 2% per tern colony per year throughout the Columbia Plateau region will not be achieved until alternative tern nesting habitat is reduced from current levels, especially in the Blalock Islands and perhaps at the new colony in Potholes Reservoir.

Collis, K., Roby, D. D., Loschl, P. J., Suzuki, Y., Munes, A., Mulligan, J., Schniedermeyer, E., Evans, A. F., Turecek, A., & Payton, Q. (2016). *Implementation of the Inland Avian Predation Management Plan, 2015* (p. 100). http://www.birdresearchnw.org/2015%20IAPMP%20Final%20Report.pdf

In 2015, the U.S. Army Corps of Engineers - Walla Walla District and the U.S. Bureau of Reclamation continued implementation of the Inland Avian Predation Management Plan (IAPMP) in order to reduce predation by Caspian terns (Hydroprogne caspia) on U.S. Endangered Species Act (ESA)-listed populations of salmonids (Oncorhynchus spp.) from the Columbia River basin (USACE 2014). The primary objective of management in the second year of implementation of the IAPMP was to reduce the size of the Caspian tern breeding colonies on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River to less than 40 breeding pairs each. To accomplish this task, the availability of suitable Caspian tern nesting habitat was reduced on both islands by installing a variety of “passive nest dissuasion” materials designed to preclude tern nesting over extensive areas on both islands prior to the 2015 nesting season. Ultimately, about 4.1 acres, or more than 85% of the upland area on Goose Island

and its surrounding islets, were covered with passive nest dissuasion materials consisting exclusively of stakes, rope, and flagging. On Crescent Island, about 2.2 acres of potential Caspian tern nesting habitat were covered with passive nest dissuasion materials consisting of fences rows of privacy fabric, stakes, rope, flagging, and woody debris. On both islands, passive dissuasion was placed over all of the former Caspian tern nesting area, as well as all areas of open sparsely-vegetated habitat that might be used by ground-nesting Caspian terns or gulls (Larus spp.). An effort was also made to prevent nesting by the two species of gulls that nest abundantly on both islands (California gulls [L. californicus] and ring-billed gulls [L. delawarensis]), on the theory that nesting gulls would attract prospecting Caspian terns and could limit the ability to dissuade Caspian terns from nesting on the two islands. Once Caspian terns and gulls arrived on Goose and Crescent islands to initiate nesting, active nest dissuasion (i.e. human hazing) was used to dissuade both Caspian terns and gulls from nesting anywhere on either island. Both California and ring-billed gulls quickly acclimated to both the passive and active dissuasion employed at Goose Island and, as occurred in 2014, initiated nesting (laid eggs) despite our dissuasion efforts. Once gulls laid eggs, hazing gulls that were attending eggs was precluded due to the risk of gull nest failure. As the area on Goose Island with active gull nests expanded, the opportunities to actively haze Caspian terns that were prospecting for nest sites on Goose Island declined. Nevertheless, between the passive dissuasion deployed on typical Caspian tern nesting habitat, and active dissuasion (hazing) including a green laser, only two pairs of Caspian terns succeeded in laying eggs and raising young on Goose Island and nearby islets in 2015. These two nests were not located together, but both were near the former colony area on the main island under nest dissuasion materials. Nesting by Caspian terns on the Northwest Rocks, site of the Caspian tern colony at Goose Island in 2014, was precluded in 2015 using a combination of passive and active dissuasion techniques. Despite the lack suitable Caspian tern nesting habitat on Goose Island in 2015, some Caspian terns displayed considerable breeding site fidelity to Pothole Reservoir area throughout the nesting season, likely due to the history of Caspian tern nesting on Goose Island since 2004 and the presence of a large gull colony on the island that persistently attracted prospecting Caspian terns to the site. Another factor that might explain the strong site fidelity of Caspian terns to Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. Caspian tern use of Goose Island for roosting and nesting was largely limited to areas near the shoreline where passive nest dissuasion had not been installed. Active nest dissuasion (hazing), collection of any Caspian tern eggs discovered, and high rates of gull predation on newly-laid Caspian tern eggs were successful in preventing the formation of a sizable Caspian tern colony on Goose Island. A total of 43 Caspian tern eggs were found on Goose Island and nearby islets in 2015, and these eggs were laid in 39 nest scrapes. Seventeen Caspian tern eggs were collected under permit, 23 eggs were depredated by gulls soon after laying, and three producing chicks (see above). Passive and active nest dissuasion techniques were successful in preventing nesting and roosting by both Caspian terns and gulls on Crescent Island in 2015. This result was somewhat unexpected because it was the first year that nest dissuasion was implemented at Crescent Island and because Caspian terns and gulls have nested consistently on Crescent Island for nearly three decades. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the use of closely-spaced fence rows of privacy fabric as passive dissuasion over much of the suitable Caspian tern nesting habitat on Crescent Island; similar fencing was not deployed at Goose Island due to shallow rocky soils. Another factor was the successful dissuasion of all nesting gulls from Crescent Island in 2015; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to our hazing techniques and abandoned Crescent Island to establish a new colony on Badger Island (located on the mid-Columbia River just one kilometer upstream from Crescent Island) in 2015. Similarly, Caspian terns displaced from Crescent Island were able to relocate to an alternative colony site on the mid-Columbia River, the Blalock Islands (70 river kilometers downriver from Crescent Island), where Caspian terns have nested in small numbers over the last decade. Resightings of terns that were color-banded previously indicated that the Blalock Islands experienced a large influx of Caspian terns from the Crescent Island colony in 2015. System-wide action effectiveness monitoring confirmed that Caspian terns attempted to nest at four historical colony sites in 2015: the Blalock Islands on the mid-Columbia River (677 breeding pairs), Twinning Island in Banks Lake (64 breeding pairs), Harper Island in Sprague Lake (10 breeding pairs), and an unnamed island in Lenore Lake (16 breeding pairs). The Caspian tern colonies on Twinning Island, Harper Island, and the small island in Lenore Lake were similar in size (i.e., number of breeding pairs) in 2015 compared to the previous year, while the tern colony in the Blalock Islands increased from 45 breeding pairs in 2014 to 677 breeding pairs in 2015. This also represented an increase in Caspian tern colony size at the Blalock Islands compared to the historical average (2005-2014; 58 breeding pairs). The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2015 was 769 breeding pairs at five separate colonies. All but one of the six Caspian tern colonies that were active in the region during 2014 were active again in 2015; the exception was the Crescent Island colony, where nest dissuasion efforts were successful in preventing Caspian terns from nesting in 2015. The estimated total size of the breeding population of Caspian terns in the Columbia Plateau region in 2015 (769 breeding pairs) was similar to the estimated population size in 2014 (755 breeding pairs), but still generally lower than the numbers observed during 2000-2013. These results suggest that although nest dissuasion actions implemented on Goose and Crescent islands in 2015 were highly effective in reducing the numbers of Caspian terns nesting at these two colonies, formerly the largest Caspian tern colonies in the region, they did not result in a significant reduction in the total number of Caspian terns breeding in the region to date. This was due to the more than 10-fold increase in the number of Caspian tern nesting in the Blalock Islands in 2015 compared to 2014. The Blalock Islands colony in 2015 was similar in size to the largest Caspian tern colony recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2000. Resightings of terns that were color-banded previously indicated that some Caspian terns exhibited site fidelity to Potholes Reservoir area, and the Blalock Islands experienced a large influx of Caspian terns from the Crescent Island colony in 2015. Evaluation of inter-regional movements of Caspian terns revealed net movements to the Columbia River Plateau region from the managed colony at East Sand Island and from the Corps-constructed alternative colony sites in interior Oregon and northeastern California in 2015; the latter region experienced severe drought in 2015. Based on an analysis of per capita (per bird) predation rates by Caspian terns nesting at various colonies in the Columbia Plateau region during 2007-2014, predicted predation rates in 2015 were less than 2% (the goal of the IAPMP) on many, but not all, ESA-listed salmonid populations. Specifically, predicted predation rates on ESA-listed Upper Columbia River steelhead were below 2% for Caspian terns nesting at Potholes Reservoir in 2015 for the first time since management was initiated in 2014. Also, predicted predation rates on ESA-listed Snake and Upper Columbia River salmonid populations by Caspian terns nesting on Crescent Island were close to zero due

to a lack of nesting adults at Crescent Island in 2015. Because of the large size (677 breeding pairs) of the Caspian tern breeding colony at the Blalock Islands, however, predicted predation rates were above the 2% threshold for Upper Columbia River steelhead (6.3%; 95% prediction interval [PI] = 4.8-8.7%), Snake River steelhead (4.8%; 95% PI = 3.9-6.1%) and Snake River sockeye (2.7%; 95% PI = 0.6-7.7%) in 2015, losses that partially or completely offset benefits achieved by reduced predation rates by Caspian terns nesting at Goose and Crescent islands in 2015. Due to a lack of adequate historical predation rate data from Caspian terns nesting on Twinning Island, predicted predation rates were not available for this colony in 2015.

Collis, K., Roby, D. D., Thompson, C. W., Lyons, D. E., & Tirhi, M. (2002). Barges as temporary breeding sites for Caspian terns: Assessing potential sites for colony restoration. *Wildlife Society Bulletin*, *30*(4), 10.

Management proposals to reduce Caspian tern (Sterna caspia) predation on juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary include relocating some terns from the large colony in the estuary to several smaller colonies outside the Columbia River basin. The welfare of other listed or beleaguered salmonid stocks has been a primary concern in areas considered for restoration of Caspian tern colonies, demonstrating a need for empirical evidence on the effects of tern predation on fisheries prior to restoration of permanent colonies. The main objectives of this study were to determine 1) whether Caspian terns would readily use a barge as a temporary nesting site and 2) whether tern diet composition and productivity data could be collected at the barge. A small, sand-covered barge equipped with tern decoys and sound systems was anchored in Commencement Bay, Washington in 2001. Approximately 388 tern nests were initiated on the barge in a 17-day time period. We monitored diet composition at the barge site by direct observation of fish (n =1,097) in the bills of nesting adults. Tern diets during May were 65% juvenile salmonids; marine forage fishes comprised the remainder of the diet. Predation on tern eggs by glaucous-winged gulls (Larus glaucescens) was frequently observed during the first 10 days following the onset of egg laying; however, predation declined once incubating terns were densely packed on the barge. This study demonstrated that terns might rapidly colonize a barge and that diet composition and productivity data can be collected at the barge site. Barges may be used to assess prospective colony restoration sites; however, these efforts must be carefully conceived and coordinated with resource managers to avoid new resource management conflicts.

Connon, R. E., D'Abronzo, L. S., Hostetter, N. J., Javidmehr, A., Roby, D. D., Evans, A. F., Loge, Frank. J., & Werner, I. (2012). Transcription Profiling in Environmental Diagnostics: Health Assessments in Columbia River Basin Steelhead (Oncorhynchus mykiss). *Environmental Science & Technology*, *46*(11), 6081–6087. https://doi.org/10.1021/es3005128

The health condition of out-migrating juvenile salmonids can influence migration success. Physical damage, pathogenic infection, contaminant exposure, and immune system status can affect survival probability. The present study is part of a wider investigation of out-migration success in juvenile steelhead (Oncorhynchus mykiss) and focuses on the application of molecular profiling to assess sublethal effects of environmental stressors in field-collected fish. We used a suite of genes in O. mykiss to specifically assess responses that could be directly related to steelhead health condition during out-migration. These biomarkers were used on juvenile steelhead captured in the Snake River, a tributary of the Columbia River, in Washington, USA, and were applied on gill and anterior head kidney tissue to assess immune system responses, pathogen-defense (NRAMP, Mx, CXC), general stress (HSP70), metal-binding (metallothionein-

A), and xenobiotic metabolism (Cyp1a1) utilizing quantitative polymerase chain reaction (PCR) technology. Upon capture, fish were ranked according to visual external physical conditions into good, fair, poor, and bad categories; gills and kidney tissues were then dissected and preserved for gene analyses. Transcription responses were tissue-specific for gill and anterior head kidney with less significant responses in gill tissue than in kidney. Significant differences between the condition ranks were attributed to NRAMP, MX, CXC, and Cyp1a1 responses. Gene profiling correlated gene expression with pathogen presence, and results indicated that gene profiling can be a useful tool for identifying specific pathogen types responsible for disease. Principal component analysis (PCA) further correlated these responses with specific health condition categories, strongly differentiating good, poor, and bad condition ranks. We conclude that molecular profiling is an informative and useful tool that could be applied to indicate and monitor numerous population-level parameters of management interest.

Connor, W. P., Burge, H. L., Yearsley, J. R., & Bjornn, T. C. (2003). Influence of Flow and Temperature on Survival of Wild Subyearling Fall Chinook Salmon in the Snake River. *North American Journal of Fisheries Management*, *23*(2), 362–375. https://doi.org/10.1577/1548-8675(2003)023<0362:IOFATO>2.0.CO;2

Summer flow augmentation to increase the survival of wild subyearling fall chinook salmon Oncorhynchus tshawytscha is implemented annually to mitigate for the development of the hydropower system in the Snake River basin, but the efficacy of this practice has been disputed. We studied some of the factors affecting survival of wild subyearling fall chinook salmon from capture, tagging, and release in the free-flowing Snake River to the tailrace of the first dam encountered by smolts en route to the sea. We then assessed the effects of summer flow augmentation on survival to the tailrace of this dam. We tagged and released 5,030 wild juvenile fall chinook salmon in the free-flowing Snake River from 1998 to 2000. We separated these tagged fish into four sequential within-year release groups termed cohorts (N = 12). Survival probability estimates (mean ± SE) to the tailrace of the dam for the 12 cohorts when summer flow augmentation was implemented ranged from 36% ± 4% to 88% ± 5%. We fit an ordinary least-squares multiple regression model from indices of flow and temperature that explained 92% (N = 12; P < 0.0001) of the observed variability in cohort survival. Survival generally increased with increasing flow and decreased with increasing temperature. We used the regression model to predict cohort survival for flow and temperature conditions observed when summer flow augmentation was implemented and for approximated flow and temperature conditions had the summer flow augmentation not been implemented. Survival of all cohorts was predicted to be higher when flow was augmented than when flow was not augmented because summer flow augmentation increased the flow levels and decreased the temperatures fish were exposed to as they moved seaward. We conclude that summer flow augmentation increases the survival of young fall chinook salmon.

Conover, M. R. (1983). Recent Changes in Ring-Billed and California Gull Populations in the Western United States. *The Wilson Bulletin*, *95*(3), 362–383. JSTOR.

During the last 50 years, the Ring-billed Gull (Larus delawarensis) breeding population in the western United States has increased from a minimum of 4800 to 106,000 individuals in 1980. This increase, approximately 22-fold, is manifested in two forms: an increase in mean colony size from 397 to 1867 breeding adults and a proliferation of colonies from 12 to 16 in the 1920s to 57 today. Concomitantly, the breeding population of California Gulls (L. californicus) in the

western U.S. has more than doubled, from ca. 101,000 to 276,000 in 1980. Interestingly, while the number of California Gull colonies has increased from 15 in 1930 to 80 in 1980, the mean number of gulls per colony has decreased, from 6734 to 3455 during the same period. Both gull species have apparently benefitted from increased food supplies resulting from edible human garbage and agricultural practices. Also aiding the proliferation of these gulls has been the creation of new nesting habitat on islands formed by large reservoirs and the reduction of human predation by egg and plumage hunters.

Conover, M. R., & Miller, D. E. (1979). Reaction of Ring-Billed Gulls to Predators and Human Disturbances at at Their Breeding Colonies. *Proceedings of the Colonial Waterbird Group*, *2*, 41–47. JSTOR. https://doi.org/10.2307/1520932

Conover, M. R., & Miller, D. E. (1980). Daily activity patterns of breeding Ring-billed and California gulls. *Journal of Field Ornithology*, *51*(4), 329–339.

Conover, M. R., Thompson, B. C., Fitzner, R. E., & Miller, D. E. (1979). Increasing populations of Ring-billed and California gulls in Washington state. *Western Birds*, *10*, 31–36.

Cornely, J. E., Thompson, S. P., Henny, C. J., & Littlefield, C. D. (1993). Nests and Eggs of Colonial Birds Nesting in Malheur Lake, Oregon, with Notes on DDE. *Northwestern Naturalist*, *74*(2), 41–48. JSTOR. https://doi.org/10.2307/3536792

We describe the nests and eggs of 7 species of colonial birds that nested on Malheur Lake in Malheur National Wildlife Refuge, Oregon, in 1980 and 1981. All nests were constructed over water in stands of hardstem bulrush (Scirpus acutus). We compared nest measurements among species and found significant differences. Nest size was highly correlated with bird body mass. The heavier the bird, the larger the nest and the higher the nest crown was above water. Egg volume was also highly correlated with body mass. We found evidence of shell thinning and DDE residues in great egret eggs and low levels of pesticide residues in eggs of Franklin's Gull. We summarize all available DDE and shell thickness data from colonial bird eggs collected from Malheur Lake.

Côté, I. M., & Sutherland, W. J. (1997). The Effectiveness of Removing Predators to Protect Bird Populations. *Conservation Biology*, *11*(2), 395–405. https://doi.org/10.1046/j.1523-1739.1997.95410.x

The control of predators for nature conservation purposes is becoming an increasingly important issue. The growing populations of predator species in some areas and the introduction of predators in other areas have led to concerns about their impact on vulnerable bird species and to the implementation of predator control in some cases. This is set against a background of increasingly fragmented semi-natural habitats and declining populations for many species. To assess the efficiency of predator removal as a conservation measure, the results of 20 published studies of predator removal programs were meta-analyzed. Removing predators had a large, positive effect on hatching success of the target bird species, with removal areas showing higher hatching success, on average, than 75% of the control areas. Similarly, predator removal increased significantly post-breeding population sizes (i.e. autumn densities) of the target bird species. The effect of predator removal on breeding population sizes was not significant, however, with studies differing widely in their reported effects. We conclude that predator removal often fulfills the goal of game management, which is to enhance harvestable post-breeding populations, but that it is much less consistent in achieving the usual aim of conservation managers, which is to maintain and, where appropriate, increase bird breeding population sizes. This may be due to inherent characteristics of avian population regulation, but also to ineffective predator removal and inadequate subsequent monitoring of the prey populations.

Couch, S. L. L., & Lance, M. M. (2004). Diet Composition and Breeding Success of Brandt's Cormorants in the Columbia River Estuary. *Northwestern Naturalist*, *85*(2), 62–66. JSTOR.

Courtot, K. N., Roby, D. D., Adkins, J. Y., Lyons, D. E., King, D. T., & Larsen, R. S. (2012). Colony connectivity of Pacific Coast double-crested cormorants based on post-breeding dispersal from the region's largest colony. *The Journal of Wildlife Management*, *76*(7), 1462–1471. https://doi.org/10.1002/jwmg.403

To reduce conflicts with fish resources, other colonial waterbirds, and damage to habitats, double-crested cormorants (Phalacrocorax auritus) are currently controlled (lethally and non-lethally) throughout much of their range. Concerns are growing over the Pacific Coast's largest double-crested cormorant colony at East Sand Island (ESI), Oregon near the mouth of the Columbia River, where cormorants forage on juvenile salmonids, many of which are listed under the United States Endangered Species Act. Management of this colony is currently under consideration and may call for a redistribution of a portion of this colony numbering more than 12,000 breeding pairs in 2009. We investigated regional and site-specific connectivity of ESI cormorants using satellite-telemetry to track post-breeding dispersal. Cormorants dispersed widely west of the Cascade-Sierra Nevada Mountains from British Columbia, Canada to northern Mexico. Tracking data demonstrated direct connectivity between the double-crested cormorant colony at ESI and nesting sites throughout the dispersal area. Results of this study indicate that some cormorants from ESI could disperse to prospect for nesting sites throughout much of the western portion of the range of the Western Population; however, regional variation in connectivity with the ESI population, distance from ESI, and site-specific nesting history will likely result in variable prospecting rates among regions and sub-regions. Management efforts aimed at redistributing ESI cormorants across western North America (e.g., social attraction or dissuasion techniques) might be best allocated to areas or sites known to be used by tagged cormorants, particularly those sites with an established nesting history.

Courtot, K. N., Roby, D. D., Kerr, L. H., Lyons, D. E., & Adkins, J. Y. (2016). A Low-Disturbance Capture Technique for Ground-Nesting Double-Crested Cormorants (Phalacrocorax auritus). *Waterbirds*, *39*(2), 193–198. https://doi.org/10.1675/063.039.0210

Capturing breeding adults of colonially nesting species can entail risks of nest failure and even colony abandonment, especially in species that react strongly to human disturbance. A low-disturbance technique for capturing specific adult Double-crested Cormorants (Phalacrocorax auritus) at a ground-nesting colony was developed to reduce these risks and is described here. Nesting habitat enhancement was used to attract Doublecrested Cormorants to nest adjacent to above-ground tunnels constructed so that researchers could capture birds by hand. Using this technique, Double-crested Cormorants (n = 87) were captured during the incubation and chick-rearing stages of the nesting cycle. Unlike alternative capture techniques, this approach allowed targeting of specific individuals for capture and recapture, minimized local disturbance, and eliminated colony-wide disturbances. The tunnel-based system presented here could be adapted to capture adults or to access the nest contents of other ground-nesting colonial species that are inclined to nest in areas of enhanced nesting habitat and adapt to anthropogenic structures in their nesting area. This system would be particularly beneficial for other wary and easily disturbed species.

Cowx, I. G. (2007). Interactions Between Fisheries and Fish-Eating Birds: Optimising the Use of Shared Resources. In *Interactions Between Fish and Birds: Implications for Management* (pp. 361–372). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470995372.ch28
This chapter contains sections titled: Introduction Bird—fisheries interactions Fisheries—bird interactions Options for the future

Custer, T. W., & Bunck, C. (1992). Feeding Flights of Breeding Double-Crested Cormorants at Two Wisconsin Colonies. *Journal of Field Ornithology*, *63*(2), 203–211. JSTOR.
Unmarked Double-crested Cormorants (Phalacrocorax auritus) (n = 523) were followed by airplane from Cat Island and Spider Island, two nesting colonies in Wisconsin, to their first landing site. Cormorants flew an average of 2.0 km from Cat Island (maximum 40 km) and 2.4 km from Spider Island (maximum 12 km). The mean direction of landing sites differed seasonally for flights from Spider Island, but not from Cat Island. Cormorants generally landed in Green Bay or Lake Michigan (>99%) and rarely landed in inland lakes or ponds. The most frequent (>80%) water depth at landing sites for each colony was <9.1 m. Water depths ≥9.1 m were used less frequently than available within the maximum observed flight distance for each colony. The average flight speed for cormorants was 61 km/h.

Cuthbert, F. J. (1985a). Intraseasonal Movement between Colony Sites by Caspian Terns in the Great Lakes. *The Wilson Bulletin*, *97*(4), 502–510. JSTOR.
Colony-site use patterns were studied in Caspian Terns (Sterna caspia) nesting on five islands in northeastern Lake Michigan to address the following questions: (1) do individual terns frequent more than one colony site during a single breeding season; and (2) what are the factors that influence intraseasonal colony site movement in this population? Intraseasonal movements of terns between colonies in northeastern Lake Michigan were common. Birds that were not nesting were observed significantly more often at two or more colonies than nesting terns, and intercolony movement was precipitated by lack of a mate or nest site and by reproductive failure (e.g., nest destruction by storms or predators and investigator disturbance). Intercolony movement during courtship and following reproductive failures probably is intensified during periods of flooding or high water in the Great Lakes.

Cuthbert, F. J. (1985b). Mate Retention in Caspian Terns. *The Condor*, *87*(1), 74–78. https://doi.org/10.2307/1367133
Colonial seabirds that nest in stable, predictable environments tend to breed with the same mate for consecutive seasons. In some of these populations, mate retention has been shown to be correlated with previous reproductive success. Caspian Terns (Sterna caspia) were observed in northeastern Lake Michigan at several colony sites that vary in stability because of fluctuating water levels. Objectives of my study were to determine if (1) individuals tend to keep the same mate for consecutive breeding attempts, (2) mate retention is influenced by previous reproductive success or inter-year nest site stability, and (3) reproductive success is affected by mate change. Only 25% of the original pairs bred together for consecutive seasons, mate

retention was independent of reproductive success the previous year but not of inter-year nest site stability, and I found no significant advantage in retaining the same mate for consecutive seasons. These results indicate that factors other than previous reproductive success (e.g., habitat stability) influence mate selection and retention in this population of Caspian Terns. Caution should be exercised in assuming that the relationship between mate retention and previous reproductive success holds for other species of colonial seabirds.

Cuthbert, F. J. (1988). Reproductive Success and Colony-Site Tenacity in Caspian Terns. *The Auk*, *105*(2), 339–344. https://doi.org/10.2307/4087499
Colony-site use by individually marked Caspian Terns (Sterna caspia) was studied at four breeding colonies in northeastern Lake Michigan during 1976-1979. I examined two related aspects of colony-site use: (1) colony-site preference in experienced breeders and (2) the relationship between reproductive success and colony-site tenacity. Terns showed a significant preference for the colony of previous breeding unless their preceding reproductive effort was unsuccessful. Caspian Terns tended to use the same colony site if young were produced but moved to a new location if reproductive success had been terminated or threatened at the traditional site.

Cuthbert, F. J., & Wires, L. R. (1999, January). *Caspian Tern—Hydroprogne caspia—V2.0 from Birds of North America—Birds of the World*. https://birdsoftheworld.org/bow/historic/bna/caster1/2.0/introduction

David C. Smith and Associates, Inc. (2015). *Enumeration and Monitoring Surveys of Double-Crested Cormorants in the Lower Columbia River Estuary for the 2015 Nesting Season* (p. 37). https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll3/id/789
Objective This study supported efforts by the U.S. Army Corps of Engineers, Portland District (CENWP) to evaluate the status of the Columbia River Estuary population of double-crested cormorants (Phalacrocoraxauritus) (DCCO). It supports the CENWP Management Plan to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary. Study Area This project was divided into two primary study areas: 1) Enumeration and monitoring of DCCO and Brandt's cormorants (Phalacrocoraxpenicillatus) (BRAC) on East Sand Island (ESI), and 2) Enumeration and monitoring of DCCO at other colony sites throughout the Columbia River Estuary (CRE), and exclusive of ESI. The ESI study area is shown on Map 01. The other colony sites throughout the CRE that were surveyed and monitored are shown on Map 02a (entire study area) and Map 02b (detail area of highest concentration of colonies). Methods The enumeration and monitoring work on ESI relied primarily on photogrammetric surveys utilizing high resolution stereo imagery and field observations. General reconnaissance by boat and aircraft were used to supplement field and photogrammetry surveys in areas of limited visibility. The enumeration and monitoring work for other colony sites in the CRE utilized aerial and boat-based reconnaissance and observation. Both boat and aerial reconnaissance were conducted to identify key loafing and roosting areas, and to identify new nesting areas (five or more active nests in one contiguous location). Where more than five active DCCO nests were detected in one contiguous location, detailed counts were obtained by observation from boat. Oblique aerial imagery was used to verify boat counts; in most cases the counts from boat observation were used for reporting. Required metrics for the ESI work, reported separately for DCCO and BRAC, included: • number of nesting DCCO/ BRAC • number of breeding pairs • nest density and distribution • total area (acreage) occupied by DCCO/BRAC • characteristics of habitat use •

nesting chronology (limited to what could be observed from blinds in the time allotted) and any other relevant observational information pertaining to nesting success and failures and colony productivity (e.g., site conditions, evidence of predators, etc.) Evaluation of nesting success was not a focus of the study and could not be fully determined within the scope of the tasks authorized under this contract. All CRE colony sites detected and monitored (other than ESI) were located on bridge structures or channel markers. Nest density and total area were not reported. Nesting chronology observations were limited to the observation of birds on nests and audible or visible chicks or fledglings. Eggs in nests could not be observed. Results, ESI The largest observed population (12,150 DCCO breeding pairs and 2,071 BRAC breeding pairs) was observed on ESI during the Week 10 (July 1, 2015) aerial imagery counts. This observation followed a three week gap in observations due to contracting delays. The Week 10 counts were the highest observed value and are assumed to represent the peak cormorant population on ESI for the 2015 breeding season. This observed peak DCCO population was about 10 percent less than the peak population reported for the 2014 breeding season. Results, Comparison with Past Methodologies A comparison with past 2D aerial image counting methods was performed. The stereophotogrammetry results fell within the overall error range of the 2D methodology used in past studies, but had a higher level of confidence for total nest counts and species delineation. Results, other CRE colonies An estimated 1,022 additional DCCO nests were observed at other colony sites in the CRE. The largest of these colonies was found on the Astoria-Megler bridge. Other notable colonies include marine navigation markers between river miles 20 and 30, Longview Bridge, and transmission towers near Troutdale/Camas. Conclusions and Recommendations The overall approach and methodology proved to be a successful means to efficiently enumerate DCCO and BRAC nesting pairs on ESI and other colonies throughout the CRE. Stereophotogrammetry methods used for ESI produced results that are consistent with past methods and have the advantage of establishing a more accurate baseline and more repeatable methodology for future work. Use of GIS technologies for georeferenced deliverables will allow the study data to better facilitate future evaluation of changes in population trends. Field observations provided critical and necessary information, though observations of nesting chronology were limited due to lack of access to blind 4 and contracting delays. Recommendations for future efforts include addressing contracting timing issues to better track nesting chronology (if desired), and to ensure observations capture the peak colony population. Additional site preparation is also recommended in order to achieve more value from field observations.

Dawson, W. L., & Bowles, J. H. (1932). *The Birds of Washington (Volume 1 of 2)*. https://www.gutenberg.org/files/46764/46764-h/46764-h.htm

De Robertis, A., Ryer, C. H., Veloza, A., & Brodeur, R. D. (2003). Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. *Canadian Journal of Fisheries and Aquatic Sciences*, *60*(12), 1517–1526. https://doi.org/10.1139/f03-123
Contrast degradation theory predicts that increased turbidity decreases the visibility of objects that are visible at longer distances more than that of objects that are visible at short distances. Consequently, turbidity should disproportionately decrease feeding rates by piscivorous fish, which feed on larger and more visible prey than particle-feeding planktivorous fish. We tested this prediction in a series of laboratory feeding experiments, the results of which indicated that prey consumption by two species of planktivorous fish (juvenile chum salmon (Oncorhynchus

keta) and walleye pollock (Theragra chalcogramma)) is much less sensitive to elevated turbidity than piscivorous feeding by sablefish (Anoplopoma fimbria). Planktivorous feeding in the turbidity range tested (0–40 nephelometric turbidity units (NTU)) was reduced at high light intensity, but not at low light intensity. Comparatively low (5–10 NTU) turbidity decreased both the rate at which sablefish pursued prey and the probability of successful prey capture. These results suggest that turbid environments may be advantageous for planktivorous fish because they will be less vulnerable to predation by piscivores, but will not experience a substantial decrease in their ability to capture zooplankton prey.

DeBruyne, R. L., Coleman, J. T. H., Jackson, J. R., Rudstam, L. G., & VanDeValk, A. J. (2013). Analysis of Prey Selection by Double-Crested Cormorants: A 15-Year Diet Study in Oneida Lake, New York. *Transactions of the American Fisheries Society*, *142*(2), 430–446. https://doi.org/10.1080/00028487.2012.746239

Piscivorous birds, in particular cormorants Phalacrocorax spp., have been reported to cause declines in some fish populations in both Europe and North America, but not in others. This difference may be due to prey selection by cormorants that is further dependent on the composition of the fish assemblage present. We present 15 years of diet data collected from Oneida Lake, New York, where we have previously documented negative effects of double-crested cormorants Phalacrocorax auritus on two fish populations valued by anglers: Walleye Sander vitreus and Yellow Perch Perca flavescens. The Oneida Lake fish community changed through the study period and this change was reflected in cormorant diet samples. Diet samples were variable based on season and year with Emerald Shiner Notropis atherinoides, Gizzard Shad Dorosoma cepedianum, Lepomis spp., Logperch Percina caprodes, Walleye, and Yellow Perch having the highest overall relative importance. In years when age-0 Gizzard Shad were abundant they dominated double-crested cormorant diets in the fall after the shad reached a length of 45 mm. Consumption of Emerald Shiner and Gizzard Shad was positively related to each species' abundance, but no significant correlation between availability and consumption was found for Walleye, White Perch Morone americana, or Yellow Perch. Double-crested cormorants may be displaying prey-switching behavior and selecting for smaller, soft-rayed, prey species. We conclude that variation in fish recruitment influences double-crested cormorant food selection habits and highlight the importance of continued monitoring with changing fish communities to reliably assess potential impacts of cormorants on a fish community over time.

Decker, F. R., & Bowles, J. H. (1932). Two New Breeding Records for the State of Washington. *The Murrelet*, *13*(2), 53–53. JSTOR.

Denno, R. F., & Lewis, D. (2009). II.7 Predator–Prey Interactions. In *The Princeton Guide to Ecology* (pp. 202–212). Princeton University Press. https://princetonup.degruyter.com/view/book/9781400833023/10.1515/9781400833023.202.xml

In natural food webs, consumers fall victim to other consumers such as predators, parasitoids, parasites, or pathogens. Predators kill and consume all or parts of their prey and do so either before or after their catch has reproduced. A lynx stalking , attacking, and consuming snowshoe hare is an example from the vertebrate world. Spiders snaring moths in their webs, assassin bugs lancing caterpillars with their beaks, and starfish ravaging mussel beds in rocky intertidal habitats are all instances of invertebrate predation. By contrast, parasitoids such as small wasps and flies usually attack only the immature stages of their arthropod hosts, thus killing them before they reproduce. Parasites live on (e.g., fleas and lice) or in (e.g., tape worms) host tissues, often reducing the fitness of their host but not killing it. Pathogens (e.g., viruses, bacteria, and fungi) induce disease and either weaken or ultimately kill their hosts. Although this chapter focuses on predators, there are many similarities among predator-prey, host-parasitoid, and host-pathogen interactions.

Derby, C. E., & Lovvorn, J. R. (1997). Predation on fish by cormorants and pelicans in a cold-water river: A field and modeling study. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(7), 1480–1493. https://doi.org/10.1139/f97-055

We studied diets of double-crested cormorants (Phalacrocorax auritus) and American white pelicans (Pelecanus erythrorhynchos) collected on the North Platte River, Wyoming, from May to August. Rainbow (Oncorhychus mykiss) and cutthroat (O. clarki) trout 10-16 cm long were stocked in late June - early July. Cormorants ate mainly suckers (Catastomus spp., 61% of numbers, 85% of fresh mass) before trout stocking; but trout consumed increased from 17% (12% of mass) in samples before stocking to 60% (82% of mass) after stocking. Pelicans ate mostly suckers (64% of numbers, 84% of mass) and minnows (Rhinichthys cataractae, Pimephales promelas; 21% of numbers, 1% of mass) throughout the study; trout were 1% (0.1% of mass) of the pelican diet before stocking, and 22% (14% of mass) after stocking. A bioenergetics model estimated that these birds consumed up to 80% of trout stocked in 1994. In August 1993, cormorants ate mostly trout (86% of numbers, 98% of mass), suggesting that many stocked trout survived until autumn. However, the much smaller fraction of trout eaten by cormorants in spring 1994 before stocking (mean 17% of numbers, 13% of mass) than after stocking (60% of numbers, 82% of mass) suggests that stocked trout declined substantially during winter. Because overwinter survival might have limited trout recruitment between years, it is unclear whether bird predation was additive or compensatory.

Di Lorenzo, E., Schneider, N., Cobb, K. M., Franks, P. J. S., Chhak, K., Miller, A. J., McWilliams, J. C., Bograd, S. J., Arango, H., Curchitser, E., Powell, T. M., & Rivière, P. (2008). North Pacific Gyre Oscillation links ocean climate and ecosystem change. *Geophysical Research Letters*, *35*(8). https://doi.org/10.1029/2007GL032838

Decadal fluctuations in salinity, nutrients, chlorophyll, a variety of zooplankton taxa, and fish stocks in the Northeast Pacific are often poorly correlated with the most widely-used index of large-scale climate variability in the region - the Pacific Decadal Oscillation (PDO). We define a new pattern of climate change, the North Pacific Gyre Oscillation (NPGO) and show that its variability is significantly correlated with previously unexplained fluctuations of salinity, nutrients and chlorophyll. Fluctuations in the NPGO are driven by regional and basin-scale variations in wind-driven upwelling and horizontal advection – the fundamental processes controlling salinity and nutrient concentrations. Nutrient fluctuations drive concomitant changes in phytoplankton concentrations, and may force similar variability in higher trophic levels. The NPGO thus provides a strong indicator of fluctuations in the mechanisms driving planktonic ecosystem dynamics. The NPGO pattern extends beyond the North Pacific and is part of a global-scale mode of climate variability that is evident in global sea level trends and sea surface temperature. Therefore the amplification of the NPGO variance found in observations and in global warming simulations implies that the NPGO may play an increasingly important role in forcing global-scale decadal changes in marine ecosystems.

Dieperink, C., Bak, B. D., Pedersen, L.-F., Pedersen, M. I., & Pedersen, S. (2002). Predation on Atlantic salmon and sea trout during their first days as postsmolts. *Journal of Fish Biology*, *61*(3), 848–852. https://doi.org/10.1111/j.1095-8649.2002.tb00917.x
Radio-tagged smolts of Atlantic salmon Salmo salar and sea trout Salmo trutta were predated heavily by sea birds after crossing the saline limit in the estuary of the River Skjern, Denmark. Most predation took place within the first 9 h after estuarine entry. The field data do not contradict the hypothesis of maladaptive anti-predatory behaviour.

Dieperink, C., Pedersen, S., & Pedersen, M. I. (2001). Estuarine predation on radiotagged wild and domesticated sea trout (Salmo trutta L.) smolts. *Ecology of Freshwater Fish*, *10*(3), 177–183. https://doi.org/10.1034/j.1600-0633.2001.100307.x
Avian predation on emigrating wild and domesticated sea trout smolts was investigated in a fjord in the western Baltic Sea. In April 1997, 50 domesticated and 50 wild smolts were intraperitoneally tagged with radio-transmitters and released in a small coastal stream. Predation was recorded by signal interception in an estuarine breeding colony of cormorants and herons near the outlet of the stream. Of the 78 emigrating smolts, 51 (65%) were recorded as eaten. Predation rates were significantly higher among small than large smolts and significantly higher among domesticated smolts. The first 2 days after entering the sea, both wild and domesticated smolts suffered a severe daily predation rate (range 20–34%). The results support the hypothesis of a transient period immediately after exposure to full-strength sea water, where smolts experience an elevated risk of predation. A transient increase in postsmolt mortality may be found also in moderately saline environments (20–23 ppt).

Dietrich, J. P., Boylen, D. A., Thompson, D. E., Loboschefsky, E. J., Bravo, C. F., Spangenberg, D. K., Ylitalo, G. M., Collier, T. K., Fryer, D. S., Arkoosh, M. R., & Loge, F. J. (2011). An Evaluation of the Influence of Stock Origin and Out-migration History on the Disease Susceptibility and Survival of Juvenile Chinook Salmon. *Journal of Aquatic Animal Health*, *23*(1), 35–47. https://doi.org/10.1080/08997659.2011.568859
Various methods have been developed to mitigate the adverse effects of the Federal Columbia River Power System on juvenile Pacific salmon out-migrating through the Columbia River basin. In this study, we found that hatchery-reared spring Chinook salmon Oncorhynchus tshawytscha in the river are in varying degrees of health, which may affect delayed mortality and the assessment of the effectiveness of management actions to recover listed stocks (e.g., barging fish downstream versus leaving fish in the river). A laboratory disease challenge with Listonella anguillarum was completed on fish from Rapid River Hatchery and Dworshak National Fish Hatchery (NFH) with different out-migration histories: (1) transported by barge, (2) removed from the river before barging, or (3) left to travel in-river. Barged fish from Rapid River Hatchery experienced less mortality than fish from Dworshak NFH. No statistical differences were found between the hatcheries with fish that had in-river out-migration histories. We suggest that the stressors and low survival associated with out-migration through the hydropower system eliminated any differences that could have been present. However, 18–25% of the fish that were barged or collected before barging died in the laboratory before the disease challenge, compared with less than 2% of those that traveled in-river. Owing to disproportionate prechallenge mortality, the disease-challenged populations may have been biased; thus, they were also considered together with the prechallenge mortalities. The synthesis of prechallenge and disease-challenged mortalities and health characteristics evaluated during out-migration indicated that

the benefit of barging was not consistent between the hatcheries. This finding agrees with adult survival and delayed mortality estimates for the individual hatcheries determined from adult returns. The results suggest that the health status of fish and their history before entering the hydropower system (hatchery of origin and out-migration path) are critical variables affecting the conclusions drawn from studies that evaluate mitigation strategies.

Dobson, F. S., & Jouventin, P. (2010). The trade-off of reproduction and survival in slow-breeding seabirds. *Canadian Journal of Zoology*, *88*(9), 889–899. https://doi.org/10.1139/Z10-054

A trade-off between reproduction and survival is one of the most consistent empirical aspects of life-history diversification. One explanation for this interspecific pattern is evolved differences in the balance of allocation to reproduction versus individual maintenance and survival. The same pattern is expected, however, simply as a result of differences among species in body size. We tested these alternatives using original data from 44 species of albatrosses and petrels, long-lived seabirds that breed very slowly. After application of regression techniques to remove the effects of body size and phylogeny, annual reproduction and survival exhibited a significant trade-off. Our measures of reproductive effort also exhibited significant trade-offs with age at maturity, the latter strongly associated with survival. Feeding rate of chicks, success at fledging chicks, and annual chick production were also significantly associated. In conclusion, after removing the effects of body size, we found a significant trade-off of reproduction and survival, in spite of the fact that these long-lived birds lay only one egg at a time. Our examination of the pattern among life-history traits of these slow breeders and their pelagic feeding ecology provide support for the evolutionary explanation of a trade-off of reproduction and survival.

Dolbeer, R. A. (1991). Migration patterns of double-crested cormorants east of the Rocky Mountains. *Journal of Field Ornithology*, *62*(1), 83–93.

The 5589 recovery records for Double-crested Cormorants (Phalacrocorax auritus) banded in North America from 1923 to 1988 were analyzed to determine migration patterns and the source of populations wintering in the lower Mississippi Valley and Gulf of Mexico coastal region. Autumn migration from areas north of latitude 42°N primarily occurred in October and November. Spring migration occurred mainly in April for birds >2 yr old and in May for birds <1 yr old. During summer,1-yr-old birds were recovered significantly farther from their natal colony than were older birds. Cormorants nesting in Canada and the northern United States from Alberta to the Gulf of St. Lawrence migrated in winter primarily to the southern United States between Texas and Florida. There was considerable mixing and overlap in winter of nesting populations from widely divergent areas. From 38 to 70% of the birds from Saskatchewan throughout the Great Lakes region were recovered in the lower Mississippi Valley as were 10% of the birds from such disparate areas as Alberta and the New England coast. There was little mixing of populations from east and west of the Rocky Mountains.

Dorr, B., King, D. T., Tobin, M. E., Harrel, J. B., & Smith, P. L. (2004). Double-crested Cormorant Movements in Relation to Aquaculture in Eastern Mississippi and Western Alabama. *Waterbirds*, *27*(2), 147–154. https://doi.org/10.1675/1524-4695(2004)027[0147:DCMIRT]2.0.CO;2

Concomitant with increasing numbers of the Double-crested Cormorant (Phalacrocorax auritus), catfish producers in eastern Mississippi and western Alabama have reported damage caused by cormorant predation. VHF telemetry was used to document movements of 25 cormorants from all known night roosts in the aquaculture producing areas of eastern Mississippi and western Alabama, January-April 1998. A total of 193 day locations and 396 night roost locations of the cormorants were obtained. Each cormorant was found in the study area for 57 ± 4 (SE) days. Each cormorant averaged three night roosts (range: 1-8) and spent 20 (±2) days at each night roost site. Over 95% of cormorant day locations were within 19 km of their night roosts. Catfish pond use by cormorants varied between roost sites. Cormorants from five of eleven night roosts had ≥30% of subsequent daytime locations on catfish ponds and birds from five of the six remaining night roosts did not visit catfish ponds on the following day. Foraging distance and frequency of night roost interchange was less for birds in this study than those reported from other aquaculture regions. We suggest roost harassment efforts should be focused on specific roost sites and some roost sites should serve as unharrassed refugia from which cormorants are less likely to cause damage to aquaculture.

Dorr, B. S., Hatch, J. J., & Weseloh, D. V. (2014). *Double-crested Cormorant—Phalacrocorax auritus—Birds of the World*. https://birdsoftheworld.org/bow/species/doccor/cur/introduction

Draulans, D. (1988). Effects of fish-eating birds on freshwater fish stocks: An evaluation. *Biological Conservation*, *44*(4), 251–263. https://doi.org/10.1016/0006-3207(88)90019-5

An evaluation is given of the effects of fish-eating birds on freshwater fish stocks. Controversy exists in the literature on the impact of bird predation on commercial catches. This is due to the often disputable assumptions made in calculating such impacts. It is crucial for an objective assessment that quantitative data on the diet, size and energy requirement of the predator population are available, and that these are compared on appropriate spatial and temporal scales with the demography of the fish stocks. Most studies have not even approached this. Given is an example drawn from grey herons Ardea cinerea fishing in small freshwater ponds. The herons consumed a maximum of 8% of the total fish yield, depending on stocking density and fish availability. It is argued that fish-eating birds do not cause any significant losses of fish production unless prey are very easily available (for example, when ponds are drained).

Drent, R. H., Klaassen, M., & Zwaan, B. (1992). Predictive growth budgets in terns and gulls. *Ardea*, *80*(1), 5–17.

Energy budgets for nestling growth are presented for the Sandwich Tern Sterna sandvicensis, Common Tern S. hirundo, Arctic Tern S. paradisaea, and Herring Gull Larus argentatus. Chicks were either raised in captivity (growth efficiencies) or removed from the nest periodically for measurement of basal metabolic rate (BMR). Validation of the laboratory budgets relies on determinations of chick field metabolic rate assessed by the doubly labelled water technique (available for Arctic Tern and one other larid). Comparative analysis suggests that when chicks of these species experience growth rates typical of field conditions avenues of energy allocation summed over the entire period up to fledging show close similarity. Energy used in the production of body tissue averaged 27% (of which 7% for biosynthesis) while BMR accounted for 45%, the remainder being cost of activity and thermoregulation (28%). Where quantified, cost of temperature regulation accounted for only 10% of the total expenditure under field conditions. A regression made of metabolic energy (ME) intake over the entire nestling period against body mass of the fledging based on eight studies of gulls and terns resulted in ME = 35.15.M1.015. This predictive equation also gave satisfying results in non-larids beyond the weight range of the birds studied (100-1000 g).

Duerr, A. E., Donovan, T. M., & Capen, D. E. (2007). Management-Induced Reproductive Failure and Breeding Dispersal in Double-Crested Cormorants on Lake Champlain. *Journal of Wildlife Management*, *71*(8), 2565–2574. https://doi.org/10.2193/2006-527

We studied breeding dispersal of double-crested cormorants (Phalacrocorax auritus) associated with management practices that suppressed their reproduction on Lake Champlain in the northeastern United States. We implemented an experiment on one colony by spraying corn oil on cormorant eggs in portions of the colony and leaving other portions untreated. Gulls (Larus spp.) consumed cormorant eggs during the oiling process, but we reduced and then eliminated predation levels after the first year of the study. We used mark–recapture techniques within the experimental framework to measure rates of breeding dispersal for cormorants from the experimental colony and an unmanaged colony in Lake Champlain. Egg oiling increased the movement rate to the unmanaged colony by 3% during the year with no egg predation by gulls. When gulls depredated cormorant eggs at high rates during egg oiling, movement to the unmanaged colony increased by 20%. When cormorants are managed to reduce population sizes, methods that limit dispersal away from the managed colony may be most effective. Such methods would mitigate effects to nontarget populations and allow for a greater portion of the metapopulation to be managed.

Duffy, D. C. (1995). Why Is the Double-Crested Cormorant a Problem? Insights from Cormorant Ecology and Human Sociology. *Colonial Waterbirds*, *18*, 25–32. JSTOR. https://doi.org/10.2307/1521521

Cormorants Phalacrocoracidae have a long history of conflict with fishermen and more recently with fish-farmers. Cormorant species tend to be opportunistic, adaptable, and highly attracted to concentrated food sources. At the population level, there is little evidence to suggest that cormorants seriously deplete commercial food sources, although at small scales, individuals or small numbers of cormorants may cause problems, especially at fish farming operations or hatcheries. On the other hand, despite a high potential rate of population increase, cormorants are among the more sensitive seabirds to human disturbance during breeding. Control measures would be very effective at breeding sites, but it is not clear that such efforts would remove the proportion of the population likely to be in direct conflict with humans, except at colonies adjacent to fish farms.

Dunn, E. H. (1975). Caloric Intake of Nestling Double-Crested Cormorants. *The Auk*, *92*(3), 553–565. https://doi.org/10.2307/4084609

Dunn, E. K. (1975). The Role of Environmental Factors in the Growth of Tern Chicks. *Journal of Animal Ecology*, *44*(3), 743–754. JSTOR. https://doi.org/10.2307/3716

(1) A step-down multiple regression analysis was carried out to determine if the factors found to affect the fishing success of adult Sandwich and common terns also influenced the growth rate of chicks of these species and of roseate terns. (2) Both the amount of variation in growth rates explained, and the contributory variables, differed markedly between species and between years. Part of this heterogeneity is attributable to different weather conditions in the three seasons of study, and to changes in the availability of food which could not be evaluated. (3) Wind had the greatest effect on growth rates but was not consistently important, suggesting that, under most conditions, it does not alter fishing success sufficiently to influence the chicks' daily intake of food. (4) Windspeed had a strongly linear depressive effect on the weight increase of roseate tern

chicks in 1968, and simple regression showed that a 10-knot wind would cause a 67% reduction in growth rate. In the same year, windspeed2 accounted for most of the variation in weight changes of common tern chicks and it is suggested that very low windspeeds may reduce the growth rate in this species. This in turn can be explained by the depressive effect of low windspeeds on the foraging success of adults. Wind had a negligible effect on the growth rate of Sandwich tern chicks. (5) In addition to wind, rainfall and sea conditions had measurable effects on the weight increase of common tern chicks. Other environmental variables recorded (sunshine, tide) were of little significance to any of the species. (6) These results are discussed in relation to the feeding ecology of each species.

Ellis, K. S., Larsen, R. T., & Koons, D. N. (2020). The importance of functional responses among competing predators for avian nesting success. *Functional Ecology*, *34*(1), 252–264. https://doi.org/10.1111/1365-2435.13460

The relationship between the rate of predation and prey abundance is an important component of predator–prey dynamics. However, functional responses are less straightforward when multiple predators compete for shared prey. Interactions among competing predators can reduce or enhance effects of predation on prey populations. Because many avian populations experience high rates of nest predation, understanding the role of specific predators on nest mortality will lead to more informed conservation and management strategies which attempt to increase productivity by removing certain predators or managing habitat to limit their impact. Our goal was to evaluate effects of specific predators and the influence of nest abundance on nest mortality. We monitored snowy plover Charadrius nivosus nests across 7 years at two study areas in Utah, USA, with remote cameras. We modelled predator-specific hazard rates for nest mortality in a Bayesian framework to assess relationships between competing predators and the role of nest abundance on predator-specific hazard rates. We found that hazard rates for nest mortality by gulls Larus spp. decreased with increasing nest abundance, whereas nest mortality by foxes Vulpes spp. and ravens Corvus corax initially increased, indicating that dietary switching may occur when nests become more abundant. Nest mortalities of specific predators were often not independent and ranged between compensatory (e.g. mammalian mesopredators) and superadditive (e.g. avian predators) across the breeding season. The non-independence between nest mortalities suggests that reductions in some predators may not translate to additive increases in overall nest success. Analyses of cause-specific mortality are rarely applied to avian nests, but examination of interacting impacts among competing predators on nest survival may provide insight into specific drivers of avian population dynamics. A free Plain Language Summary can be found within the Supporting Information of this article.

Ellison, L. N., & Cleary, L. (1978). Effects of Human Disturbance on Breeding of Double-Crested Cormorants. *The Auk*, *95*(3), 510–517. JSTOR.

In 1975 and 1976, studies of the Double-crested Cormorant were conducted in the St. Lawrence Estuary to assess the influence of investigators visiting colonies during the breeding season. Frequent visits caused nest abandonment, gull predation, and discouraged late-nesting birds from settling in disturbed experimental colonies. Late clutch commencement was more prevalent in the relatively undisturbed controls. Birds were less susceptible to disturbance in the second year of study, but for some reason other than habituation.

Emmett, R. L., & Brodeur, R. D. (2000). Recent Changes in the Pelagic Nekton Community Off Oregon and Washington in Relation to Some Physical Oceanographic Conditions. *North Pacific Anadromous Fisheries Commission Bulletin*, *2*, 11–20.

Since approximately 1977, there have been dramatic declines in West Coast salmonid (Oncorhynchus spp.) resources and salmonid marine survival. At the same time, there are indications that the pelagic nekton fauna off Oregon and Washington has shifted in species composition and abundance since the late 1970s. While Pacific hake (Merluccius productus), Pacific herring (Clupea pallasi), American shad (Alosa sapidissima), Pacific mackerel (Scomber japonicus), jack mackerel (Trachurus symmetricus), and Pacific sardine (Sardinops sagax) populations off the Northwest coast have increased in abundance since 1977, ocean survival of salmonids, and populations of northern anchovy (Engraulis mordax), eulachon (Thaleichthys pacificus), and market squid (Loligo opalescens) declined. Northwest sea surface temperatures have shown a strong warming trend since 1977. Our results suggest that salmon marine survival is affected by the interplay between biological and physical factors in the northern California Current.

Emmett, R. L., Krutzikowsky, G. K., & Bentley, P. (2006). Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998–2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. *Progress in Oceanography*, *68*(1), 1–26. https://doi.org/10.1016/j.pocean.2005.08.001

From 1998 to 2003, we observed large fluctuations in the abundance and distribution of four pelagic predatory (piscivorous) fishes off northern Oregon and southern Washington, USA. Fluctuations in predatory fish species composition and abundance were strongly linked to the date of the spring transition and to ocean temperatures. Predatory fishes, forage fishes, and juvenile salmonids had distinct spatial distributions, with predators distributed primarily offshore and forage fish and salmonids onshore, but this varied depending on ocean conditions. We suggest that predatory and forage fish distributions respond to ocean temperatures, predator/prey interactions, and possibly turbidity. A shift in ocean conditions in 1999 decreased overall predator fish abundance in the Columbia River plume, particularly for Pacific hake. Marine survival of juvenile salmon started to increase in 1999, and forage fish densities increased in 2000, lagging by one year.

Erhardt, J. M., Tiffan, K. F., & Connor, W. P. (2018). Juvenile Chinook Salmon Mortality in a Snake River Reservoir: Smallmouth Bass Predation Revisited. *Transactions of the American Fisheries Society*, *147*(2), 316–328. https://doi.org/10.1002/tafs.10026

Predation by nonnative fishes has been identified as a contributing factor in the decline of juvenile salmonids in the Columbia River basin. We examined the diet composition of Smallmouth Bass Micropterus dolomieu and estimated the consumption and predation loss of juvenile Chinook Salmon Oncorhynchus tshawytscha in Lower Granite Reservoir on the Snake River. We examined 4,852 Smallmouth Bass stomachs collected from shoreline habitats during April–September 2013–2015. Chinook Salmon were the second most commonly consumed fish by all size-classes of Smallmouth Bass (≥150 mm TL) throughout the study. Over the 3 years studied, we estimated that a total of 300,373 Chinook Salmon were consumed by Smallmouth Bass in our 22-km study area, of which 97% (291,884) were subyearlings (age 0) based on length frequency data. A majority of the loss (61%) occurred during June, which coincided with the timing of hatchery releases of subyearling fall Chinook Salmon. Compared to an earlier study, mean annual predation loss increased more than 15-fold from 2,670 Chinook Salmon during 1996–

1997 to 41,145 Chinook Salmon during 2013–2015 (in reaches that could be compared), despite lower contemporary Smallmouth Bass abundances. This increase can be explained in part by increases in Smallmouth Bass consumption rates, which paralleled increases in subyearling Chinook Salmon densities—an expected functional response by an opportunistic consumer. Smallmouth Bass are currently significant predators of subyearling Chinook Salmon in Lower Granite Reservoir and could potentially be a large source of unexplained mortality.

Errington, P. L. (1946). Predation and Vertebrate Populations. *The Quarterly Review of Biology*, *21*(2), 144–177. https://doi.org/10.1086/395220

Erwin, R. M., Truitt, B. R., & Jimenez, J. E. (2001). Ground-Nesting Waterbirds and Mammalian Carnivores in the Virginia Barrier Island Region: Running out of Options. *Journal of Coastal Research*, *17*(2), Article 2. https://journals.flvc.org/jcr/article/view/81290

We examined changing patterns of distribution of two large mammalian predators, the raccoon (Procyon lotor) and red fox (Vulpes uulpes), and beach-nesting terns and Black Skimmers iRynchops niger) along ca. 80 km of the Virginia barrier island landscape between the periods 1975-1977 and 1998. Based on evidence from trapping, scent stations, den observations and sightings of the two predators, there has been a marked increase in their island ranges. In 1975-77, only 6 of the 11 surveyed barrier islands definitely harbored at least one of the two mammals, but by 1998, 11 of 14 islands showed evidence of one or both during the spring and summer. Concurrently, annual beach-nesting bird surveys have been conducted since the mid 1970s during June. From 1977 to 1998, the number of colonies of terns [Common (Sterna hiruruloi, Gull-billed (S. nilotica), Least (S. antillarum), Royal (S. maxima), and Sandwich (S. sandvicensis)] and Black Skimmers declined from 23 colonies on 11 barrier islands to 13 colonies on 10 islands. In addition, the populations decreased dramatically for all species except the marginal Sandwich Tern and Least Tern. This pattern suggests that mammalian predation may be a major factor in colony site selection or success, although we have no data on success at most locations. The only consistently large colony over the years has been the Royal Tern colony on Fisherman Island, one of the few with no resident large mammals. Because these declining waterbirds appear to be running out of options for safe colony sites in coastal Virginia, we discuss the prospects of conducting limited predator removals on certain islands. In addition, considerations of strict management and enforcement of protection at critical manmade colony sites that now attract large numbers of certain species, are timely. Lastly, where dredged material disposal projects are planned, providing nesting sites for these colonial species and roosting sites for migrant birds may be appropriate.

Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., Carpenter, S. R., Essington, T. E., Holt, R. D., Jackson, J. B. C., Marquis, R. J., Oksanen, L., Oksanen, T., Paine, R. T., Pikitch, E. K., Ripple, W. J., Sandin, S. A., Scheffer, M., Schoener, T. W., … Wardle, D. A. (2011a). Trophic Downgrading of Planet Earth. *Science*, *333*(6040), 301–306. https://doi.org/10.1126/science.1205106

Until recently, large apex consumers were ubiquitous across the globe and had been for millions of years. The loss of these animals may be humankind's most pervasive influence on nature. Although such losses are widely viewed as an ethical and aesthetic problem, recent research reveals extensive cascading effects of their disappearance in marine, terrestrial, and freshwater ecosystems worldwide. This empirical work supports long-standing theory about the role of top-down forcing in ecosystems but also highlights the unanticipated impacts of trophic cascades on processes as diverse as the dynamics of disease, wildfire, carbon sequestration, invasive species, and biogeochemical cycles. These findings emphasize the urgent need for interdisciplinary research to forecast the effects of trophic downgrading on process, function, and resilience in global ecosystems.

Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., Carpenter, S. R., Essington, T. E., Holt, R. D., Jackson, J. B. C., Marquis, R. J., Oksanen, L., Oksanen, T., Paine, R. T., Pikitch, E. K., Ripple, W. J., Sandin, S. A., Scheffer, M., Schoener, T. W., … Wardle, D. A. (2011b). Trophic Downgrading of Planet Earth. *Science*, *333*(6040), 301–306. https://doi.org/10.1126/science.1205106

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Evans, A. F., Hostetter, N. J., Collis, K., Roby, D. D., & Loge, F. J. (2014). Relationship between Juvenile Fish Condition and Survival to Adulthood in Steelhead. *Transactions of the American Fisheries Society*, *143*(4), 899–909. https://doi.org/10.1080/00028487.2014.901248

Understanding how individual characteristics are associated with survival is important to programs aimed at recovering fish populations of conservation concern. To evaluate whether individual fish characteristics observed during the juvenile life stage were associated with the probability of returning as an adult, juvenile steelhead Oncorhynchus mykiss from two distinct population segments (DPSs; Snake River and upper Columbia River) were captured, photographed to determine external condition (body injuries, descaling, signs of disease, fin damage, and ectoparasites), measured, classified by rearing type (hatchery, wild), marked with a PIT tag, and released to continue out-migration to the Pacific Ocean during 2007–2010. The PIT tags of returning adults were interrogated in fishways at hydroelectric dams on the lower Columbia River 1–3 years following release as juveniles. Juvenile-to-adult survival models were investigated independently for each DPS and indicated that similar individual fish characteristics were important predictors of survival to adulthood for both steelhead populations. The data analysis provided strong support for survival models that included explanatory variables for fish length, rearing type, and external condition, in addition to out-migration year and timing. The probability of a juvenile surviving to adulthood was positively related to length and was higher for wild fish compared with hatchery fish. Survival was lower for juveniles with body injuries, fin damage, and external signs of disease. Models that included variables for descaling and ectoparasite infestation, however, had less support than those that incorporated measures of body injuries, fin damage, and disease. Overall, results indicated that individual fish characteristics recorded during the juvenile life stage can be used to predict adult survivorship in multiple steelhead populations.

Evans, A., Payton, Q., Cramer, B., Collis, K., Hewitt, D., & Roby, D. D. (2015). *Colonial Waterbird Predation on Lost River and Shortnose Suckers Based on Recoveries of Passive Integrated Transponder Tags* (p. 22). http://www.birdresearchnw.org/Avian%20Predation%20of%20ESA%20Suckers_Final%20Report.pdf

We evaluated predation on Lost River suckers (Deltistes luxatus) and shortnose suckers (Chasmistes brevirostris), both listed under the Endangered Species Act (ESA), from American white pelicans (Pelecanus erythrorhynchos) and double-crested cormorants (Phalacrocorax auritus) nesting at mixedspecies colonies on Clear Lake Reservoir, CA and Upper Klamath Lake, OR during 2009-2014. Predation was evaluated by recovering (detecting) passive integrated transponder (PIT) tags that were implanted in suckers, consumed by pelicans or cormorants, and subsequently deposited on the birds' nesting colony. Data from PIT tag recoveries were used to estimate predation rates (proportion of available tagged suckers consumed by birds) and to evaluate the relative susceptibility of suckers to avian predation in the Upper Klamath Basin. Data on the size of pelican and cormorant colonies (number of breeding adults) were also collected and reported in the context of sucker predation rates. Results indicate that predation rates varied by sucker species (Lost River, shortnose), sucker age-class (adult, juvenile), bird colony location (Upper Klamath Lake, Clear Lake), and year (2009-2014), demonstrating that predator-prey interactions were dynamic in the system. Tagged suckers ranging from 72 mm to 730 mm were susceptible to cormorant or pelican predation; all but the largest of the tagged Lost River suckers were susceptible to avian predation. Estimates of minimum, annual predation rates ranged from < 0.1% to 4.6% of the available Lost River suckers and from < 0.1% to 4.2% of the available shortnose suckers during the study period. Of the two colony locations evaluated, predation rates on suckers in Clear Lake were generally higher by birds nesting at mixed-species colonies on Clear Lake. Birds nesting on Clear Lake also commuted over 75 kilometers to forage on suckers in Upper Klamath Lake. Conversely, there was no evidence that birds nesting in Upper Klamath Lake foraged on tagged suckers in Clear Lake. Although sample sizes of tagged juvenile suckers were small and limited to fish tagged in Upper Klamath Lake, there was evidence that bird predation on juvenile suckers was higher than on adult suckers, with minimum predation rate estimates on juvenile suckers ranging from 5.7% to 8.4% of available fish per year. Minimum predation rates presented here suggest that avian predation may be a factor limiting recovery of populations of Lost River and shortnose suckers, particularly juvenile suckers in Upper Klamath Lake and adult suckers in Clear Lake. Additional research is needed, however, to better assess the impacts of avian predation on sucker populations in the Upper Klamath Basin by (1) recovering PIT tags in a manner so that the species of avian predator is known (i.e., pelican vs. cormorant), (2) measuring predator-specific PIT tag deposition probabilities to generate more accurate (instead of minimum) predation rate estimates, (3) increasing the sample of juvenile suckers in the population that are PIT-tagged, and (4) recovering sufficient sample sizes of PIT tags on bird colonies to describe how various biotic and abiotic factors (e.g., fish condition, water levels and quality, and other factors) contribute to sucker susceptibility to avian predation.

Evans, A., Payton, Q., Cramer, B., Collis, K., Hostetter, N. J., & Roby, D. D. (2019). *System-wide effects of avian predation on the survival of Upper Columbia River steelhead: Implications for*

predator management (p. 71). http://www.birdresearchnw.org/project-info/publications-&-reports/unpublished-reports/

Predator-prey interactions involving piscivorous colonial waterbirds and anadromous juvenile salmonids (Oncorhynchus spp.) have been the subject of numerous research, monitoring, and evaluation studies in the Columbia River basin. Previous research has identified predation by Caspian terns (Hydroprogne caspia), double-crested cormorants (Phalacrocorax auritus), California gulls (Larus californicus), and ring-billed gulls (L. delawarensis) as a significant mortality factor for some salmonid populations during smolt outmigration to the Pacific Ocean. This previous work was largely focused on quantifying the impacts of piscivorous birds from specific nesting colonies on smolt mortality, but some salmonid populations, like the Endangered Species Act (ESA)-listed Upper Columbia River (UCR) steelhead trout (O. mykiss), must migrate through the foraging ranges of breeding birds from multiple colonies during outmigration. The system-wide, cumulative impacts of piscivorous colonial waterbirds on smolt survival are largely unknown. Juvenile salmonids are also subject to numerous other non-avian sources of mortality during outmigration (e.g., hydroelectric dam passage, predation by piscivorous fish, disease, and other factors) and determining to what extent avian predation limits fish survival relative to these other sources of mortality is critical for prioritizing recovery actions for ESA-listed salmonid populations in the region. To address concerns over Caspian tern predation on juvenile salmonids, management plans have been implemented to reduce the size or eliminate the largest Caspian tern nesting colonies in the Columbia River basin. A critical but unanswered question regarding management is whether mortality due to avian predation is an additive or compensatory source of smolt mortality. For instance, would reductions in predation rates on steelhead smolts by Caspian terns result in higher rates of smolt survival (i.e. tern predation adds to smolt mortality) or are smolts that are consumed by terns destined to die during outmigration or before returning as adults regardless of tern predation (i.e. tern predation is compensated for by other sources of mortality)? If the latter is true, efforts to reduce Caspian tern predation rates by reducing the size of nesting colonies in the Columbia River basin would have little effect on fish survival. Conversely, if terns are consuming smolts that would otherwise survive outmigration and return as adults to spawn, then reductions in tern predation rates due to avian predation management actions may be an important component in efforts to recover ESA-listed salmonid populations in the Columbia River basin. As part of a multi-year, system-wide study of avian predation funded by Grant County Public Utility District and the Priest Rapids Coordinating Committee, we investigated the cumulative effects of avian predation on the survival of UCR steelhead smolts and estimated what proportion of total mortality (1-survival) was due to avian predation during smolt outmigration. We also investigated to what degree predation by Caspian terns, a managed colonial waterbird species, was an additive versus compensatory source of steelhead mortality and whether avian predation management actions that have been implemented to-date have been successful at reducing predation on UCR steelhead smolts. These two objectives are addressed in two separate, but related, chapters entitled “Cumulative Effects of Avian Predation on Upper Columbia River Steelhead” and “Additive Effects of Caspian Tern Predation on the Survival of Upper Columbia River Steelhead: Implications for Predator Management.”

Evans, A., Payton, Q., Cramer, B., Collis, K., Lyons, D., & Loschl, P. (2016). *Predation Impacts on Juvenile Salmonids by Double-crested Cormorants and Caspian Terns Nesting on East Sand*

Island in the Columbia River Estuary, 2015 (p. 66). http://www.birdresearchnw.org/2015%20ESI%20PIT%20Recovery%20FINAL%20Report.pdf

As a component of a comprehensive strategy for salmonid (Oncorhynchus spp.) recovery in the Columbia River Basin, management plans have been developed to reduce the impacts of double-crested cormorants (Phalacrocorax auritus) and Caspian terns (Hydroprogne caspia) nesting on East Sand Island on the survival of juvenile salmonids listed under the Endangered Species Act (ESA). Management initiatives are currently being implemented to reduce the size of the East Sand Island colonies through primarily lethal strategies (i.e., culling and egg oiling) for double-crested cormorants and dispersal of nesting birds to areas outside the Columbia River Basin for Caspian terns. The primary goal of this study was to estimate predation rates (percentage of available tagged fish consumed by birds) based on recoveries of passive integrated transponder (PIT) tags implanted in juvenile salmonids on the double-crested cormorant and Caspian tern colonies on East Sand Island. More specifically, the objective was to generate population-specific (salmonid evolutionary significant units [ESU] or distinct population segments [DPS]) predation rates on ESA-listed juvenile salmonids from the Columbia River Basin. Predation rate estimates generated as part of this study integrated multiple factors of uncertainty in the tag recovery process, including imperfect detection of PIT tags on bird colonies, on-colony PIT-tag deposition probabilities, and temporal changes in fish availability to predators nesting on East Sand Island. Predation rates were used to compare and contrast impacts within a given fish population based on the fish's rear-type (hatchery, wild) and migration history (in-river, transported). Predation rates were also used to compare and contrast smolt losses prior to and following bird management actions on East Sand Island; data critical in evaluating the effectiveness of management plans aimed at reducing predation rates. We also evaluated the relationship between predation rates and various biotic and abiotic conditions in the estuary that have potentially influenced these rates during 2000-2015. The goal of this analysis was to describe the influence of "management relevant" variables on predation rates, variables that resource managers may be able to control to some degree. Predation rates indicated that impacts by double-crested cormorants on ESA-listed juvenile salmonids in 2015 were some of the highest ever recorded, with estimates of 14.5% (95% creditable interval [CI] = 10.5–22.4%) and 12.8% (95% CI = 9.3–19.6%) for Snake River spring/summer Chinook salmon (O. tshawytscha) and Snake River steelhead (O. mykiss), respectively. Impacts on salmon ESUs were comparable to those of steelhead DPSs in 2015, although the lowest rates were observed on two salmon populations (Snake River sockeye salmon O. nerka and upper Willamette River spring Chinook salmon, with < 2.5% of available fish consumed by cormorants in 2015). An investigation of temporal trends in predation rates indicated that double-crested cormorants consumed smolts in proportion to their relative availability, with the highest predation rates observed in May, when the largest numbers of PITtagged fish were available in the estuary. An investigation of predation rates dating back to 2000 indicated that smolt losses to double-crested cormorants were substantial in most years but highly variable over time. For example, annual predation rates by East Sand Island double- 2 crested cormorants on Snake River steelhead have ranged from 1.9–16.6% for that particular DPS during 2000-2015. In comparison to smolt losses by double-crested cormorants, results indicated that Brandt's cormorants (Phalacrocorax penicillatus) nesting on East Sand Island posed little risk to smolt survival in the estuary, with predation rates ≤ 0.6% for each salmonid ESU/DPS evaluated in 2015. Despite a steady increase in the size of the Brandt's colony since it was first established on East Sand Island in 2006, predation rate estimates have remained below 1.0% for each salmonid ESU/DPS in all years. Predation rates indicated that impacts by Caspian terns nesting on East Sand Island on ESAlisted juvenile salmonids were generally lower in 2015 compared with years past, with estimates ranging from 0.4% (95% CI = 0.1–1.5%) to 10.5% (95% CI = 8.2–15.0%) in Upper Willamette River spring Chinook and Upper Columbia River steelhead, respectively. Of those ESUs/DPSs evaluated, steelhead DPSs were predated at significantly higher rates than salmon ESUs. For instance, predation rates were 10.2% (95% CI = 8.2–14.6%) for Snake River steelhead but just 0.8% (95% CI = 0.2–1.5%) for Snake River fall Chinook in 2015. The finding that Caspian terns disproportionately consumed steelhead DPSs compared with salmon ESUs has been consistent since research was initiated on East Sand Island Caspian tern colony in 2000. Contrary to temporal results from double-crested cormorants, Caspian tern predation rates were the lowest when PIT-tagged smolt availability in the estuary was the highest; a finding consistent with predator-swamping, whereby an individual fish's susceptibility to tern predation decreases when larger numbers of fish were available in the estuary. If management is successful in significantly reducing the number of double-crested cormorants and Caspian terns that reside in the Columbia River Estuary during the spring/summer smolt outmigration, it is expected that there will be a commensurate reduction in smolt mortality. In 2015, the first year of double-crested cormorant management in the Columbia River Estuary, actions to reduce the number of double-crested cormorants nesting on East Sand Island were implemented after the peak of the smolt outmigration period. The percent of adult cormorants culled (ca. < 1% of adults) was also not large enough to have an effect in reducing cormorant predation. There was some evidence that management efforts to reduce the number of Caspian terns nesting on East Sand Island are associated with lower predation rates on ESAlisted salmonid populations. For instance, predation rates by East Sand Island terns on Upper Columbia River steelhead averaged 17.2% (95% CI = 15.7–19.3%) during 2000-2010, but were 9.9% (95% CI = 8.5–12.0%) during 2011-2015, associated in part with reductions in colony size due to tern nesting habitat restrictions on East Sand Island during the latter period. Despite the apparent reductions in Caspian tern predation associated with management, the target colony size for Caspian terns in the Columbia River Estuary has not been met, so the gains in survival of ESA-listed juvenile salmonids associated Caspian tern management have not been fully realized. A relative comparison of predation impacts based on the fish's rearing-type (hatchery, wild) indicated that hatchery and wild fish were equally susceptible to double-crested cormorant predation in the Columbia River estuary, with no consistent predation trend or preference by rear-type identified during 2006-2015. Unlike cormorants, there was evidence that Caspian 3 terns disproportionately consumed hatchery spring/summer Chinook salmon compared with their wild counterparts during 2006-2015. Comparisons of predation impacts by a fish's migration history (in-river, transported) also indicated differences in the relative susceptibility of smolts to bird predation, with transported Snake River fall Chinook and transported Snake River sockeye salmon disproportionately consumed by double-crested cormorants compared with in-river migrants during 2006-2015. There was also some evidence that in-river steelhead and in-river spring/summer Chinook were disproportionately consumed by Caspian terns and double-crested cormorants compared with transported fish but results were not consistent across all weeks and years. Data from this and other studies suggest the difference in fish susceptibility to bird predation is related to several behavioral and physical traits, including the size and condition of fish, the run-timing of fish, the abundance of fish, and predator-specific foraging techniques and behaviors. Additional research is needed to better understand these factors and how (or if) these factors can be managed to decrease predation rates on juvenile salmonids by double-crested cormorants and Caspian terns

in the Columbia River estuary. An evaluation of predation impacts from both double-crested cormorants and Caspian terns (i.e., cumulative predation rates) indicated that birds nesting on East Sand Island have annually consumed between 1.5–16.5% of available salmon per ESUs and between 12.0–40.6% of available steelhead per DPS during 2000-2015. Losses were comparable to or greater than those of other documented sources of smolt mortality (e.g., dam passage, predation by piscine predators) in the Columbia River Basin. Furthermore, impacts from bird predation in the estuary are on juvenile salmonids that have survived freshwater outmigration, including passage through the Federal Columbia River Power System, fish that have a higher probability of surviving than those that have yet to complete outmigration. Additionally, juvenile salmonids belonging to every ESA-listed ESU/DPS from the Columbia River Basin must pass through the Columbia River Estuary and are therefore susceptible to predation by birds nesting on East Sand Island. Despite recent reductions in the numbers of Caspian terns nesting on East Sand Island and predation rates by these birds on juvenile salmonids, the total number of birds (terns and cormorants combined) nesting on East Sand Island has remained fairly constant since 2000, as have average annual predation rates at the level of steelhead DPS and salmon ESU. A multivariate analysis of factors influencing predation rates indicated that colony size was just one of several factors that explained variation in predation rates by Caspian terns and doublecrested cormorants nesting on East Sand Island during 2000-2015. Fluctuations in large-scale climate indices (Multivariate El-Nino Index, North Pacific Gyre Oscillation), river operational strategies (spill, discharge), smolt abundance, and other factors were also important variables; demonstrating that a fish's susceptibility to bird predation in the estuary is determined by a complex set of interacting factors. Results suggest that reductions in colony size will have to be both large and sustained before management goals to reduce avian predation can be fully realized in the Columbia River estuary.

Evans, A., Payton, Q., Cramer, B., Collis, K., & Tennyson, J. (2018). *East Sand Island Passive Integrated Transponder Tag Recovery and Avian Predation Rate Analysis, 2018* (p. 50). http://www.birdresearchnw.org/2018%20ESI%20PIT%20Recovery%20Final%20Report.pdf

To address concerns of avian predation on Endangered Species Act (ESA) listed juvenile salmonids (Oncorhynchus spp.) in the Columbia River Estuary, management plans have been developed to reduce the number of Caspian terns (Hydroprogne caspia) and double-crested cormorants (Phalacrocorax auritus) nesting on East Sand Island. The primary goal of this study was to provide the U.S. Army Corps of Engineers (USACE) and other regional stakeholders with information to evaluate the effectiveness of management plans in reducing predation rates (percentage of available fish consumed) on ESA-listed juvenile salmonids by terns and cormorants nesting on East Sand Island in 2018. The primary tasks were to (1) recover juvenile salmonid passive integrated transponder (PIT) tags from the tern and cormorant colonies on East Sand Island and (2) use those data to model predation rates. More specifically, we generated population-specific (salmonid evolutionary significant units [ESU] or distinct population segments [DPS]) predation rates on juvenile salmonids that integrated multiple factors of uncertainty in the tag recovery process, including imperfect detection of tags on bird colonies, on-colony tag deposition probabilities that varied by bird species (tern, cormorant), and temporal changes in fish availability to avian predators nesting on East Sand Island. To ensure relative comparability of predation rate results collected in 2018 to years past, we use the tag recovery and analytical methods of Evans et al. (2012) and Hostetter et al. (2015), previously peer-reviewed methods that allow for direct comparisons of predation rates among predator species,

salmonid ESUs/DPSs, and years. To facilitate the review of data collected in 2018 relative to previous years, the organization and general content of this report is similar to that of past reports (see Evans et al. 2016a, Evans et al. 2018). PIT Tag Recovery Following the 2018 nesting season, a total of 10,886 and 2,680 PIT tags from 2018 migration year smolts (Chinook salmon [O. tshawytscha], coho salmon [O. kisutch], sockeye salmon [O. nerka], and steelhead trout [O. mykiss] tags combined) were recovered on the East Sand Island Caspian tern and doublecrested cormorant colonies, respectively. PIT tags were detected by systematically scanning the entire area (referred to as a "pass") occupied by nesting birds during the breeding season, with a total of five passes conducted on the tern colony and four passes on the cormorant colony. Average annual detection efficiency (proportion of deposited tags detected by researchers after the breeding season) was estimated at 77% (seasonal range = 57–97%) on the tern colony and 88% (seasonal range = 76– 100%) on the cormorant colony, amongst the highest rates of detection ever recorded on East Sand Island. All newly detected PIT tags recovered on the tern and cormorant colonies were uploaded to the PIT Tag Information System (PTAGIS) on 2 December 2018, so that the data was readily available to other researchers, managers, and the general public. Predation Rates Caspian terns – Predation rates on juvenile salmonids by Caspian terns nesting on East Sand Island in 2018 were amongst the lowest ever recorded, with rates on most ESA-listed ESUs/DPSs significantly lower than in years past. Predation rates on salmon ESUs in 2018 ranged from 1.3% (95% credible interval [CRI] = 0.7–2.1%) on Snake River Fall Chinook to 4.2% (95% CRI = 2.9–6.4%) on Snake River sockeye. Predation rates on steelhead DPSs in 2018 ranged from 5.3% (95% CRI = 3.8–8.0%) on Middle Columbia River steelhead to 6.9% (95% CRI = 5.3–10.2%) on Snake River steelhead. By comparison, predation rates averaged 14.9% (95% CRI = 13.1–17.6%) and 22.2% (95% CRI = 20.3–24.8%) for Middle and Snake River steelhead DPSs, respectively, prior to reductions in the size of the tern colony on East Sand Island associated with management. Reductions in Caspian tern predation rates in 2018 were commensurate with reductions in tern colony size, indicating that tern management actions to reduce the number of terns on East Sand Island are resulting in lower rates of predation on juvenile salmonids by this colony. The East Sand Island colony has been reduced from an average of 9,221 breeding pairs (range = 8,283–10,668 pairs) prior to management (2000-2010) to 5,957 breeding pairs (annual range = 3,500–7,387 pairs) following management (2011-2018). The 2018 colony size of 4,959 breeding pairs is approaching, but has not reached, the target colony size goal of 3,125 breeding pairs (USFWS 2005). More importantly from a fish conservation perspective, predation rates on salmonid ESUs/DPSs by East Sand Island Caspian terns are now significantly lower than those observed prior to management, with an approximately one-half reduction in steelhead predation rates observed since management was implemented and approaching the two-thirds reduction stated in the tern management plan (USFWS 2005). One unintended consequence of Caspian tern management actions on East Sand Island has been the large number of terns (several hundred to several thousand) that have attempted to nest on Rice Island in the upper Columbia River Estuary, birds presumably displaced from East Sand Island as a result of management. The impact on smolts from terns that have attempted but were prevented from nesting on Rice Island partially off-set, to an unknown degree, reductions in predation rates by terns nesting on East Sand Island. To fully evaluate the efficacy of the Caspian Tern Management Plan for reducing predation rates on ESA-listed smolts throughout the Columbia River Estuary, an investigation of cumulative predation rates by all Caspian terns – those on East Sand Island and Rice Island – in the estuary would be necessary but was beyond the scope of this study. An investigation of East Sand Island Caspian tern predation rates based on a fish's ESU/DPS, rear-type (hatchery, wild), outmigration history (in-river, transported), and abundance (density) indicated that multiple factors influence smolt susceptibility to tern predation. A relative comparison of predation impacts from 2018 and from years past (2006-2017) indicated that predation rates on steelhead DPSs were significantly higher than those of salmon ESUs. There was also evidence that hatchery spring Chinook salmon from both the Upper Columbia River and Snake River ESUs were more susceptible to tern predation than their wild counterparts, while there were no statistically credible differences in susceptibility by rear-type (wild, hatchery) for steelhead DPSs. There was some evidence that fish with an in-river migration history were more susceptible to Caspian tern predation on East Sand Island than those that were transported, although differences in susceptibility between in-river and transported fish were generally small and inconsistent across the study period. Weekly differences in smolt susceptibility based on the relative abundance of PIT-tagged smolts in the estuary were also observed, with tern predation rates generally decreasing as the number of steelhead smolts in the estuary increased. Double-crested cormorants – ESU/DPS-specific predation rates by double-crested cormorants in 2018 were amongst the lowest ever recorded on East Sand Island, ranging from just 0.4% (95% CRI = 0.1– 1.0%) of Middle Columbia River steelhead to 0.9% (95% CRI = 0.5–1.9%) of Snake River sockeye. The relatively small colony (3,672 nesting pairs), coupled with a late or right-shifted nesting chronology for East Sand Island cormorants in 2018, explained the record low rates of predation observed in 2018. Predation rates in 2018 were significantly lower than those observed prior to management actions for all ESUs/DPSs evaluated. For instance, prior to management, predation rates on Snake River spring/summer Chinook salmon and Snake River steelhead averaged 5.2% (95% CRI = 4.4–1.9%) and 9.3% (95% CRI = 8.0–11.0%), respectively, during 2003-2015. The East Sand Island cormorant colony has been reduced from an average of 12,744 breeding pairs (range = 10,646–14,916 pairs) prior to management actions that reduced peak colony size (2003-2015) to 4,663 breeding pairs (annual range = 544–9,771 pairs) following management actions that reduce peak colony size (2016-2018). The goal of the Double-crested Cormorant Management Plan was to reduce the peak size of the East Sand Island colony to no more than approximately 5,600 nesting pairs, and to limit steelhead predation rates to approximately 3% or less per DPS (USACE 2015), goals that were achieved in 2018. Prior to 2016, when the management plan was first implemented, the vast majority of double-crested cormorants in the Columbia River Estuary nested on East Sand Island, allowing for a holistic evaluation of predation rates based on recoveries of smolt PIT tags at just that single colony. Starting in 2016, however, cormorants have not successfully established a nesting colony on East Sand Island throughout the entire peak of the smolt outmigration period (April to June). Instead, large numbers of birds have dispersed from East Sand Island to other locations, some of which are within the Columbia River Estuary (e.g., Astoria-Megler Bridge). As such, analogous to the presence of Caspian terns on Rice Island, future predation rate monitoring and evaluation studies may need to consider the cumulative impact of all cormorants in the estuary – those on East Sand Island and the Astoria-Megler Bridge – on smolts to fully evaluate the efficacy of management plans to reduce predation rates on ESA-listed salmonid ESUs/DPSs. A multiyear (2006-2018) investigation of East Sand Island double-crested cormorant predation impacts indicated significant annual variation in predation rates, with differences in predation rates often greater between years within the same ESU/DPS than differences between ESUs/DPSs in the same year. An investigation of smolt abundance and predation rates indicated that, unlike Caspian terns, predation rates increased as the number of prey available in the Columbia River Estuary increased. Also, unlike

Caspian terns, there was no consistent evidence that hatchery fish or in-river migrants were more or less susceptible to cormorant predation, suggesting that cormorants indiscriminately consumed juvenile salmonids in the estuary. Collectively, result suggest that a different suite of mechanisms may regulate juvenile salmonid susceptibly to double-crested cormorant predation compared with Caspian tern predation. Taken together, results indicate that predator-prey interactions in the Columbia River Estuary are dynamic and that multiple factors were associated with variation in avian predation rates on juvenile salmonids.

Evans, A., Payton, Q., Cramer, B., Collis, K., Tennyson, J., Loschl, P., & Lyons, D. (2017). *East Sand Island Passive Integrated Transponder Tag Recovery and Avian Predation Rate Analysis, 2017* (p. 43). http://www.birdresearchnw.org/2017%20ESI%20PIT%20Recovery_%20Final%20Reportv2.pdf

To address concerns of avian predation on Endangered Species Act (ESA) listed juvenile salmonids Oncorhynchus spp. in the Columbia River Estuary, management plans have been developed to reduce the number of Caspian terns Hydroprogne caspia and double-crested cormorants Phalacrocorax auritus nesting on East Sand Island (USFWS 2005; USACE 2015). The primary goal of work described herein was to provide the U.S. Army Corps of Engineers (USACE) with information to evaluate the effectiveness of these management plans in reducing predation rates (percentage of available fish consumed) on juvenile salmonids by terns and cormorants nesting on East Sand Island in 2017. The primary tasks were to (1) recover juvenile salmonid passive integrated transponder (PIT) tags from the tern and cormorant colonies on East Sand Island and (2) use those data to model predation rates on juvenile salmonids. More specifically, we generated population-specific (salmonid evolutionary significant units [ESU] or distinct population segments [DPS]) predation rates on ESA-listed juvenile salmonids that integrated multiple factors of uncertainty in the tag recovery process, including imperfect detection of tags on bird colonies, on-colony tag deposition probabilities that varied by bird species (tern, cormorant), and temporal changes in fish availability to avian predators nesting on East Sand Island in 2017. Predation rates from 2017 were then compared with smolt losses prior to reductions in colony size (number of nesting pairs) due to bird management actions on East Sand Island in years past. Predation rates were further evaluated based on the run-timing, abundance, rear-type (hatchery, wild), and outmigration history (in-river, transported) of each salmonid ESU/DPS, factors previously linked to variation in predation rates. To ensure relative comparability of predation rate results collected in 2017 to years past, we use the tag recovery and analytical methods Evans et al. (2012) and Hostetter et al. (2015), previously peer-reviewed methods that allow for direct comparisons of predation rates among predator species, salmonid ESUs/DPSs, and years. PIT Tag Recovery Following the nesting season, a total of 8,407 and 1,340 PIT tags from 2017 migration year smolts (Chinook salmon O. tshawytscha, coho salmon O. kisutch, sockeye salmon O. nerka, and steelhead trout O. mykiss tags combined) were recovered on the East Sand Island Caspian tern and double-crested cormorant colonies, respectively. PIT tags were detected by systematically scanning the entire area (referred to as a "pass") occupied by nesting birds during the breeding season, with a total of six passes conducted on the tern colony and three passes on the cormorant colony. Detection efficiency (proportion of deposited tags detected by researchers after the breeding season) was estimated at 73% (range = 40–88%) and 71% (range = 60–78%) on the tern and cormorant colonies, respectively. All newly detected PIT tags recovered on East Sand Island bird colonies were uploaded to the PIT Tag Information System (PTAGIS) on 18 December 2017, making the data readily available to other researchers, managers, and the public alike. Predation Rates Caspian terns – ESU/DPS-specific predation rates by Caspian terns nesting on East Sand Island in 2017 were some of the lowest ever recorded. Predation rates on salmon ESUs ranged from 0.2% (95% credible interval [CRI] = 0.1–0.5%) on Snake River Fall Chinook to 1.4% (95% CRI = 0.9–2.3%) on Upper Columbia River spring Chinook. By comparison, predation rates averaged 2.5% (95% CRI = 2.2–3.0%) and 3.9% (95% CRI = 3.4–4.6%) on Snake River Fall and Upper Columbia River spring Chinook, respectively, prior to reductions in the size of the tern colony on East Sand Island due to management actions. Predation rates on steelhead DPSs in 2017 ranged from 5.3% (95% CRI = 3.9–7.7%) on Snake River steelhead to 8.4% (95% CRI = 5.6–13.1%) on Middle Columbia River steelhead. By comparison, predation rates average of 22.2% (95% CRI = 20.3–24.8%) and 14.9% (95% CRI = 13.1–17.6%) for Snake and Middle Columbia River steelhead DPSs, respectively, prior to reductions in the size of the tern colony on East Sand Island due to management actions. Reductions in tern predation rates were commensurate with reductions in tern colony size, indicating that Caspian tern management actions to reduce numbers of terns on East Sand Island are resulting in lower average annual predation rates on juvenile salmonids by this colony. An investigation of predation rates in 2017 and years past (2006-2016) based on a fish's ESU/DPS, reartype (hatchery, wild), outmigration history (in-river, transported), and abundance (density) indicated that multiple factors influence smolt susceptibility to Caspian tern predation. A relative comparison of impacts indicated that predation rates on steelhead DPSs were significantly higher than those of salmon ESUs. There was also evidence that hatchery spring/summer Chinook salmon were more susceptible to tern predation than their wild counterparts, although no statistically credible differences in susceptibility by rear-type were observed amongst steelhead DPSs. Weekly differences in smolt susceptibility based on the relative abundance of tagged smolts in the estuary were also observed, with tern predation rates decreasing as the number of steelhead smolts in the estuary increased. Taken together, results indicate that predator-prey interactions in the Columbia River Estuary were dynamic and that multiple factors are associated with variation in East Sand Island Caspian tern predation rates on juvenile salmonids. In addition to the established Caspian tern colony on East Sand Island, where 3,500 nesting pairs were counted in 2017, Caspian terns also attempted to nest on Rice Island in the upper Columbia River Estuary in 2017. Nesting attempts on Rice Island were unsuccessful, but upwards of 1,000 pairs attempted to nests during the breeding season. The impact on smolts from birds that attempted but failed to successfully nest on Rice Island likely off-set, to an unknown degree, the record low rates of predation by terns that successfully nested on East Sand Island in 2017. Thus, to fully evaluate the efficacy of the Tern Management Plan for reducing predation rates on ESA-listed smolts throughout the Columbia River Estuary, an investigation of cumulative predation rates by all Caspian terns – those on East Sand Island and Rice Island – in the estuary is necessary, but was beyond the scope of this study. Double-crested cormorants – Prior to 2016, the vast majority of double-crested cormorants in the Columbia River Estuary nested on East Sand Island, allowing for a holistic evaluation of predation rates based on recoveries of smolt PIT tags at just that single colony. In 2017, however, cormorants did not establish a nesting colony on East Sand Island during the peak smolt outmigration period of April to June, but rather dispersed from East Sand Island to other locations. A similar colony dispersal event occurred on East Sand Island in 2016. Rather than completely dispersing to colony sites outside of the Columbia River Estuary, large numbers of cormorants (at least 7,000 adults) remained in the estuary and continued to forage on juvenile salmonids to an unknown degree. As such, estimates of predation rates based on numbers of PIT-tags deposited by cormorants on East Sand Island in 2017 are minimum estimates and are not representative of smolt losses by all cormorants that remained in the Columbia River Estuary during the smolt outmigration period. Predation rate estimates associated with double-crested cormorants which briefly attempted to nest on East Sand Island during the smolt outmigration period in 2017 ranged from 0.1% (95% CRI = 0–4.2%) of Snake River Fall Chinook to 1.4% (95% CRI = 0.8–2.7%) of Upper Columbia River steelhead. Insufficient sample sizes limited our ability investigate the relative susceptibility of fish to cormorant predation based on the fish's ESU/DPS, rear-type (hatchery, wild), outmigration history (in-river, transported), and abundance in 2017. Data from previous studies indicated that, unlike Caspian terns, East Sand Island double-crested cormorant predation rates were more similar between steelhead DPSs and salmon ESUs. Results also indicated that double-crested cormorants consumed smolts in proportion to their availability, with the highest predation rates observed when the largest numbers of PIT-tagged fish were available as prey in the estuary. Double-crested cormorants also showed little or no preference for fish based on their rear-type (hatchery, wild) or outmigration history (in-river, transport), indicating all smolts were equally susceptible to predation. Due to the lack of cormorants on East Sand Island during the peak smolt outmigration period in 2016 and 2017, a relative comparison of predation rates prior to and following management actions could not be conducted as part of this study. An analysis of predation rates during 2003-2015 indicated that smolt losses to East Sand Island double-crested cormorants were substantial in most years, but also highly variable over time. For example, predation rate estimates by East Sand Island double-crested cormorants on Snake River steelhead ranged annually from 1.9% (95% CRI = 1.2–3.0%) to 16.6% (95% CRI = 12.0–25.7%) during 2003-2015 (years when normal nesting behavior on East Sand Island occurred). Analogous to the presence of Caspian terns on Rice Island, given the presence of large number of double-crested cormorants at sites other than East Sand Island in the estuary, future predation rate monitoring and evaluation studies may need to consider the cumulative impact of all cormorants in the estuary on ESA-listed smolts to fully evaluate the efficacy of management plans to reduce predation rates.

Evans, A., Payton, Q., Turecek, A., Cramer, B., Collis, K., Roby, D., Loschl, P., Sullivan, L., Weiland, M., Skalski, J., & Townsend, R. (2015). *Avian predation on juvenile salmonids in the Columbia River: A spatial and temporal analysis of impacts in relation to fish survival* (p. 43). http://www.birdresearchnw.org/Evans%20et%20al%202015_Avian%20Predation%20on%20AT%20smolts%20_Final%20Report.pdf

To address concerns over the impact of avian predation on juvenile salmonids in the Columbia River Basin, we evaluated predation probabilities on steelhead, yearling Chinook salmon, and subyearling Chinook salmon by piscivorous birds from 11 different breeding colonies. Salmonid smolts were tagged and released as part of survival studies using the Juvenile Salmonid Acoustic Telemetry System, a network of hydrophones that provided detections of acoustic-tagged fish at various spatial and temporal scales during seaward migration. Fish were released and tracked during passage through a 251 kilometer (km) section of the lower Snake River and lower Columbia River in 2012, a 192 km section of the lower Columbia River in 2014, and a 184 km section of the middle Columbia River during 2014. Detections of tagged smolts at telemetry arrays, coupled with the recovery of tags on nearby bird colonies, were used to quantify where avian predation occurred, when it occurred, and the cumulative impact of predation by colonial waterbirds on the survival of tagged fish. Results were also used to estimate unaccounted for smolt mortality (total smolt mortality – mortality due to colonial waterbirds), which was due in part to factors other than bird predation (e.g., piscine predation, mortality during dam passage, and other non-avian mortality factors). Impacts of avian predation on survival of tagged smolts varied by fish species/age-class, species of avian predator (i.e., Caspian tern, double-crested cormorant, American white pelican, California gull, ring-billed gull), colony location, river reach, week, and year, demonstrating that predator-prey interactions were dynamic at both spatial and temporal scales. Results indicated that avian predation was a substantial source of smolt mortality, especially for steelhead, with reach-specific predation probabilities or rates of 5.5%, 10.9%, and 27.7% of the available tagged fish released into sections of the middle Columbia River, lower Columbia River, and lower Snake River, respectively. For yearling Chinook salmon, predation by colonial waterbirds was lower than juvenile steelhead, with corresponding reach-specific predation rates of 2.8%, 5.8%, and 9.1% of the available tagged fish. For subyearling Chinook salmon, predation by colonial waterbirds was the lowest among the three species/age-classes evaluated in this study (less than 5.3% of available tagged fish in all three reaches studied). An investigation of predation hotspots indicated higher probabilities of avian predation on smolts near dams on the lower Columbia River and on smolts in the lower Snake River near its confluence with the Columbia River. In general, California and ring-billed gulls disproportionately consumed smolts near dams, while Caspian terns disproportionately consumed smolts in the reservoirs. No clear predation hotspots were evident for colonies of American white pelicans or double-crested cormorants, with the exception that cormorants disproportionately preyed on tagged smolts in the lower Snake River relative to the lower Columbia River. A comparison of smolt mortality due to colonial waterbird predation with total smolt mortality (1- survival) indicated that in some cases avian predation was one of the greatest, if not the single greatest, sources of mortality affecting survival of steelhead and yearling Chinook salmon during out-migration. Colonial waterbird predation on subyearling Chinook salmon, however, was generally low and a minor component of total smolt mortality, suggesting that factors other than bird predation (e.g., piscine predation) were responsible for the high mortality of subyearling Chinook salmon during out-migration in 2012 and 2014.

Evans, Allen F., Hewitt, D. A., Payton, Q., Cramer, B. M., Collis, K., & Roby, D. D. (2016). Colonial Waterbird Predation on Lost River and Shortnose Suckers in the Upper Klamath Basin. *North American Journal of Fisheries Management*, *36*(6), 1254–1268. https://doi.org/10.1080/02755947.2016.1208123

We evaluated predation on Lost River Suckers Deltistes luxatus and Shortnose Suckers Chasmistes brevirostris by American white pelicans Pelecanus erythrorhynchos and double-crested cormorants Phalacrocorax auritus nesting at mixed-species colonies in the Upper Klamath Basin of Oregon and California during 2009–2014. Predation was evaluated by recovering (detecting) PIT tags from tagged fish on bird colonies and calculating minimum predation rates, as the percentage of available suckers consumed, adjusted for PIT tag detection probabilities but not deposition probabilities (i.e., probability an egested tag was deposited on- or off-colony). Results indicate that impacts of avian predation varied by sucker species, age-class (adult, juvenile), bird colony location, and year, demonstrating dynamic predator–prey interactions. Tagged suckers ranging in size from 72 to 730 mm were susceptible to cormorant or pelican predation; all but the largest Lost River Suckers were susceptible to bird predation. Minimum predation rate estimates ranged annually from <0.1% to 4.6% of the available PIT-tagged Lost River Suckers and from <0.1% to 4.2% of the available Shortnose Suckers, and predation rates were consistently higher on suckers in Clear Lake Reservoir, California, than on suckers in Upper Klamath Lake, Oregon.

There was evidence that bird predation on juvenile suckers (species unknown) in Upper Klamath Lake was higher than on adult suckers in Upper Klamath Lake, where minimum predation rates ranged annually from 5.7% to 8.4% of available juveniles. Results suggest that avian predation is a factor limiting the recovery of populations of Lost River and Shortnose suckers, particularly juvenile suckers in Upper Klamath Lake and adult suckers in Clear Lake Reservoir. Additional research is needed to measure predator-specific PIT tag deposition probabilities (which, based on other published studies, could increase predation rates presented herein by a factor of roughly 2.0) and to better understand biotic and abiotic factors that regulate sucker susceptibility to bird predation.

Evans, Allen F., Hostetter, N. J., & Collis, K. (2013). *Caspian Tern Predation on Upper Columbia River Steelhead in the Priest Rapids Project: A Retrospective Analysis of Data from 2008 - 2010* (p. 31). http://www.birdresearchnw.org/Evans%20et%20al%202013_GPUD%20Final%20Avian%20Predation%202008%20to%202010.pdf

We evaluated avian predation of juvenile steelhead Oncorhynchus mykiss tagged (acoustic transmitter and passive integrated transponder) as part of behavioral and survival studies in the Priest Rapids Project (Wanapum and Priest Rapids dams and reservoirs) owned and operated by Public Utility District No. 2 of Grant County. Steelhead were tagged and released into the tailraces of Rock Island (n = 2,094), Wanapum (n = 1,925) and Priest Rapids (n = 1,905) dams, with avian predation rates calculated based on the percentage of tags deposited by birds on their nesting colonies during 2008-2010. The analysis focused on predation by a colony of Caspian terns Hydroprogne caspia nesting on Goose Island in Potholes Reservoir, WA. Results demonstrated that Caspian tern predation was a substantial source of mortality, with terns nesting on Goose Island in Potholes Reservoir annually consuming 12.8% (95% confidence interval [c.i.] = 8.8 - 17.1), 20.8% (95% c.i. = 15.0 - 27.8) and 15.1% (95% c.i. = 10.4 - 20.7) of steelhead released into the tailrace of Rock Island Dam during 2008, 2009, and 2010, respectively. The majority of this predation (range = 56-73%) occurred within the Priest Rapids Project, with Project predation rates of 8.5% (95% c.i. = 5.3 - 12.0), 15.1% (95% c.i. = 10.0 - 21.1), and 8.4% (95% c.i. = 5.1 - 12.7) during 2008, 2009, and 2010, respectively. Reservoir-specific predation rates ranged from a low 4.0% (95% c.i. = 1.6 - 6.9) in the Priest Rapids Reservoir in 2010 to a high of 10.0% (95% c.i. = 6.2 - 14.6) in the Wanapum Reservoir in 2009. A positive association between the size of the Goose Island Caspian tern colony and steelhead predation rates was observed, with predation rates increasing with an increase in tern abundance (number of adults) on Goose Island. Comparisons between survival rates and predation rates indicate that a substantial proportion of steelhead mortality within the Priest Rapids Project can be attributed to predation by Caspian terns nesting on Goose Island in Potholes Reservoir. Overall, an estimated 49%, 85%, and 37% of all steelhead mortality in the Priest Rapids Project during 2008, 2009, and 2010, respectively, could be attributed to predation by Caspian terns nesting on Goose Island. Small sample sizes of tagged fish, high incidence of tag failure, and differences in the detection efficiency of acoustic tags compared to PIT tags could have influenced the precision and accuracy of tern predation rate estimates. Regardless, results suggest that the average three-year Project survival requirement for smolts of 86.5% may have been achieved in the absence of predation on juvenile steelhead by Caspian terns nesting on Goose Island in Potholes Reservoir during 2008 - 2010.

Evans, Allen F., Hostetter, N. J., Roby, D. D., Collis, K., Lyons, D. E., Sandford, B. P., Ledgerwood, R. D., & Sebring, S. (2012). Systemwide Evaluation of Avian Predation on Juvenile Salmonids from the Columbia River Based on Recoveries of Passive Integrated Transponder Tags. *Transactions of the American Fisheries Society*, *141*(4), 975–989. https://doi.org/10.1080/00028487.2012.676809

We recovered passive integrated transponder (PIT) tags from nine piscivorous waterbird colonies in the Columbia River basin to evaluate avian predation on Endangered Species Act (ESA)-listed salmonid Oncorhynchus spp. populations during 2007–2010. Avian predation rates were calculated based on the percentage of PIT-tagged juvenile salmonids that were detected as passing hydroelectric dams and subsequently were consumed and deposited by birds on their nesting colonies. Caspian terns Hydroprogne caspia (hereafter, “terns”) and double-crested cormorants Phalacrocorax auritus (hereafter, “cormorants”) nesting on East Sand Island in the Columbia River estuary consumed the highest proportions of available PIT-tagged salmonids, with minimum predation rates ranging from 2.5% for Willamette River spring Chinook salmon O. tshawytscha to 16.0% for Snake River steelhead O. mykiss. Estimated predation rates by terns, cormorants, gulls of two species (California gull Larus californicus and ring-billed gull L. delawarensis), and American white pelicans Pelecanus erythrorhynchos nesting near the confluence of the Snake and Columbia rivers were also substantial; minimum predation rates ranged from 1.4% for Snake River fall Chinook salmon to 13.2% for upper Columbia River steelhead. Predation on ESA-listed salmonids by gulls and American white pelicans were minor (<2.0% per ESA-listed salmonid population) relative to predation by terns and cormorants. Cumulative impacts were greater for Snake River and upper Columbia River salmonids than for salmonids originating closer to the estuary because upriver salmonids must migrate past more bird colonies to reach the ocean. Predation rates adjusted for colony size (per capita rates) were significantly higher for terns and cormorants nesting at inland colonies (upstream of Bonneville Dam) than for those nesting in the estuary, suggesting that inland colonies have a greater reliance on salmonids as a food source. Management actions to increase salmonid survival by reducing avian predation in the estuary could be offset if birds that disperse from the estuary relocate to inland nesting sites on or near the Columbia River.

Evans, Allen F., Payton, Q., Cramer, B. M., Collis, K., Hostetter, N. J., Roby, D. D., & Dotson, C. (2019). Cumulative Effects of Avian Predation on Upper Columbia River Steelhead. *Transactions of the American Fisheries Society*, *148*(5), 896–913. https://doi.org/10.1002/tafs.10197

To investigate the cumulative effects of colonial waterbird predation on fish mortality and to determine what proportion of all sources of fish mortality (1 − survival) was due to bird predation, we conducted a mark–recapture–recovery study with upper Columbia River steelhead Oncorhynchus mykiss that were PIT-tagged and released (N = 78,409) at Rock Island Dam on the Columbia River, USA. We used a state–space Bayesian model that incorporated live detections and dead recoveries of tagged fish to jointly estimate predation and survival probabilities during smolt out-migration to the Pacific Ocean over an 11-year study period. Estimated cumulative (all colonies combined) avian predation probabilities ranged from 0.31 (95% credible interval [CRI] = 0.27–0.38) to 0.53 (95% CRI = 0.42–0.64) annually, indicating that avian predation was a substantial source of mortality. Of the predator species evaluated, predation by Caspian terns Hydroprogne caspia was often the highest, with predation probabilities ranging from 0.11 (95% CRI = 0.09–0.14) to 0.38 (95% CRI = 0.29–0.47).

Probabilities of predation by double-crested cormorants Phalacrocorax auritus and mixed colonies of California gulls Larus californicus and ring-billed gulls L. delawarensis were generally lower than the probabilities for terns but were also substantial, with upwards of 0.04 (95% CRI = 0.03–0.07; cormorants) and 0.31 (95% CRI = 0.25–0.39; gulls) of steelhead consumed. Comparisons of total smolt mortality with mortality due to avian predation indicated that avian predation accounted for 42% (95% CRI = 30–56%) to 70% (95% CRI = 53–87%) of total mortality, suggesting that more steelhead were consumed by avian predators than died from all other mortality sources combined. Results indicate that avian predation, although not the original cause of steelhead declines in the basin, is now a factor limiting the survival of upper Columbia River steelhead. Using the analytical framework developed in this study, future studies can consider the cumulative impact of multiple mortality sources across large spatial and temporal scales to more fully understand the extent to which they limit fish survival.

Evans, Allen F., Payton, Q., Turecek, A., Cramer, B., Collis, K., Roby, D. D., Loschl, P. J., Sullivan, L., Skalski, J., Weiland, M., & Dotson, C. (2016). Avian Predation on Juvenile Salmonids: Spatial and Temporal Analysis Based on Acoustic and Passive Integrated Transponder Tags. *Transactions of the American Fisheries Society*, *145*(4), 860–877. https://doi.org/10.1080/00028487.2016.1150881

We evaluated the impact of predation on juvenile steelhead Oncorhynchus mykiss and yearling and subyearling Chinook Salmon O. tshawytscha by piscivorous waterbirds from 11 different breeding colonies in the Columbia River basin during 2012 and 2014. Fish were tagged with both acoustic tags and PIT tags and were tracked via a network of hydrophone arrays to estimate total smolt mortality (1 – survival) at various spatial and temporal scales during out-migration. Recoveries of PIT tags on bird colonies, coupled with the last known detections of live fish passing hydrophone arrays, were used to estimate the impact of avian predation relative to total smolt mortality. Results indicated that avian predation was a substantial source of steelhead mortality, with predation probability (proportion of available fish consumed by birds) ranging from 0.06 to 0.28 for fish traveling through the lower Snake River and the lower and middle Columbia River. Predation probability estimates ranged from 0.03 to 0.09 for available tagged yearling Chinook Salmon and from 0.01 to 0.05 for subyearlings. Smolt predation by gulls Larus spp. was concentrated near hydroelectric dams, while predation by Caspian terns Hydroprogne caspia was concentrated within reservoirs. No concentrated areas of predation were identified for double-crested cormorants Phalacrocorax auritus or American white pelicans Pelecanus erythrorhynchos. Comparisons of total smolt mortality relative to mortality from colonial waterbirds indicated that avian predation was one of the greatest sources of mortality for steelhead and yearling Chinook Salmon during out-migration. In contrast, avian predation on subyearling Chinook Salmon was generally low and constituted a minor component of total mortality. Our results demonstrate that acoustic and PIT tag technologies can be combined to quantify where and when smolt mortality occurs and the fraction of mortality that is due to colonial waterbird predation relative to non-avian mortality sources.

Evans, Allen F., Roby, D. D., Collis, K., Cramer, B. M., Sheggeby, J. A., Adrean, L. J., Battaglia, D. S., & Lyons, D. E. (2011). Recovery of Coded Wire Tags at a Caspian Tern Colony in San Francisco Bay: A Technique to Evaluate Impacts of Avian Predation on Juvenile Salmonids. *North American Journal of Fisheries Management*, *31*(1), 79–87. https://doi.org/10.1080/02755947.2011.562429

We recovered coded wire tags (CWTs) from a colony of Caspian terns Hydroprogne caspia on Brooks Island in San Francisco Bay, California, to evaluate predation on juvenile salmonids originating from the Sacramento and San Joaquin rivers. Subsamples of colony substrate representing 11.7% of the nesting habitat used by the terns yielded 2,079 salmonid CWTs from fish released and subsequently consumed by terns in 2008. The estimated number of CWTs deposited on the entire tern colony was 40,143 (ranging from 26,763 to 80,288), once adjustments were made to account for tag loss and the total amount of nesting habitat used by terns. Tags ingested by terns and then egested on the colony were undamaged, and the tags' complete numeric codes were still identifiable. The CWTs found on the tern colony indicated that hatchery Chinook salmon Oncorhynchus tshawytscha trucked to and released in San Pablo Bay were significantly more likely to be consumed by Caspian terns than Chinook salmon that migrated in-river to the bay; 99.7% of all tags recovered were from bay-released Chinook salmon. Of the CWTs recovered on the tern colony, 98.0% were from fall-run Chinook salmon, indicating a higher susceptibility to tern predation than for the spring run type. None of the approximately 518,000 wild Chinook salmon that were coded-wire-tagged and released in the basin were recovered on the tern colony, suggesting that the impacts on wild, U.S. Endangered Species Act–listed Chinook salmon populations were minimal in 2008. Overall, we estimate that 0.3% of the approximately 12.3 million coded-wire-tagged Chinook salmon released in the basin in 2008 were subsequently consumed by Caspian terns from the Brooks Island colony. These results indicate that CWTs implanted in juvenile salmon can be recovered from a piscivorous waterbird colony and used to evaluate smolt losses for runs that are tagged.

Faulkner, J. R., Bellerud, B. L., Widener, D. L., & Zabel, R. W. (2019). Associations among Fish Length, Dam Passage History, and Survival to Adulthood in Two At-Risk Species of Pacific Salmon. *Transactions of the American Fisheries Society*, *148*(6), 1069–1087. https://doi.org/10.1002/tafs.10200

Threatened or endangered salmon and steelhead originating in the Snake River basin must pass through a series of eight major hydroelectric dams during their seaward migration. Understanding the effects of specific dam passage routes on lifetime survival for these stocks is essential for successful management. Juvenile fish may pass these dams via three primary routes: (1) spillways, (2) turbines, or (3) juvenile bypass systems, which divert fish away from turbines and route them downstream. Bypass systems may expose fish to trauma, increased stress, or disease. However, numerous studies have indicated that direct survival through bypass systems is comparable to and often higher than that through spillways. Some researchers have suggested that the route of dam passage affects mortality in the estuary or ocean, but this is complicated by studies finding that fish size affects the route of passage. We tested whether passage through bypass systems was associated with the probability of adult return after accounting for fish length and other covariates for two species of concern. We also investigated the association between fish length and the probability of bypass at dams and how this relationship could lead to spurious conclusions regarding effects of bypass systems on survival if length is ignored. We found that (1) larger fish had lower bypass probabilities at six of seven dams; (2) larger fish had a higher probability of surviving to adulthood; (3) bypass history had little association with adult return after accounting for fish length; and (4) simulations indicated that spurious effects of bypass on survival may arise when no true bypass effect exists, especially in models without length. Our results suggest that after fish leave the hydropower system, bypass passage history

has little effect on mortality. Our findings underscore the importance of accounting for fish size in studies of dam passage or survival.

Fayet, A. L., Freeman, R., Shoji, A., Kirk, H. L., Padget, O., Perrins, C. M., & Guilford, T. (2016). Carry-over effects on the annual cycle of a migratory seabird: An experimental study. *Journal of Animal Ecology*, *85*(6), 1516–1527. https://doi.org/10.1111/1365-2656.12580

Long-lived migratory animals must balance the cost of current reproduction with their own condition ahead of a challenging migration and future reproduction. In these species, carry-over effects, which occur when events in one season affect the outcome of the subsequent season, may be particularly exacerbated. However, how carry-over effects influence future breeding outcomes and whether (and how) they also affect behaviour during migration and wintering is unclear. Here we investigate carry-over effects induced by a controlled, bidirectional manipulation of the duration of reproductive effort on the migratory, wintering and subsequent breeding behaviour of a long-lived migratory seabird, the Manx shearwater Puffinus puffinus. By cross-fostering chicks of different age between nests, we successfully prolonged or shortened by ∼25% the chick-rearing period of 42 breeding pairs. We tracked the adults with geolocators over the subsequent year and combined migration route data with at-sea activity budgets obtained from high-resolution saltwater-immersion data. Migratory behaviour was also recorded during non-experimental years (the year before and/or two years after manipulation) for a subset of birds, allowing comparison between experimental and non-experimental years within treatment groups. All birds cared for chicks until normal fledging age, resulting in birds with a longer breeding period delaying their departure on migration; however, birds that finished breeding earlier did not start migrating earlier. Increased reproductive effort resulted in less time spent at the wintering grounds, a reduction in time spent resting daily and a delayed start of breeding with lighter eggs and chicks and lower breeding success the following breeding season. Conversely, reduced reproductive effort resulted in more time resting and less time foraging during the winter, but a similar breeding phenology and success compared with control birds the following year, suggesting that 'positive' carry-over effects may also occur but perhaps have a less long-lasting impact than those incurred from increased reproductive effort. Our results shed light on how carry-over effects can develop and modify an adult animal's behaviour year-round and reveal how a complex interaction between current and future reproductive fitness, individual condition and external constraints can influence life-history decisions.

Feltham, M. J., & MacLean, J. C. (1996). Carlin tag recoveries as an indicator of predation on salmon smolts by goosanders and red-breasted mergansers. *Journal of Fish Biology*, *48*(2), 270–282. https://doi.org/10.1111/j.1095-8649.1996.tb01118.x

Between 1984 and 1990 a total 221 Carlin tags used to mark salmon Salmo salar smolts in the River North Esk, NE Scotland, were recovered from the stomachs of goosanders Mergus merganser and red-breasted mergansers M. serrator. Both Carlin-tagging and adipose-clipping affected the predation of salmon smolts by sawbill ducks. The mean (± S.D.) sizes of tagged smolts taken by both species were similar (117 ± 3 mm) and significantly smaller than the mean sizes of smolts in the river, possibly due to a reduction in the swimming performance of small smolts bearing tags. Large adipose-clipped smolts (±mean smolt size) were predated significantly more than unclipped smolts, but no such difference was observed for small smolts (<mean smolt size). Data suggested that some ducks cued into smolt release sites where they took a disproportionately high number of tagged smolts on or near the day of release and continued to do so for several

days. Although tag recoveries are commonly used to estimate the impact of piscivores on fish stocks, our study suggests that some predators respond to the presence of tagged fish in ways that directly reflect the tagging procedure and that caution should be exercised when extrapolating conclusions based on such data to untagged fish.

Ferguson, J. W., Absolon, R. F., Carlson, T. J., & Sandford, B. P. (2006). Evidence of Delayed Mortality on Juvenile Pacific Salmon Passing through Turbines at Columbia River Dams. *Transactions of the American Fisheries Society*, *135*(1), 139–150. https://doi.org/10.1577/T05-080.1

We evaluated the survival of juvenile salmon through turbines in Columbia River dams and found no differences between two operations but strong evidence of delayed mortality from turbine passage. After tagging with a passive integrated transponder (PIT) tag and a radio tag, yearling Chinook salmon Oncorhynchus tshawytscha were released at McNary Dam on the Columbia River through a turbine operating both within 1% of peak efficiency (a discharge rate of 317 m3/s) and outside the 1% range at the maximum blade angle (464 m3/s). Estimated relative survival to a detection array 15 km downstream was 0.871 at 317 m3/s and 0.856 at 464 m3/s and 0.858 and 0.814, respectively, to an array 46 km downstream. The highest point estimates of survival occurred under the lower discharge, suggesting that operating turbines within 1% of peak efficiency is a useful guideline for fish protection at McNary Dam. In a concurrent evaluation using balloon tags, estimated mean direct survival ranged from 0.930 to 0.946. Radio tag estimates were significantly lower than balloon tag estimates under both operations. Based on these differences, we estimated that delayed mortality comprised from 46% to 70% of total estimated mortality. We reviewed the literature and concluded that delayed mortality was caused by sublethal impacts to fish sensory systems, which increased vulnerability to predation in the tailrace. We recommend that future research to improve turbine designs and operations for fish passage focus on this major component of mortality.

Feyrer, F., Nobriga, M. L., & Sommer, T. R. (2007). Multidecadal trends for three declining fish species: Habitat patterns and mechanisms in the San Francisco Estuary, California, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(4), 723–734. https://doi.org/10.1139/f07-048

We examined a 36-year record of concurrent midwater trawl and water quality sampling conducted during fall to evaluate habitat trends for three declining fish species in the San Francisco Estuary, California, USA: delta smelt (Hypomesus transpacificus), striped bass (Morone saxatilis), and threadfin shad (Dorosoma petenense). Generalized additive modeling revealed that Secchi depth and specific conductance were important predictors of occurrence for delta smelt and striped bass, while specific conductance and water temperature were important for threadfin shad. Habitat suitability derived from model predictions exhibited significant long-term declines for each species; the southeastern and western regions of the estuary exhibited the most dramatic changes. Declines in habitat suitability were associated with anthropogenic modifications to the ecosystem. For delta smelt, an imperiled annual species endemic to the estuary, the combined effects of fall stock abundance and water quality predicted recruit abundance during recent years of chronically low food supply. Our results are consistent with existing evidence of a long-term decline in carrying capacity for delta smelt and striped bass and demonstrate the utility of long-term data sets for evaluating relationships between fish and their habitat.

Finley, W. L. (1907a). The Grebes of Southern Oregon. *The Condor*, *9*(4), 97–101. JSTOR. https://doi.org/10.2307/1361117

Finley, W. L. (1907b). Among the Gulls on Klamath Lake. *The Condor*, *9*(1), 12–16. https://doi.org/10.2307/1361523

Fleskes, J. P., & Yee, J. L. (2007). Waterfowl Distribution and Abundance During Spring Migration in Southern Oregon and Northeastern California. *Western North American Naturalist*, *67*(3), 409–428. https://doi.org/10.3398/1527-0904(2007)67[409:WDAADS]2.0.CO;2

We used aerial surveys to study abundance and distribution of waterfowl (ducks, geese, swans, and coots) during spring in southern Oregon and northeastern California (SONEC). Total waterfowl-use days in SONEC during the 119-day, 5 January–3 May, spring period was similar during 2002 (127,977,700) and 2003 (128,076,200) and averaged 1,075,900 birds per day (bpd); these estimates should be adjusted upward 4%–10% to account for areas not surveyed. Waterfowl abundance peaked in mid-March in both years: 2,095,700 in 2002 and 1,681,700 in 2003. Northern Pintail (Anas acuta) was the most abundant species in both years, accounting for 25.6% of the 2002 and 24.5% of the 2003 waterfowl-use days. Pintail abundance peaked during the 13 March survey at 689,300 in 2002 and 532,100 in 2003. All other dabbling ducks accounted for 27.6% and 28.6%, diving ducks for 13.5% and 9.2%, geese for 24.6% and 29.3%, swans for 2.8% and 1.9%, and coots for 5.8% and 6.4% of the spring waterfowl-use days in SONEC during 2002 and 2003, respectively. Although use days changed little for total waterfowl (0.08%) and dabbling ducks (−0.1%), diving duck use was lower (−32%), and goose use days were greater (19%) in 2003 than in 2002. Distribution was similar in both years, with the most waterfowl use in the Lower (66%) and Upper (14%) Klamath subregions; 2%–6% occurred in each of the other subregions. Although the Lower Klamath subregion received the greatest overall waterfowl use, distribution among subregions varied among species and surveys, and all subregions were important during some part of the spring for 1 or more species. Peak spring abundance in SONEC during 2002 and 2003 averaged 50.3% of the midwinter abundance in California (all survey regions) and southern Oregon (69-3 survey region) for all waterfowl, 46.1% for dabbling ducks, 62.4% for diving ducks, 68.8% for geese, 109.4% for swans, and 43.8% for coots. Each spring, 75% of all waterfowl use in SONEC occurred on federal, state, or Nature Conservancy lands (i.e., protected areas). On protected areas there was a higher percentage of dabbling ducks (80.5%), geese (70.5%), and coots (81.5%) than diving ducks (60.4%) and swans (49%). Waterfowl use of Klamath Basin National Wildlife Refuge (NWR) averaged 42% greater during spring 2002–2003 (568,500 bpd) than during 1998–2001 (Gilmer et al. 2004). Numerous factors likely impacted magnitude and distribution of waterfowl use of SONEC during spring, including weather, waterfowl populations, SONEC habitat, and species ecology. SONEC is a critical spring staging area for waterfowl that winter in the Central Valley of California and other Pacific Flyway regions and should be a major focus area for waterfowl-habitat conservation efforts.

Frechette, D., Osterback, A.-M. K., Hayes, S. A., Bond, M. H., Moore, J. W., Shaffer, S. A., & Harvey, J. T. (2012). Assessing Avian Predation on Juvenile Salmonids using Passive Integrated Transponder Tag Recoveries and Mark–Recapture Methods. *North American Journal of Fisheries Management*, *32*(6), 1237–1250. https://doi.org/10.1080/02755947.2012.728171

Many populations of coho salmon Oncorhynchus kisutch and steelhead O. mykiss are listed under the U.S. Endangered Species Act. Until recently, the role of avian predation in limiting recovery of coho salmon and steelhead in central California coastal watersheds has been overlooked. We used recoveries of passive integrated transponder (PIT) tags from Año Nuevo Island (ANI), a breeding site for several species of piscivorous seabirds, to estimate predation rates on juvenile salmonids and identify susceptible life stages and species responsible for predation. A total of 34,485 PIT tags were deployed in coho salmon and steelhead in six watersheds in San Mateo and Santa Cruz counties. Tags were deposited on ANI by predators after ingestion of tagged fish. Because tags were not removed from the island and were detected on multiple sampling occasions, we were able to use mark–recapture models to generate a corrected minimum predation estimate. We used POPAN, a variation of the Jolly–Seber model, to generate an estimate of gross population abundance, which accounted for tags deposited on the island but not detected during surveys. Detections of 196 tags from surveys conducted between autumn 2006 and spring 2009 were incorporated into the model, producing a gross population estimate of 242 tags (SE = 9.8). Addition of tags detected between autumn 2009 and 2010 to the abundance estimate from POPAN produced a new minimum estimate of 362 tags on ANI. Western gulls Larus occidentalis probably were the primary predator depositing tags on ANI. Minimum predation estimates ranged from 0.1% (Soquel Creek) to 4.6% (Waddell Creek) of outmigrating coho salmon and steelhead smolts. Predation was potentially greater given still unquantified deposition of tags off-colony and destruction of tags during digestive processes of predators. Finally, avian predators targeted estuary-reared fish, which contributed disproportionately to adult populations, further impacting imperiled salmon populations.

Frechette, D., Osterback, A.-M. K., Hayes, S. A., Moore, J. W., Shaffer, S. A., Pavelka, M., Winchell, C., & Harvey, J. T. (2015). Assessing the Relationship between Gulls Larus spp. And Pacific Salmon in Central California Using Radiotelemetry. *North American Journal of Fisheries Management*, *35*(4), 775–788. https://doi.org/10.1080/02755947.2015.1032450

Predation by marine birds has resulted in substantial losses to runs of Pacific salmon Oncorhynchus spp., in some cases necessitating management action. Recovery of PIT tags on a seabird breeding colony (Año Nuevo Island) indicated that western gulls Larus occidentalis prey upon federally listed Coho Salmon Oncorhynchus kisutch and steelhead O. mykiss in central California. Whereas salmonid populations in central California have decreased in recent decades, the western gull population on Año Nuevo Island has increased. We observed gulls Larus spp. within estuaries to document predation and used radiotelemetry to examine gull movement in relation to the availability of salmonids. During 2008 and 2009, observed predation events of out-migrating salmonids by gulls were rare; 21 events occurred during 338 h of observations at two estuaries. During the prehatch and chick-rearing phases of breeding, which coincided with migration of salmonids from fresh to salt water, 74% of the detections of radio-tagged western gulls occurred within 25 km of Año Nuevo Island, suggesting that the relative susceptibility of predation by western gulls using Año Nuevo Island decreased with distance from the island. Western gull presence at creek mouths was greatest during daylight hours (91% of detections), while juvenile salmonids were present predominantly at night (65% of detections). The greatest overlap between western gulls and salmonids occurred at dusk, and predation of out-migrating salmonids was likely opportunistic. Deterring gulls from creek mouths when overlap between predator and prey might otherwise occur may buffer out-migrating salmonids from predation. Our results will inform management strategies to most effectively reduce the impacts of gull predation on central California salmonids.

Frederiksen, M., Lebreton, J.-D., & Bregnballe, T. (2001). The interplay between culling and density-dependence in the great cormorant: A modelling approach. *Journal of Applied Ecology*, *38*(3), 617–627. https://doi.org/10.1046/j.1365-2664.2001.00620.x

1 The population of great cormorants Phalacrocorax carbo sinensis breeding in northern Europe has increased from 5000 pairs around 1970 to c. 100 000 pairs in the late 1990s, leading to serious conflicts with fishery and aquaculture interests. Management action, including widespread culling, has been taken in several countries. 2 Since 1990, presumed density-dependent declines in demographic performance have appeared in cormorant populations. We employed an extended Leslie matrix model to study the interaction between culls and density-dependence in regulating breeding and autumn population sizes, with emphasis on evaluating the effects of culling. 3 During 1979–92, the breeding population of great cormorants in northern Europe increased by 18% year−1, in accordance with observed life-cycle parameters before the appearance of density-dependent declines. 4 We modelled six scenarios with varying assumptions about the strength of density-dependence in adult survival and the proportions of breeding cormorants. A series of cull estimates was also included. Scenarios with moderate or strong levels of density-dependence provided predictions that fit the observed numbers of breeding pairs, whereas scenarios without density-dependence in survival overestimated real population growth. 5 The most well-supported scenarios indicated that the effect of culls at the present level (1998–99: 17 000 cormorants shot) was limited (< 10% reduction at equilibrium). Increasing the annual cull to 30 000 still had a limited effect, whereas shooting 50 000 birds year−1 led to population extinction within 20–40 years. Shooting a fixed proportion of the population exceeding a threshold, through density-dependent culling, could eliminate differences among scenarios and stabilize the population. 6 We conclude that culls probably have had a limited effect on cormorant populations, but if carried out in a density-dependent way they could stabilize numbers near a desired level. However, a reduction in the number of cormorants may not lead to a similar reduction in conflicts, and actions to control damage rather than cormorant populations are likely to be more cost-effective. If culling is to be continued, we recommend the adoption of an adaptive and co-ordinated management strategy across Europe. We also advocate the need to account for density-dependent mechanisms in general culling strategies.

Fritts, A. L., Scott, J. L., & Pearsons, T. N. (2007). The effects of domestication on the relative vulnerability of hatchery and wild origin spring Chinook salmon (Oncorhynchus tshawytscha) to predation. *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(5), 813–818. https://doi.org/10.1139/f07-057

We tested whether one generation of state-of-the-art hatchery culture influenced the vulnerability of Chinook salmon (Oncorhynchus tshawytscha) fry to predators. Size-matched hatchery and wild origin spring Chinook salmon fry were exposed to rainbow trout (Oncorhynchus mykiss) and torrent sculpin (Cottus rhotheus) predators in 10.8 m3 net pens. The hatchery origin fry were the offspring of first generation hatchery-reared broodstock, and the wild origin fry had no history of hatchery culture; both originated from the same stock. Wild origin fry were found to have a 2.2% (p = 0.016) survival advantage over hatchery origin fry during 2 years of predation challenges. The most important findings of this study are (i) domestication can affect the susceptibility to predators after only one generation of state-of-the-art hatchery culture practices, and (ii) the domestication effect was very small.

Furey, N. B., Hinch, S. G., Bass, A. L., Middleton, C. T., Minke-Martin, V., & Lotto, A. G. (2016). Predator swamping reduces predation risk during nocturnal migration of juvenile salmon in a high-mortality landscape. *Journal of Animal Ecology*, *85*(4), 948–959. https://doi.org/10.1111/1365-2656.12528

Animal migrations are costly and are often characterized by high predation risk for individuals. Three of the most oft-assumed mechanisms for reducing risk for migrants are swamping predators with high densities, specific timing of migrations and increased body size. Assessing the relative importance of these mechanisms in reducing predation risk particularly for migrants is generally lacking due to the difficulties in tracking the fate of individuals and population-level characteristics simultaneously. We used acoustic telemetry to track migration behaviour and survival of juvenile sockeye salmon (Oncorhynchus nerka) smolts released over a wide range of conspecific outmigration densities in a river associated with poor survival. The landscape was indeed high risk; smolt survival was poor (˜68%) over 13·5 km of river examined even though migration was rapid (generally <48 h). Our results demonstrate that smolts largely employ swamping of predators to reduce predation risk. Increased densities of co-migrant conspecifics dramatically improved survival of smolts. The strong propensity for nocturnal migration resulted in smolts pausing downstream movements until the next nightfall, greatly increasing relative migration durations for smolts that could not traverse the study area in a single night. Smolt size did not appear to impact predation risk, potentially due to unique characteristics of the system or our inability to tag the entire size range of outmigrants. Movement behaviours were important in traversing this high-risk landscape and provide rare evidence for swamping to effectively reduce individual predation risk.

Furness, R. W. (1978). Energy Requirements of Seabird Communities: A Bioenergetics Model. *Journal of Animal Ecology*, *47*(1), 39–53. JSTOR. https://doi.org/10.2307/3921

(1) Methods used to estimate energy requirements of avian communities are listed, and their inadequacies discussed. In particular, the published estimates lack confidence intervals. (2) A simulation model is described which estimates daily energy requirements of seabird populations. Biomasses of breeders, non-breeders and chicks present in the vicinity of the colony, are coupled with an ambient temperature function, the bioenergetic equations of Kendeigh, and calculations of the energy costs of digestion, activity, egg production and growth. (3) The model is tested using input data sets for great skua Catharacta skua Brunnich and Arctic tern Sterna paradisaea Pontopp. Sensitivity of the model to errors in input parameters, and the output errors resulting from known imprecisions in the forty-four input parameters are examined. Output precision is largely determined by a few parameters, which depend partly on the life-style energy allocation of the species. (4) A Monte Carlo simulation is used to determine the precision of the estimated energy requirements of the two species' populations. This suggests that, using currently available input data, the population energy requirement estimate has a 95% confidence interval of +-50% of the mean. (5) Energy requirements could be considerably more precisely determined if only a small number of input parameters were more precisely known. These limiting parameters are listed. (6) The model is applied to one particular seabird community, on Foula, Shetland, for which detailed data have been collected. The mean estimate of the total energy requirement of this community (1.2 X 1010 kcal yr-1) represents 29% of the mean estimate of the total annual fish production within a 45 km radius of the colony. This implies that seabirds, predatory demersal fish and industrial fisheries are in direct competition for the energy flow from pelagic

fish, such that any increase in the energy flow to one of these would result in a reduced energy availability to the others.

Gaston, A. J., & Smith, G. E. J. (1984). The interpretation of aerial surveys for seabirds: Some effects of behavior. *Canadian Wildlife Service Occasional Paper*, *53*, 1–20.

Aerial surveys have been used extensively to observe the distribution and abundance of marine birds at sea. Although biases caused by weather and sea conditions, aircraft type, and the state and experience of the observer have been discussed by others, little has been done to interpret the effect of biological variables inherent in the behaviour of the birds. In this paper we explore five ways in which the analysis of aerial survey data can enhance our understanding of seabird distributions compared with inspection of the raw data alone. We consider the effects of (1) colony attendance, (2) travel time between colony and feeding grounds, (3) relative motion of birds and aircraft, and (4) duration and frequency of dives. We also consider the effect of flock size on the accuracy of survey results and the adequacy of sampling. We give examples that illustrate the degree to which the proposed corrections may improve the interpretation of results.

Gende, S. M., Edwards, R. T., Willson, M. F., & Wipfli, M. S. (2002). Pacific Salmon in Aquatic and Terrestrial Ecosystems: Pacific salmon subsidize freshwater and terrestrial ecosystems through several pathways, which generates unique management and conservation issues but also provides valuable research opportunities. *BioScience*, *52*(10), 917–928. https://doi.org/10.1641/0006-3568(2002)052[0917:PSIAAT]2.0.CO;2

Gill, R. (1977). Breeding Avifauna of the South San Francisco Bay Estuary. *Western Birds*, *8*(1), 12.

Gill, R. E., & Mewaldt, L. R. (1983). Pacific Coast Caspian Terns: Dynamics of an Expanding Population. *The Auk*, *100*(2), 369–381. https://doi.org/10.1093/auk/100.2.369

Nesting distribution, age-related seasonal movements, survivorship, and mechanisms of population expansion in Pacific Coast Caspian Terns (Sterna caspia) were examined primarily through analysis of 412 recoveries of birds banded as juveniles between 1935 and 1980. Since the beginning of this century, the population has shifted from nesting in numerous small colonies associated with freshwater marshes in interior California and southern Oregon to nesting primarily in large colonies on human-created habitats along the coast. Colonies at Grays Harbor, Washington and San Francisco and San Diego bays, California account for 77% of the current Pacific Coast population (6,000 pairs), which has breeding and wintering areas separate from those of populations east of the continental divide. There also appears to be some segregation on the wintering grounds by birds from the three major colonies within the Pacific population. Age-related seasonal movements in the Pacific population are characterized by (1) a brief period of northward dispersal by newly fledged birds before migrating to the wintering grounds, (2) a residency on the wintering grounds through their second winter, (3) a return to the breeding grounds the third summer, when most birds are thought to prospect breeding sites and some may breed, and (4) attainment of adulthood the fourth summer, with subsequent annual movements between wintering and breeding grounds. The Pacific population has increased 70% since 1960, apparently all by intrinsic growth. Over half (57%) of the fledglings reach their fourth year, and they have a subsequent annual survival rate of 89% and a mean breeding life expectancy of 8.6 yr. An average annual fledging rate of 0.64 young per pair was calculated as necessary to have provided the observed growth of the population during its recent expansion.

Growth of some of the individual colonies, however, particularly those in Washington, could only have resulted from extensive recruitment of birds from other Pacific Coast colonies. Philopatry is low in this population, and the growth of the northern colonies involved recruitment primarily of first-time breeders but also of some older adults. Factors promoting both first-time breeders and older adults to join new and often distant colonies are discussed.

Giudici, A., Navarro, J., Juste, C., & González-Solís, J. (2010). Physiological ecology of breeders and sabbaticals in a pelagic seabird. *Journal of Experimental Marine Biology and Ecology*, *389*(1), 13–17. https://doi.org/10.1016/j.jembe.2010.04.002

In long-lived seabirds, intermittent nonbreeding years in an adult life, the so called 'sabbatical years', are common. However, proximal causes that make animals decide whether to breed or not to breed are poorly known. In this study we assessed different components of the physiological state of a long-lived pelagic seabird, the Cory's shearwaters Calonectris diomedea, during the pre-laying period to understand which components are influencing breeding decisions. We analyzed plasma biochemistry, haematocrit, leukocyte counts and stable isotope (δ15N and δ13C) values in blood and claws. We also recorded body mass, ectoparasite loads and fault bars in primary and tail feathers. All parameters were compared between breeders and sabbaticals and between males and females. Among all biochemical variables analyzed we found triglyceride levels in plasma to be significantly greater in breeders than in sabbaticals and in females than males. H/L ratio was lower in breeders than in sabbaticals and greater in males than females. These results suggest the ability to store fat and the immunological condition are important components compromising breeding decisions. Our study also suggests that H/L ratio can be used as a good predictor of the breeding decisions.

Glabek, J. H., Ryan, B. A., Nunnallee, E. P., & Ferguson, J. W. (2003). *Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River Basin, 2001* (p. 69). https://www.nwfsc.noaa.gov/assets/26/6555_07142010_094351_Glabek.et.al.2003-rev.pdf

In 2001, the National Marine Fisheries Service detected the passive integrated transponder (PIT) tags of 45,065 juvenile salmonids on piscivorous bird colonies in the Columbia River Basin. These PIT tags accounted for 4.1% of the 1,099,291 PIT-tagged juvenile salmonids released into the Columbia River Basin to migrate during 2001. By species, they accounted for 8.7, 4.8, 3.4, and 2.6% of the PIT-tagged steelhead Oncorhynchus mykiss, coho O. kisutch, chinook O. tshawytscha, and sockeye salmon O. nerka respectively. Piscivorous bird colonies sampled were of Caspian terns (Sterna caspia), double-crested cormorants Phalacrocorax auritas, gulls Larus spp., American white pelicans Pelecanus erythrorhynchos, and three species of heron: Ardea alba, A. herodias, and Nycticorax nycticorax. The greatest number of tags was detected on East Sand Island in the Columbia River estuary. At Bonneville Dam (the first impoundment upstream from the Columbia River estuary), 47,246 PIT tagged juvenile salmonids were detected in the bypass systems in 2001, of which 12,847 originated in the Snake River Basin (SRB). Detections on bird colonies accounted for 24.2% of the SRB steelhead and 10.1% of the SRB spring/summer chinook salmon previously detected at Bonneville Dam. Of the remaining 34,399 non-SRB tags detected at Bonneville Dam, detections on the bird colonies accounted for 13.4, 10.3, 7.7, and 4.7% of the coho, steelhead, sockeye and chinook salmon, respectively. The second greatest number of tags was detected on Crescent Island in the McNary Dam reservoir. Upstream from Crescent Island at Lower Monumental Dam (the nearest upstream PIT tag detection facility), 48,779 juvenile spring/summer chinook and 15,486 steelhead tags from migration year 2001 were detected. Of these, 13.0% of the steelhead and 4.1% of the spring/summer chinook salmon were detected on the Crescent Island tern colony. Due to the low water flow and lack of spill in 2001, 168,734 PIT-tagged juvenile salmonids were barged around the Federal Columbia River Power System and released downstream from Bonneville Dam, which was a substantial increase compared to previous years. Of these we detected 6,405 tags, which accounted for 9.3, 7.5, 3.4, and 2.1% of the transported PIT-tagged coho, steelhead, chinook, and sockeye, respectively. In addition, we PIT tagged 8,754 juvenile salmonids during migration year 2001 and released them into rivers that discharge directly into the Columbia River estuary. From these releases, we detected 15.9, 8.4, and 3.7% of the fall chinook, steelhead and iii spring chinook salmon, respectively. While detection percentages of steelhead and spring chinook salmon were not that different from those of upriver stocks, the percentage of fall chinook salmon detected was significantly higher than that of their upriver cohorts. Our PIT-tag detections in 2001 continue to provide minimum estimates of avian predation in the Columbia River Basin along with relative vulnerabilities of juvenile salmonids. In addition, these data were entered into the Columbia Basin PIT Tag Information System for use by other researchers and salmon managers.

Glahn, J. F., & Brugger, K. E. (1995). The Impact of Double-Crested Cormorants on the Mississippi Delta Catfish Industry: A Bioenergetics Model. *Colonial Waterbirds*, *18*, 168–175. JSTOR. https://doi.org/10.2307/1521537

A bioenergetics model was constructed and evaluated for estimating Double-crested Cormorant (Phalacrocorax auritus) energy expenditures, food demand and impact on the Channel Catfish (Ictalurus punctatus) industry in the Delta region of Mississippi. Large body mass (mean = 2.27 kg) and higher basal metabolism (115% to 128% of predicted) resulted in an average predicted food demand of 504 g/bird/day (range: 449 to 551) from November to March or 22% of body mass. Factoring in population sizes and proportional intake of catfish, Double-crested Cormorants may have eaten up to 20 million catfish per winter in 1989-90 and 1990-91 or approximately 4% of the estimated standing crop at a replacement cost of $2 million (US$) annually. More than 50% of catfish losses were projected to occur in February and March; negligible losses occurred in November.

Good, T., McClure, M., Sandford, B., Barnas, K., Marsh, D., Ryan, B., & Casillas, E. (2007). Quantifying the effect of Caspian tern predation on threatened and endangered Pacific salmon in the Columbia River estuary. *Endangered Species Research*, *3*, 11–21. https://doi.org/10.3354/esr003011

Caspian terns Sterna caspia breeding in the Columbia River estuary exploit Pacific salmon Oncorhynchus spp. as prey, consuming millions of outmigrating juvenile salmonids annually. We analyzed recoveries of salmonid passive integrated transponder (PIT) tags from the East Sand Island tern colony to calculate predation rates (% of available fish taken) on 4 Columbia and Snake River steelhead O. mykiss Evolutionarily Significant Units (ESUs). A life cycle modeling approach was used to estimate potential increases in ESU population growth rate (λ) given potential reductions in Caspian tern numbers on East Sand Island. Reducing tern predation on steelhead ESUs by 50 – 100% increased λ from 0.8 to 2.5%, depending on the ESU and the reproductive contribution of hatchery fish, and assuming no compensatory mortality. This is comparable to survival improvements modeled for hydropower improvements in the basin but less than those modeled for harvest reductions. Reducing avian predation as part of an effort to reduce all sources of mortality may assist in ESU recovery. A thorough understanding of such predator–prey relationships is needed to manage conflicts between predators and their threatened and endangered Pacific salmonid prey.

Green, M. C., Waits, J. L., Avery, M. L., Tobin, M. E., & Leberg, P. L. (2006). Microsatellite Variation of Double-Crested Cormorant Populations in Eastern North America. *Journal of Wildlife Management*, *70*(2), 579–583. https://doi.org/10.2193/0022-541X(2006)70[579:MVODCP]2.0.CO;2

Gregory, R. S. (1993). Effect of Turbidity on the Predator Avoidance Behaviour of Juvenile Chinook Salmon (Oncorhynchus tshawytscha). *Canadian Journal of Fisheries and Aquatic Sciences*, *50*(2), 241–246. https://doi.org/10.1139/f93-027

The effect of turbidity on the predator avoidance behaviour of juvenile chinook salmon (Oncorhynchus tshawytscha) was determined in controlled laboratory experiments. Bird and fish models were used to simulate predator risk. In the absence of risk, juvenile chinook were distributed randomly within an experimental arena in turbid conditions (≈23 NTU), but in clear conditions (<1 NTU) they associated with the bottom. When introduced to bird and fish predator models, the chinook altered their distribution and occupied deeper parts of the arena regardless of turbidity level. However, their responses in turbid conditions were less marked and of shorter duration. Turbidity apparently reduced the perceived risk of predation in juvenile chinook.

Greig, C., Robertson, J. M., & Banks, M. A. (2002). Rapid PCR-based species tests for threatened sympatric salmonids. *Conservation Genetics*, *3*(1), 81–84. https://doi.org/10.1023/A:1014281621473

Grémillet, D, Storch, S., & Peters, G. (2000). Determining food requirements in marine top predators: A comparison of three independent techniques in Great Cormorants, Phalacrocorax carbo carbo. *Canadian Journal of Zoology*, *78*(9), 1567–1579. https://doi.org/10.1139/z00-092

Assessment of food requirements is a key feature in the evaluation of the ecological status of the marine megafauna. However, this remains technically difficult because prey intake by marine top predators occurs mainly under water, out of sight. In this paper, we compare three independent methods currently available for use in quantitative dietary studies: (1) time-energy budget; (2) stomach-temperature measurements; and (3) automatic weighing. To this end, concurrent measurements were performed on Great Cormorants (Phalacrocorax carbo carbo) breeding in Normandy. According to the time-energy budget method, breeding males required 690 g of fish while incubating, 1050 g when rearing small chicks, and 1350 g when rearing large chicks; corresponding values for breeding females were 500, 760, and 970 g. These measurements are similar to estimates derived from automatic weighing data, which gave a mean food intake of 540 and 390 g for incubating males and females, 1150 and 830 g for those tending small chicks, and 1410 and 1010 g for those tending large ones, respectively. Stomach-temperature measurements, which can only be performed for birds raising small chicks, were lower (640 g fish in males and 450 g in females) than those obtained using the other two methods. We compare these results with former estimates obtained at the same study site and for other Great Cormorant subspecies and discuss the relative accuracies of the three techniques. Finally, we stress that better assessment of the ecological status of marine top predators requires further technical improvements and additional investigations outside of the reproductive phase.

Gremillet, D., Wright, G., Lauder, A., Carss, D. N., & Wanless, S. (2003). Modelling the daily food requirements of wintering great cormorants: A bioenergetics tool for wildlife management. *Journal of Applied Ecology*, *40*(2), 266–277. https://doi.org/10.1046/j.1365-2664.2003.00806.x

1. Great cormorants Phalacrocorax carbo, Linnaeus are large piscivorous birds which occur in Asia, Australia, Africa, Europe and North America. Their European breeding population has increased by at least 15% per annum over the last 15 years, reaching a total of c. 200 000 pairs in the late 1990s. There are concerns that this increase is adversely affecting freshwater fish populations throughout Europe, but real assessment requires a detailed knowledge of cormorant food requirements. 2. The daily food intake (DFI) of great cormorants has been measured during the breeding season, but little is known about DFI in winter when these poorly insulated birds experience consistently low temperatures. DFI is likely to vary widely according to abiotic and biotic conditions, making predictions about impact particularly difficult. 3. We modelled DFI for great cormorants wintering at Loch Leven, Scotland, using behavioural data recorded via radio-tracking of free-ranging individuals, metabolic measurements obtained from captive birds, and published data. DFI was estimated to be 672 g day−1 (predicted maximum range 441–1095 g day−1), values similar to DFI of great cormorants breeding under temperate conditions and of other aquatic bird species. 4. During winter great cormorants at Loch Leven decreased their average dive time and increased dive efficiency (higher proportion of time spent underwater). They nonetheless spent 130 min day−1 in the water and allocated more than a third of their daily energy budget to diving. 5. Synthesis and applications: In view of the need for the sound management of cormorant populations, we present a general bioenergetics model, based on simple behavioural and dietary inputs, that computes an estimate of DFI outside the breeding season for a range environmental conditions and habitats. An interactive computer programme for this model is available (http://www.cepe.c-strasbourg.fr) to help scientists and managers estimate local values for average, minimum and maximum DFI.

Grémillet, David, Schmid, D., & Culik, B. (1995). Energy requirements of breeding great cormorants Phalacrocorax carbo sinensis. *Marine Ecology Progress Series*, *121*(1/3), 1–9. JSTOR.

Cormorants and humans are purported to compete for fish resources. Recent increases in cormorant populations in western Europe have led to new conflicts between fishermen and nature conservationists, a situation which has stimulated research into the food requirements of these seabirds. However, most dietary studies are based on stomach content or pellet analysis. Both these methods are biased. We used a time-budget model to calculate the energy requirements of great cormorants Phalacrocorax carbo sinensis breeding in Schleswig-Holstein, Germany. The time budgets of the birds were recorded for different breeding phases and the energetic costs of the different activities determined through respirometric measurements or by using values derived from the literature. The food requirements of great cormorants during incubation were calculated to be 238 g adult−1 d−1. These requirements rise to 316 g d−1 during the rearing of young chicks and to 588 g d−1 during rearing of downy chicks. Human disturbance causing great cormorants to fly off their nests entails an additional consumption of 23 g fish per bird or ca 23 kg per disturbance event for a typical colony.

Gress, F., Risebrough, R. W., Anderson, D. W., Kiff, L. F., & Jehl, J. R. (1973). Reproductive Failures of Double-Crested Cormorants in Southern California and Baja California. *The Wilson Bulletin*, *85*(2), 197–208. JSTOR.
Double-crested Cormorants have experienced reproductive failures in colonies on Anacapa Island in southern California and Los Coronados Islands of northwestern Baja California. These failures were characterized by eggs with thin shells that collapsed in the nest during incubation. The pattern of reproductive failures was the same as that observed in Brown Pelicans breeding in the same areas. Shell thinning was not found on San Martín Island, and reproductive success of the cormorant colony there apparently was not affected. Data are given for eggshell measurements and chlorinated hydrocarbon residues for eggs collected from these colonies in 1969. The eggshells from Anacapa and Los Coronados show a 34 percent decrease in thickness from pre-1946 museum eggs. DDE levels in the yolk lipids show a concentration gradient decreasing southward from Anacapa to San Martín. The values of r, (Spearman rank correlation coefficient) between decreasing shell thickness and increasing concentrations of both DDE and PCB are highly significant. PCB levels parallel those of DDE; it was not possible therefore to separate the effects of PCB and DDE on eggshell thinning in this study. The relationship between DDE and shell thickness of these eggs, however, was equivalent to that of midwest fresh-water cormorant colonies. The eggshells from Anacapa and Los Coronados were found to be lacking a chalky cover characteristic of normal eggs, possibly contributing to a greater fragility of the shells. Further field observations indicate an apparent increase of productivity on Anacapa in 1972. No young were observed on Los Coronados in 1970 and 1971. The San Martín colony suffered a decline in 1970, presumably from lack of food resources, but returned to normal numbers in 1971.

Groot, C., & Margolis, L. (Eds.). (1991). *Pacific salmon life histories*. UBC Press.

Gross, J. E., Shipley, L. A., Hobbs, N. T., Spalinger, D. E., & Wunder, B. A. (1993a). Functional Response of Herbivores in Food-Concentrated Patches: Tests of a Mechanistic Model. *Ecology*, *74*(3), 778–791. https://doi.org/10.2307/1940805
Type II functional responses are frequently observed in herbivores feeding in patches where plants are concentrated in space. We tested a mechanistic model of regulation of intake rate of herbivores foraging in food—concentration patches (Laca and Demment 1992, Spalinger and Hobbs 1992) that accounts for asymptotic, Type II responses. The model is based on the hypothesis that competition between cropping and chewing regulates instataneous intake rate in response to changes in the size of bites obtained by the forager. We tested this hypothesis and examined the ability of our model to account for observations of intake rate of 12 species of mammalian herbivores ranging in body mass over 4 orders of magnitude. We measured short—term intake rates of mammalian herbivores feeding in hand—assembled patches of plants. We varied bite size by changing plant height and density in patches offered to herbivores, and observed dry matter intake rates in response to this variation. Averaged across species, our model accounted for 77% of the variance in food intake rate ($P < .001$ for all species). Predictions of maximum intake rate closely resembled observations of processing capacity, demonstrating that processing rather than cropping sets an upper limit on short—term intake. Tests of model mechanisms provided strong support for the hypothesis that competition between cropping and chewing is responsible for the Type II functional response seen in herbivores feeding in food—concentration patches. The model was able to consistently predict intake rates observed in 16

previous studies. These results indicate that plant characteristics regulating bite size (e.g., leaf size and geometry, spinescen) frequently control instantaneous rates of food intake by mammalian herbivores.

Guillaumet, A., Dorr, B., Wang, G., Taylor, J. D., Chipman, R. B., Scherr, H., Bowman, J., Abraham, K. F., Doyle, T. J., & Cranker, E. (2011). Determinants of local and migratory movements of Great Lakes double-crested cormorants. *Behavioral Ecology*, *22*(5), 1096–1103. https://doi.org/10.1093/beheco/arr096

We investigated how individual strategies combine with demographic and ecological factors to determine local and migratory movements in the double-crested cormorants (Phalacrocorax auritus). One hundred and forty-five cormorants were captured from 14 nesting colonies across the Great Lakes area and fitted with satellite transmitters. We first tested the hypotheses that sexual segregation, density-dependent effects, and the intensity of management operations influenced home range size during the breeding season. The influence of these factors appeared to be limited in part due to random variability in foraging and dispersal decisions at individual and colony levels. We also designed a statistical framework to investigate the degree and determinants of migratory connectivity. Our analyses revealed a significant migratory connectivity in cormorants, although we also observed a nonnegligible amount of individual variability and flexibility. Our data were most consistent with the existence of a migratory divide across the Great Lakes, with western populations using mainly the Mississippi Flyway and eastern populations the Atlantic Flyway. Previous and current studies suggest that the divide cannot be explained by past divergence in isolation, a way to diminish travel cost, or the Appalachians constituting an ecological barrier per se but is rather the consequence of the distribution of suitable stopover and nonbreeding areas. However, a parallel migration system and no migratory divide could not be entirely ruled out with present data.

Guillemette, M., & Brousseau, P. (2001). Does culling predatory gulls enhance the productivity of breeding common terns? *Journal of Applied Ecology*, *38*(1), 1–8. https://doi.org/10.1046/j.1365-2664.2001.00564.x

1. Large gulls Larus spp. are voracious predators of eggs and chicks of other colonial birds and may threaten rare or endangered species. In this study we tested the effectiveness of removing individual predatory gulls as a management technique for enhancing the productivity of common terns Sterna hirundo nesting in Carleton, Québec, Canada. 2. The productivity and fate of common tern chicks were assessed by following ringed individuals from hatching to fledging during three breeding seasons (1993–95). Concurrently, predation and consumption rates of all predatory gulls were measured before and after the culling started. The culling programme was conducted serially in 1994 by removing the most important predator first until all predators were removed. 3. The rate of chick disappearance was lower and the life span of tern broods was higher in 1994 when the culling was conducted, compared with 1993 and 1995. As a result, the productivity of the tern colony was zero in 1993 and 1995, but positive in 1994 (0·33 chicks/pair). Measurements of chick mass in 1993 and 1994 showed that growth was normal, indicating that poor feeding conditions or disease were not the cause of chick disappearance. 4. Average predation rates for 1993 (23·3 chicks/day) and 1995 (14·8 chicks/day) equated to 61% and 66% of available chicks being taken by gulls, respectively. The predation rate before the culling started in 1994 was similar to 1993 and 1995, with 15·9 chicks/day, but dropped to 5·1 chicks/day after the first gull was shot, and decreased to zero once all predatory gulls were

removed. Only five individual predatory gulls were identified during the cull. 5. Predation rates differed markedly amongst specialist predatory gulls, with one individual accounting for 85% of all successful attempts made during the baseline period. Once that gull was removed, the remaining predators increased their predation rate in a manner suggestive of a despotic system. Observations conducted in 1995 showed that the predation rate was almost zero at the beginning of the season but increased dramatically later in the summer, with two gulls together making about 60% of the captures. 6. It is concluded that culling predatory gulls can be an effective management tool to enhance productivity in sensitive or endangered species. However, our data suggest that such culling would need to be repeated each year in order to protect a sensitive species over consecutive years.

Haeseker, S. L., McCann, J. A., Tuomikoski, J., & Chockley, B. (2012). Assessing Freshwater and Marine Environmental Influences on Life-Stage-Specific Survival Rates of Snake River Spring–Summer Chinook Salmon and Steelhead. *Transactions of the American Fisheries Society*, *141*(1), 121–138. https://doi.org/10.1080/00028487.2011.652009

Pacific salmon Oncorhynchus spp. from the Snake River basin experience a wide range of environmental conditions during their freshwater, estuarine, and marine residence, which in turn influence their survival rates at each life stage. In addition, researchers have found that juvenile out-migration conditions can influence subsequent survival during estuarine and marine residence, a concept known as the hydrosystem-related, delayed-mortality hypothesis. In this analysis, we calculated seasonal, life-stage-specific survival rate estimates for Snake River spring–summer Chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss and conducted multiple-regression analyses to identify the freshwater and marine environmental factors associated with survival at each life stage. We also conducted correlation analyses to test the hydrosystem-related, delayed-mortality hypothesis. We found that the freshwater variables we examined (the percentage of river flow spilled over out-migration dams and water transit time) were important for characterizing the variation in survival rates not only during freshwater out-migration but also during estuarine and marine residence. Of the marine factors examined, we found that the Pacific Decadal Oscillation index was the most important variable for characterizing the variation in the marine and cumulative smolt-to-adult survival rates of both species. In support of the hydrosystem-related, delayed-mortality hypothesis, we found that freshwater and marine survival rates were correlated, indicating that a portion of the mortality expressed after leaving the hydrosystem is related to processes affected by downstream migration conditions. Our results indicate that improvements in life-stage-specific and smolt-to-adult survival may be achievable across a range of marine conditions through increasing spill percentages and reducing water transit times during juvenile salmon out-migration.

Haeseker, S. L., Scheer, G., & McCann, J. (2020). Avian Predation on Steelhead is Consistent with Compensatory Mortality. *The Journal of Wildlife Management*, *84*(6), 1164–1178. https://doi.org/10.1002/jwmg.21880

Numerous factors such as predation, disease, injury, and environmental conditions (e.g., river flows, hydropower operations) can influence survival rates of fish. Although mortality due to predation is commonly assumed to be additive and result in a directly proportional reduction on survival rates, compensatory processes may work to counteract or negate the effects of predation mortality on survival rates. We applied a random effects model to a long-term, mark-recapture-recovery data set on anadromous steelhead (Oncorhynchus mykiss) from the Snake River Basin

in the northwestern United States to assess whether avian predation mortality constitutes an additive or compensatory source of mortality. Specifically, our assessment focused on predation mortality due to double-crested cormorants (Phalacrocorax auritus) and Caspian terns (Hydroprogne caspia) on colonies in the Columbia River estuary. In addition, we evaluated several candidate environmental indices to examine potential interactions between the effects of predation versus environmental conditions on steelhead survival rates. Average predation rates were 3.3% for the double-crested cormorant colony and 17.0% for the Caspian tern colony. For both colonies, the estimated correlation between the predation rate and survival rate of steelhead was near zero, indicating that mortality due to avian predation is compensatory. Models that included variables for river flow, juvenile migration timing, and an index of forage biomass in the ocean accounted for 56–59% of the variation in steelhead survival, whereas avian predation rates accounted for <1% of the variation. Management efforts to reduce the abundance of the bird colonies are unlikely to improve the survival or conservation status of steelhead; however, results indicate that steelhead survival could be improved by hydropower management decisions that increase river flows and reduce juvenile migration delays.

Halfyard, E. A., Gibson, A. J. F., Ruzzante, D. E., Stokesbury, M. J. W., & Whoriskey, F. G. (2012). Estuarine survival and migratory behaviour of Atlantic salmon Salmo salar smolts. *Journal of Fish Biology*, *81*(5), 1626–1645. https://doi.org/10.1111/j.1095-8649.2012.03419.x

To estimate mortality rates, assess the spatio-temporal dynamics of natural mortality and examine migratory behaviour during the fresh to saltwater transition, 185 wild Atlantic salmon Salmo salar smolts were implanted with coded acoustic transmitters. Seaward migration of tagged S. salar from four river systems in an area of Nova Scotia, Canada known as the Southern Upland was monitored using fixed receivers and active telemetry over 3 years. Cumulative survival through the river, inner estuary, outer estuary and bay habitats averaged 59·6% (range = 39·4–73·5%). When standardized to distance travelled, survival rates followed two patterns: (1) constant rates of survival independent of habitat or (2) low survival most frequently associated with inner estuary habitats. In rivers where survival was independent of habitat, residency periods were also independent of habitat, post-smolts exhibited few upstream movements, took a more direct route to the ocean and reached the ocean rapidly. Alternatively, in rivers where survival was habitat specific, residency was also habitat specific with overall increased residency, more frequent upstream movements and delayed arrival to the open ocean. The sudden disappearance of most (75–100%) smolts and post-smolts assumed dead during the course of this study warrants further examination into the role of avian predators as a mortality vector.

Halsing, D. L., & Moore, M. R. (2008). Cost-Effective Management Alternatives for Snake River Chinook Salmon: A Biological-Economic Synthesis. *Conservation Biology*, *22*(2), 338–350. https://doi.org/10.1111/j.1523-1739.2008.00913.x

The mandate to increase endangered salmon populations in the Columbia River Basin of North America has created a complex, controversial resource-management issue. We constructed an integrated assessment model as a tool for analyzing biological-economic trade-offs in recovery of Snake River spring- and summer-run chinook salmon (Oncorhynchus tshawytscha). We merged 3 frameworks: a salmon-passage model to predict migration and survival of smolts; an age-structured matrix model to predict long-term population growth rates of salmon stocks; and a cost-effectiveness analysis to determine a set of least-cost management alternatives for achieving

particular population growth rates. We assessed 6 individual salmonmanagement measures and 76 management alternatives composed of one or more measures. To reflect uncertainty, results were derived for different assumptions of effectiveness of smolt transport around dams. Removal of an estuarine predator, the Caspian Tern (Sterna caspia), was cost-effective and generally increased long-term population growth rates regardless of transport effectiveness. Elimination of adult salmon harvest had a similar effect over a range of its cost estimates. The specific management alternatives in the costeffective set depended on assumptions about transport effectiveness. On the basis of recent estimates of smolt transport effectiveness, alternatives that discontinued transportation or breached dams were prevalent in the cost-effective set, whereas alternatives that maximized transportation dominated if transport effectiveness was relatively high. More generally, the analysis eliminated 80–90% of management alternatives from the cost-effective set. Application of our results to salmon management is limited by data availability and model assumptions, but these limitations can help guide research that addresses critical uncertainties and information. Our results thus demonstrate that linking biology and economics through integrated models can provide valuable tools for science-based policy and management.

Hansel, H. C., Duke, S. D., Lofy, P. T., & Gray, G. A. (1988). Use of Diagnostic Bones to Identify and Estimate Original Lengths of Ingested Prey Fishes. *Transactions of the American Fisheries Society*, *117*(1), 55–62. https://doi.org/10.1577/1548-8659(1988)117<0055:UODBTI>2.3.CO;2
We examined and measured cleithra, dentaries, opercles, and pharyngeal arches – bones found to persist during digestion of most prey fish – to identify 24 prey fish species and back-calculate their original fork length. Eighteen of the 24 species examined could be easily distinguished; however, for certain congenerics, identification was neither consistent nor reliable for all bones within the size ranges examined. Relations between bone length and fish length were linear for 14 species for which the sample sizes were adequate (N > 30); coefficients of determination (r 2) ranged from 0.79 to 0.99. Diagnostic characteristics and measurements of these bones provided reliable identification of genera and species and estimates of original fork lengths of partly digested prey fish from three predators. This method, compared with that of examining only prey fish in a measurable condition, greatly increased the amount of dietary information available from gut analysis.

Hanson, W. C. (1963). Census of Ring-billed and California Gull Colonies in Eastern Washington. *The Condor*, *65*(2), 163–164. https://doi.org/10.1093/condor/65.2.163a

Hanson, Wayne C. (1968). Recent History of Double-Crested Cormorant Colonies in Southeastern Washington. *The Murrelet*, *49*(2), 25–26. JSTOR. https://doi.org/10.2307/3535244

Harnish, R. A., Green, E. D., Deters, K. A., Ham, K. D., Deng, Z., Li, H., Rayamajhi, B., Jung, K. W., & McMichael, G. A. (2014). *Survival of Wild Hanford Reach and Priest Rapids Hatchery Fall Chinook Salmon Juveniles in the Columbia River: Predation Implications* (PNNL-23719; p. 66). https://waterpower.pnnl.gov/jsats/pdf/Harnish_etal_URB_predation_loss_report_FINAL_2014-10-30.pdf
The population of fall Chinook salmon that inhabits the Hanford Reach comprises the majority of the Columbia Upriver Bright (URB) stock and is one of the most productive Chinook salmon stocks in the Pacific Northwest. Recent studies indicated that much of the high productivity of the population may be attributed to very high survival during early freshwater life stages within the

Hanford Reach. However, some evidence suggests significant mortality of smolts occurs over a short period of time and distance as they migrate from the Hanford Reach to McNary Dam. Large populations of piscivorous fishes and birds inhabit the Columbia River and may be responsible for this mortality. We implanted 200 wild Hanford Reach and 200 Priest Rapids Hatchery (PRH) URB fall Chinook salmon with acoustic transmitters and estimated their survival through multiple reaches of the Columbia River to identify mortality "hot spots" and to help classify the putative source(s) of mortality. Acoustic-tagged wild Hanford Reach fall Chinook salmon had an estimated survival probability of 0.50 from release to McNary Dam. This estimate is considerably higher than was observed in 2014 for the group of wild Hanford Reach fall Chinook salmon juveniles implanted with passive integrated transponders (PIT-only; S = 0.34). The large discrepancy between survival estimates derived from acoustic-tagged versus PIT-only groups is likely a result of the difference in fish size between groups. We attempted to minimize the effect of the transmitter on the performance of implanted fish by only tagging fish that measured ≥80 mm FL; whereas, fish as small as 60 mm FL were implanted with PIT tags. As we demonstrated, survival of these fish is strongly, positively correlated with fish length. Therefore, we expect that the survival of the overall population of juvenile wild Hanford Reach fall Chinook salmon through the study area was substantially lower than it was for acoustic-tagged fish. However, we believe that the relative losses of tagged fish by reach were representative of the overall population. Acoustic-tagged PRH smolts also had an estimated survival probability of 0.50 from release to McNary Dam; albeit over a longer reach than was traversed by the wild group. This estimate is substantially lower than what was observed for PIT-only PRH smolts in 2014 (S = 0.66). The difference in survival between groups of acoustic-tagged and PIT-only PRH fall Chinook salmon juveniles may have been the result of a reduction in performance of acoustic-tagged fish caused by the tagging procedure or presence of the tag, and/or a result of acoustic transmitter loss (i.e., tag shedding). Although results from a 60-day laboratory study conducted at PNNL found a very high rate of fish survival (99.2%) and tag retention (100%) of 126 fish implanted with the same transmitter and surgical technique, we observed relatively high post-tagging, pre-release mortality for the group of PRH fall Chinook salmon we implanted with acoustic transmitters for the in-river survival evaluation described in this report. Because reaches differed in length, survival is better compared among reaches on a per-kilometer basis to identify potential mortality "hot spots". Survival-per-kilometer (Skm) was generally lower in the transition area between the Hanford Reach and McNary Reservoir, within McNary Reservoir, and in the upper half of John Day Reservoir (down to Crow Butte) than in reaches located downstream of Crow Butte. The lowest Skm was observed in the immediate forebay of McNary Dam for both wild and hatchery fish. As expected, travel rates were fastest in flowing reaches (i.e., Hanford Reach and dam tailraces) and slowest through reservoirs. We observed a significant, positive relationship between the probability of survival to McNary Dam and fish length. Data from this study and others indicate much of the mortality incurred by URB fall Chinook salmon juveniles between Priest Rapids and Bonneville dams can likely be attributed to predation from resident piscivorous fish. Analyzing 8 years of data, we observed no significant relationship between the survival of PIT-only wild Hanford Reach fall Chinook salmon to McNary Dam and the size of the primary avian predator nesting colonies located in McNary Reservoir. We also did not observe mortality "hot spots" in the reaches of the Columbia River that contain the largest colonies of predaceous waterbirds. Instead, we observed relatively consistent mortality rates between release and Crow Butte, which is more indicative of predation from piscivorous fish, which are more widely distributed than avian predators. In addition, results of studies conducted to assess avian predation rates have consistently estimated very low predation rates (<2%) on subyearling fall Chinook salmon upstream of Bonneville Dam. Alternatively, predation rates estimated for piscivorous fish suggest they may be consuming 17% of the juvenile salmon that enter John Day Reservoir during June, July, and August, when most salmon smolts entering the reservoir are subyearling fall Chinook salmon. Our study confirmed that the loss rates of juvenile URB fall Chinook salmon from the Hanford Reach were high in areas where habitat has been influenced by hydropower development and native and nonnative predatory fish species. Whereas our study had some limitations due to 1) the size of fish we were able to tag, 2) the potential for a tag or tagging effect on fish performance, and 3) possible tag loss, we believe that the relative loss rates are representative for the wild Hanford Reach and Priest Rapids Hatchery portions of the URB stock. Much of the mortality appears to be concentrated in the river/reservoir transition area where large predator-rich tributaries enter as well as in the immediate dam forebays where travel rates of outmigrating smolts are slowed. Additional work to document how the predation rates we observed in the larger size classes of juvenile URB fall Chinook salmon relate to the overall population, as well as efforts to determine the potential effectiveness of management actions intended to reduce the populations and/or productivity of piscivorous fish species will provide the information necessary to enable managers to design and implement strategies to improve the freshwater survival of this important stock.

Harnish, Ryan A., Johnson, G. E., McMichael, G. A., Hughes, M. S., & Ebberts, B. D. (2012). Effect of Migration Pathway on Travel Time and Survival of Acoustic-Tagged Juvenile Salmonids in the Columbia River Estuary. *Transactions of the American Fisheries Society*, *141*(2), 507–519. https://doi.org/10.1080/00028487.2012.670576

We applied acoustic telemetry methods to characterize migration pathways and estimate associated travel times and survival probabilities for juvenile Chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss migrating downstream through the Columbia River estuary (from river kilometer [rkm] 86 to rkm 8). Acoustic-tagged fish were detected as migrating in the navigation channel and in off-channel areas at each of the estuarine reaches we examined during May–August 2010. However, the majority of fish traveled in the main navigation channel from rkm 86 to rkm 37, at which point most fish left the river-influenced navigation channel; crossed a broad, shallow tidal flat; and migrated the final 37 km in a secondary channel, which was characterized as having greater tidal transport than the navigation channel. The pathway used by acoustic-tagged smolts to migrate through the estuary affected their rate of travel. In most reaches, navigation channel migrants traveled significantly faster than fish that migrated through off-channel areas. Contrary to observations from previous studies, smolts that migrated through off-channel areas at a slower rate did not experience lower survival than their cohorts that used the navigation channel. Although no significant differences in survival probability were observed between navigation channel migrants and off-channel migrants, areas of high mortality were identified between rkm 37 and rkm 8. Dispersion of juvenile salmonids into multiple pathways during downstream migration can be beneficial in terms of increased expression of life history diversity and resiliency to environmental perturbations. Our results, which document juvenile salmon migration pathways and associated travel time and survival through a large estuary, can be used to focus future research and management activities in areas identified as having high mortality and therefore can be used to aid in the recovery of Endangered Species Act-listed salmon populations.

Harper, J., & Collis, K. (2018). *2018 Hazing and Dissuasion of Caspian Terns in the Lower Columbia Estuary: Season End Summary Report* (p. 10). http://www.birdresearchnw.org/FinalAvianPredationSummaryReport2018.pdf

As a component of a comprehensive strategy for salmonid (Oncorhynchus spp.) recovery in the Columbia Basin, the Caspian Tern Management Plan for the Columbia River Estuary has been developed to reduce the impacts of Caspian terns (Hydroprogne caspia) nesting on East Sand Island on the survival of juvenile salmonids listed under the Endangered Species Act (ESA; NOAA 2017). The management initiatives that are being implemented call for dispersal of nesting Caspian terns to alternative nest sites outside the Columbia Basin (USFWS 2005, 2006), while preventing Caspian terns from nesting elsewhere in the Columbia River estuary, specifically on Rice Island and other dredge material disposal sites in the upper estuary. The primary objective of this work is to assist the U.S. Army Corps of Engineers (Corps) in implementation of the management plan by monitoring Caspian tern use of the upper estuary and to dissuade Caspian terns from nesting at these sites. As part of the Caspian Tern Management Plan, the objective of this project was to prevent Caspian terns from nesting on three dredge material disposal islands in the upper Columbia River estuary; Rice (Rkm 34), Miller Sands (Rkm 38), and Pillar Rock (Rkm 43) islands. This objective was achieved using boat and foot-based patrols, passive dissuasion (i.e., fencing, posts, rope, and flagging) and active hazing.

Hartman, C. A., Ackerman, J. T., Herzog, M. P., Strong, C., Trachtenbarg, D., & Shore, C. A. (2018). *Social attraction used to establish Caspian tern (Hydroprogne caspia) nesting colonies on modified islands at the Don Edwards San Francisco Bay National Wildlife Refuge, California—Final report* (Open-File Report U.S. Geological Survey Open-File Report 2018-1136; Open-File Report, p. 52). https://doi.org/10.3133/ofr20181136

To address the 2008/2010 and Supplemental 2014 National Oceanic and Atmospheric Administration Fisheries Biological Opinion for operation of the Federal Columbia River Power System, the U.S. Army Corps of Engineers (USACE) and the Bureau of Reclamation (Reclamation) developed and began implementation of Caspian tern (Hydroprogne caspia) management plans. This implementation includes redistribution of the Caspian terns in the Columbia River estuary and the mid-Columbia River region to reduce predation on salmonids listed under the Endangered Species Act. Key elements of the plans are (1) reduction of nesting habitat for Caspian terns in the Columbia River estuary and the mid-Columbia River region, and (2) creation or modification of nesting habitat at alternative sites within the Caspian tern breeding range. As part of this effort, USACE and Reclamation developed Caspian tern nesting habitat at the U.S. Fish and Wildlife Service Don Edwards San Francisco Bay National Wildlife Refuge (DENWR), California, prior to the 2015 nesting season. Furthermore, nesting habitat for western snowy plovers (Charadrius alexandrinus nivosus) also was developed to provide separate nesting opportunities in the same managed ponds to reduce potential conflicts with Caspian terns. Specifically, seven recently constructed islands within two managed ponds (Ponds A16 and SF2) of DENWR were modified to provide habitat attractive to nesting Caspian terns (5 islands) and snowy plovers (2 islands). These 7 islands were a subset of 46 islands recently constructed in Ponds A16 and SF2 to provide waterbird nesting habitat as part of the South Bay Salt Pond (SBSP) Restoration Project. We used social attraction methods (decoys and electronic call systems) to attract Caspian terns and snowy plovers to these seven modified islands, and conducted surveys from March to September of 2015, 2016, and 2017 to evaluate nest numbers, nest density, and productivity. Results from the 2015 nesting season, the first year of the study, indicated that island modifications and social attraction measures were successful in establishing Caspian tern breeding colonies at Ponds A16 and SF2 of DENWR. Prior to 2015, there was no history of Caspian terns nesting in either Pond A16 or Pond SF2. The success of 2015 continued in 2016 and 2017. In 2017, the third and final year of the project, Caspian terns initiated at least 664 nests, fledged at least 239 chicks, and had a breeding success rate of 0.36 fledged chicks per breeding pair. This represents a 171 percent increase in the number of breeding pairs and a 41 percent increase in the number of chicks fledged, but a 48 percent decrease in the fledglings produced per breeding pair in 2017 compared to 2015, the first year the colonies were established. The two new large and growing Caspian tern nesting colonies at Ponds A16 and SF2 demonstrate the effectiveness of social attraction measures in helping to establish tern nesting colonies in San Francisco Bay. Social attraction measures similar to those used in this study, but targeting other colonial species such as Forster's terns (Sterna forsteri) and American avocets (Recurvirostra americana), may help to establish waterbird breeding colonies at wetlands enhanced as part of the SBSP Restoration Project.

Hartman, C. Alex, Ackerman, J. T., Herzog, M. P., Strong, C., & Trachtenbarg, D. (2019). Social attraction used to establish Caspian tern nesting colonies in San Francisco Bay. *Global Ecology and Conservation*, *20*, e00757. https://doi.org/10.1016/j.gecco.2019.e00757

Conservation of colonial waterbird breeding populations often includes restoring historic nesting habitat or establishing new nesting habitat in protected areas. However, colonization of new or restored nesting habitat may be hindered by the lack of social cues from nesting conspecifics to attract prospecting birds. Social attraction, whereby decoys and colony sound recordings are used to mimic active nesting colonies, has been used successfully to establish waterbird nesting colonies throughout the world. We constructed islands, modified the substrate so that it was attractive to nesting Caspian terns (Hydroprogne caspia), and then used social attraction to establish nesting colonies within two managed ponds in San Francisco Bay, California where Caspian terns had not previously nested. During the 2015–2017 breeding seasons, we deployed decoys of adult Caspian terns, broadcasted colony sound recordings, and monitored Caspian tern response. Caspian terns formed nesting colonies within weeks of social attraction deployment at each of the two ponds in 2015, and the size of these colonies increased in each subsequent year of the study. In 2017, the final year of the study, we estimated a minimum of 501 breeding pairs between the two colonies, making them two of the three largest Caspian tern colonies in the San Francisco Bay estuary. In total, these two colonies produced 1343 nests and 531 fledglings over the three-year study period. Nest densities were low (mean: 0.29 nests/m2 of active colony area) compared to other studies, and greater than 80% of the modified island habitat remained unused by nesting Caspian terns in 2017, suggesting that there is additional space for future colony growth. The successful establishment of two of the largest Caspian tern nesting colonies in the San Francisco Bay estuary in just three years demonstrates the potential of using island construction and habitat modifications, combined with social attraction measures to establish waterbird nesting colonies.

Hartman, C. Alex, Ackerman, J. T., Herzog, M. P., Strong, C., Trachtenbarg, D., Sawyer, K. A., & Shore, C. A. (2016). Evaluation of Caspian tern (Hydroprogne caspia) and snowy plover (Charadrius alexandrinus nivosus) nesting on modified islands at the Don Edwards San Francisco Bay National Wildlife Refuge, California—2015 Annual Report. In *Evaluation of*

Caspian tern (Hydroprogne caspia) and snowy plover (Charadrius alexandrinus nivosus) nesting on modified islands at the Don Edwards San Francisco Bay National Wildlife Refuge, California—2015 Annual Report (USGS Numbered Series No. 2016–1049; Open-File Report, Vols. 2016–1049, p. 46). U.S. Geological Survey. https://doi.org/10.3133/ofr20161049

Executive Summary In order to address the 2008/10 NOAA Fisheries Biological Opinion for operation of the Federal Columbia River Power System, the U.S. Army Corps of Engineers (USACE) and the Bureau of Reclamation (Reclamation) have developed and begun implementation of Caspian tern (Hydroprogne caspia) management plans. This implementation includes relocating nesting Caspian terns out of the Columbia River estuary and the mid-Columbia River region to reduce predation on salmonids listed under the Endangered Species Act. USACE and Reclamation developed Caspian tern nesting habitat at the U.S. Fish and Wildlife Service Don Edwards San Francisco Bay National Wildlife Refuge (DENWR), California prior to the 2015 nesting season. Further, to reduce or eliminate potential conflicts between nesting Caspian terns and threatened western snowy plovers (Charadrius alexandrinus nivosus), nesting habitat for snowy plovers also was developed. Seven recently constructed islands within two managed ponds (Ponds A16 and SF2) of DENWR were modified to provide habitat attractive to nesting Caspian terns (5 islands), and snowy plovers (2 islands). These seven islands were a subset of 46 islands recently constructed in Ponds A16 and SF2 to provide waterbird nesting habitat as part of the South Bay Salt Pond (SBSP) Restoration Project. We used social attraction methods (decoys and electronic call systems) to attract Caspian terns and snowy plovers to these seven modified islands, and conducted surveys between March and September 2015 to evaluate nest numbers, nest density, and productivity. Results from the 2015 nesting season indicate that island modifications and social attraction measures were successful in establishing Caspian tern breeding colonies at Ponds A16 and SF2 of DENWR. Caspian terns nested on three of the five islands modified for Caspian terns (1 island in Pond A16 and 2 islands in Pond SF2). Caspian terns initiated at least 224 nests, fledged at least 174 chicks, and exhibited a breeding success rate of 0.78 fledged chicks/breeding pair. These results are promising considering it was the first year of the study and there was no prior history of Caspian terns nesting at Ponds A16 and SF2. In contrast, snowy plovers did not attempt to nest on any island in Ponds A16 and SF2. These results demonstrate the potential of social attraction measures to help establish tern nesting colonies in San Francisco Bay. Social attraction measures similar to those used in this study, but targeting other species such as Forster's terns and American avocets, may help to establish waterbird breeding colonies at wetlands enhanced as part of the SBSP Restoration Project.

Hartman, C. Alex, Ackerman, J. T., Herzog, M. P., Strong, C., Trachtenbarg, D., & Shore, C. A. (2017). Evaluation of Caspian tern (Hydroprogne caspia) and snowy plover (Charadrius alexandrinus nivosus) nesting on modified islands at the Don Edwards San Francisco Bay National Wildlife Refuge, California—2016 Annual Report. In *Evaluation of Caspian tern (Hydroprogne caspia) and snowy plover (Charadrius alexandrinus nivosus) nesting on modified islands at the Don Edwards San Francisco Bay National Wildlife Refuge, California—2016 Annual Report* (USGS Numbered Series No. 2017–1055; Open-File Report, Vols. 2017–1055, p. 48). U.S. Geological Survey. https://doi.org/10.3133/ofr20171055

Executive SummaryIn order to address the 2008/10 and Supplemental 2014 NOAA Fisheries Biological Opinion for operation of the Federal Columbia River Power System, the U.S. Army Corps of Engineers (USACE) and the Bureau of Reclamation (Reclamation) developed and have begun implementation of Caspian tern (Hydroprogne caspia) management plans. This implementation includes redistribution of the Caspian terns in the Columbia River estuary and the mid-Columbia River region to reduce predation on salmonids listed under the Endangered Species Act. Key elements of the plans include (1) reducing nesting habitat for Caspian terns in the Columbia River estuary and the mid-Columbia River region, and (2) creating or modifying nesting habitat at alternative sites within the Caspian tern breeding range. USACE and Reclamation developed Caspian tern nesting habitat at the U.S. Fish and Wildlife Service Don Edwards San Francisco Bay National Wildlife Refuge (DENWR), California, prior to the 2015 nesting season. Furthermore, to reduce or eliminate potential conflicts between nesting Caspian terns and threatened western snowy plovers (Charadrius alexandrinus nivosus), nesting habitat for snowy plovers also was developed. Seven recently constructed islands within two managed ponds (Ponds A16 and SF2) of DENWR were modified to provide habitat attractive to nesting Caspian terns (5 islands) and snowy plovers (2 islands). These 7 islands were a subset of 46 islands recently constructed in Ponds A16 and SF2 to provide waterbird nesting habitat as part of the South Bay Salt Pond (SBSP) Restoration Project.We used social attraction methods (decoys and electronic call systems) to attract Caspian terns and snowy plovers to these seven modified islands, and conducted surveys between March and September of 2015 and 2016 to evaluate nest numbers, nest density, and productivity. Results from the 2015 nesting season, the first year of the study, indicated that island modifications and social attraction measures were successful in establishing Caspian tern breeding colonies at Ponds A16 and SF2 of DENWR. The success of 2015 continued in 2016, the second year of the study. In 2016, Caspian terns nested on two of the five islands modified for Caspian terns (one island in Pond A16 and one island in Pond SF2). Caspian terns initiated at least 317 nests, fledged at least 158 chicks, and had a breeding success rate of 0.50 fledged chicks per breeding pair. This represents a 42 percent increase in nests initiated, a 9 percent decrease in the number of fledged chicks, and a 36 percent decrease in the number of chicks fledged per breeding pair in 2016 compared to 2015. Although overall productivity decreased from 2015, these results indicate that the Caspian tern breeding population on modified islands of the DENWR is increasing relative to 2015, the first year of the effort, and relative to years

Hatch, J. J. (1995). Changing Populations of Double-Crested Cormorants. *Colonial Waterbirds*, *18*, 8–24. JSTOR. https://doi.org/10.2307/1521520

The Double-crested Cormorant (Phalacrocorax auritus) has a wider range in North America than any of the five other breeding cormorants and is the only species to occur extensively in the interior as well as on the coasts. Breeding birds are currently known in 40 of the 50 States of the United States, all 10 Canadian Provinces, and in Mexico, Cuba and the Bahamas. There are six more-or-less distinct populations, and five subspecies have been described but their significance is unclear because measurements overlap substantially and the distributions of crest characters are poorly known. Scattered archeological and historical accounts indicate that numbers in the Interior and Atlantic populations declined during the 19th century, and subsequent increases have been facilitated, but not fully explained, by dam-building and by declines in persecution. Numbers increased from the 1920s into the 1950s when pesticides had major impacts. The Interior populations fell to low points about 1970 and the Atlantic population ceased growing. The species was recognized as of “Special Concern” in several states during this period. For the past 20 years numbers have been increasing rapidly in most areas, although information on non-breeding birds is very sparse. Particularly large increases are reported for the subspecies auritus, both the Interior population centered in the Canadian Prairie Provinces and Great Lakes (220,000 pairs) and the Atlantic population on the Northeast Coast (96,000 pairs). These birds migrate to winter in the South, chiefly in coastal areas from Texas to North Carolina, where there is considerable overlap of birds from diverse breeding areas. The numbers of the resident populations in Florida and the Caribbean comprising subspecies floridanus and heuretus (14,000 pairs) are poorly known and are probably declining. The status of the small population in Alaska (cincinatus) (3,000 pairs) is not known. On the West Coast (albociliatus) (31,000 pairs) the numbers in Canada and the United States are increasing rapidly, but the status of Mexican populations is unclear. The migrations of the populations in the Pacific are not well characterized.

Haynes, T. B., Tibbles, M., Rodriguez, K., Perrault, B. H., & Robards, M. D. (2017). Successful Breeding of Caspian Terns Hydroprogne caspia in the Arctic-Part of the New Normal? *Marine Ornithology*, *45*, 143–148.

Caspian Terns Hydroprogne caspia have expanded their range in the Eastern Pacific, including southern areas of Alaska, over the past several decades. In 2015, we discovered a pair of Caspian Terns on a small gravel island within Krusenstern Lagoon in Cape Krusenstern National Monument and monitored their breeding status until they successfully fledged two chicks. This site is 653 km north of where Caspian Terns had previously been reported to successfully fledge a chick, and represents the first observations of the species breeding above the Arctic Circle or along the Chukchi Sea coastline. The successful fledging of two chicks at Krusenstern Lagoon suggests that this site, and possibly other Arctic sites, can be suitable breeding habitat. Snow cover and sea-ice duration have decreased dramatically in the Chukchi Sea region over the past four decades; as well, seasonal melt-out has become earlier and freeze-up later. As a result of the longer ice-free season, the Arctic may have recently become available as Caspian Tern breeding habitat as it can now accommodate the long breeding season of this species.

Hayward, J. L., & Verbeek, N. A. (2020). *Glaucous-winged Gull—Larus glaucescens—Birds of the World*. https://birdsoftheworld.org/bow/species/glwgul/cur/introduction

Henny, C. J., Blus, L. J., Thompson, S. P., & Wilson, U. W. (1989). Environmental Contaminants, Human Disturbance and Nesting of Double-Crested Cormorants in Northwestern Washington. *Colonial Waterbirds*, *12*(2), 198–206. JSTOR. https://doi.org/10.2307/1521341

Double-crested Cormorants (Phalacrocorax auritus) in extreme northwestern Washington produced few young (0.27/occupied nest) in 1984; the clutch size was generally small and eggs, if laid at all, were laid later than usual. Residues (geometric means, wet weight) of DDE (0.58 and 0.59 ppm) in eggs from Colville Island and Protection Island were lower than from other locations in the Pacific Northwest, while PCBs (2.19 and 1.37 ppm) were similar to those at most locations. Both contaminants in 1984 were below levels associated with reproductive problems. Eggs also contained concentrations of mercury (0.26 and 0.27 ppm) and selenium (0.31 and 0.28 ppm) below levels associated with reproductive problems. The distribution of nesting colonies in the study area changed dramatically since 1984. The cormorants were most likely responding to increased human disturbance in the San Juan Islands, coupled to additional protection and reduced human activity on Protection and Smith Islands. This presumably led to the abandonment of all nesting islands in the San Juans. The nesting population in the study area in 1988 (all on Protection and Smith Islands) was the highest recorded.

Herring, G., Ackerman, J. T., Eagles-Smith, C. A., Adelsbach, T. L., Melancon, M. J., Stebbins, K. R., & Hoffman, D. J. (2010). Organochlorine and PBDE Concentrations in Relation to Cytochrome P450 Activity in Livers of Forster's Terns (Sterna forsteri) and Caspian Terns (Hydroprogne caspia), in San Francisco Bay, California. *Archives of Environmental Contamination and Toxicology*, *58*(3), 863–873. https://doi.org/10.1007/s00244-009-9366-z

We measured halogenated organic contaminants (HOCs) [polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), and dichloro-diphenyl-trichloroethane (DDT)] and P450 [e.g., ethoxyresorufin-O-dealkylase (EROD)] stress in livers from Caspian tern (Hydroprogne caspia) adults and Forster's tern (Sterna forsteri) adults and chicks in San Francisco Bay (SFB). Penta BDEs and tetra PBDEs composed 46–66% of ∑PBDE in terns. PCB homologues di, tri, penta, hexa, and hepta composed 93–95% of ∑PCBs and p′p-DDE composed 82–98% of all ∑DDTs. We found similar concentrations of ∑PBDEs [mean micrograms per gram wet weight (ww) ± standard error = 0.4 ± 0.1], ∑PCBs (5.9 ± 1.6), and ∑DDTs (0.6 ± 0.1) among species, sexes, and regions. However, concentrations were higher in Forster's tern adults than chicks (∑PBDEs = 0.4 ± 0.1 and 0.1 ± 0.1; ∑PCBs = 7.08 ± 2.4 and 2.4 ± 1.4; ∑DDTs = 0.5 ± 0.1 and 0.1 ± 0.1; respectively), and there was a nonsignificant trend of elevated ∑PBDEs and ∑PCBs for adult Forster's terns in the Central South Bay and Lower South Bay portions of SFB. Combined Forster's tern and Caspian tern ∑DDTs bioaccumulated similarly to selenium, but not mercury, and there was a nonsignificant but positive trend for ∑PBDEs and ∑PCBs bioaccumulation with mercury. P450 protein activity was higher in adult Forster's terns than Caspian terns, higher in Central South Bay than in Lower South Bay, and higher in adult Forster's terns than in chicks.

Hinck, J. E., Schmitt, C. J., Blazer, V. S., Denslow, N. D., Bartish, T. M., Anderson, P. J., Coyle, J. J., Dethloff, G. M., & Tillitt, D. E. (2006). Environmental contaminants and biomarker responses in fish from the Columbia River and its tributaries: Spatial and temporal trends. *Science of The Total Environment*, *366*(2), 549–578. https://doi.org/10.1016/j.scitotenv.2005.11.008

Fish were collected from 16 sites on rivers in the Columbia River Basin (CRB) from September 1997 to April 1998 to document temporal and spatial trends in the concentrations of accumulative contaminants and to assess contaminant effects on the fish. Sites were located on the mainstem of the Columbia River and on the Snake, Willamette, Yakima, Salmon, and Flathead Rivers. Common carp (Cyprinus carpio), black bass (Micropterus sp.), and largescale sucker (Catostomus macrocheilus) were the targeted species. Fish were field-examined for external and internal lesions, selected organs were weighed to compute somatic indices, and tissue and fluid samples were preserved for fish health and reproductive biomarker analyses. Composite samples of whole fish, grouped by species and gender, from each site were analyzed for organochlorine and elemental contaminants using instrumental methods and for 2,3,7,8-tetrachloro dibenzo-p-dioxin-like activity (TCDD-EQ) using the H4IIE rat hepatoma cell bioassay. Overall, pesticide concentrations were greatest in fish from lower CRB sites and elemental concentrations were greatest in fish from upper CRB sites. These patterns reflected land uses. Lead (Pb) concentrations in fish from the Columbia River at Northport and Grand Coulee, Washington (WA) exceeded fish and wildlife toxicity thresholds (>0.4 µg/g). Selenium (Se) concentrations in fish from the Salmon River at Riggins, Idaho (ID), the Columbia River at Vernita Bridge, WA, and the Yakima River at Granger, WA exceeded toxicity thresholds for piscivorous wildlife (>0.6 µg/g). Mercury (Hg) concentrations in fish were elevated throughout the basin but were greatest (>0.4 μg/g) in predatory fish from the Salmon River at Riggins, ID, the Yakima River at Granger, WA, and the Columbia River at Warrendale, Oregon (OR). Residues of p,p′-DDE were greatest (>0.8 μg/g) in fish from agricultural areas of the Snake, Yakima, and Columbia River basins but were not detected in upper CRB fish. Other organochlorine pesticides did not exceed toxicity thresholds in fish or were detected infrequently. Total polychlorinated biphenyls (PCBs; >0.11 μg/g) and TCDD-EQs (>5 pg/g) exceeded wildlife guidelines in fish from the middle and lower CRB, and ethoxyresorufin O-deethylase (EROD) activity was also elevated at many of the same sites. Temporal trend analysis indicated decreasing or stable concentrations of Pb, Se, Hg, p,p′-DDE, and PCBs at most sites where historical data were available. Altered biomarkers were noted in fish throughout the CRB. Fish from some stations had responded to chronic contaminant exposure as indicated by fish health and reproductive biomarker results. Although most fish from some sites had grossly visible external or internal lesions, histopathological analysis determined these to be inflammatory responses associated with helminth or myxosporidian parasites. Many largescale sucker from the Columbia River at Northport and Grand Coulee, WA had external lesions and enlarged spleens, which were likely associated with infections. Intersex male smallmouth bass (Micropterus dolomieu) were found in the Snake River at Lewiston, ID and the Columbia River at Warrendale, OR. Male bass, carp, and largescale sucker containing low concentrations of vitellogenin were common in the CRB, and comparatively high concentrations (>0.3 mg/mL) were measured in male fish from the Flathead River at Creston, Montana, the Snake River at Ice Harbor Dam, WA, and the Columbia River at Vernita Bridge, WA and Warrendale, OR. Results from our study and other investigations indicate that continued monitoring in the CRB is warranted to identify consistently degraded sites and those with emerging problems.

Hoag, J. C. (2018). *Planting Report for Goose Island, Potholes Reservoir, WA* (p. 44).
To determine the feasibility of establishing native vegetation on Goose Island to deter Caspian terns from nesting in upland areas, five 10' x 15' test plots were seeded with native grass and shrub seeds in late November 2017. Supplemental irrigation was installed in the Spring of 2018 to assist potential germination and determine the feasibility of irrigation the upland portion of Goose Island. Attached is a detailed report of the planting effort, and additional resources to guide future efforts to establish native grasses, shrubs, and willows at islands within Potholes Reservoir.

Holling, C. S. (1959). The Components of Predation as Revealed by a Study of Small-Mammal Predation of the European Pine Sawfly. *The Canadian Entomologist*, *91*(5), 293–320. https://doi.org/10.4039/Ent91293-5
The fluctuation of an animal's numbers between restricted limits is determined by a balance between that animal's capacity to increase and the environmenta1 cheks to this increase. Many authors have indulged in the calculating the propressive increase of a population when no checks nrerc operating. Thus Huxley calculated that the progeny of a single Aphis in the course of 10 generations, supposing all survived,would "contain more ponderable substance than five hundred millions of stout men; that is, more than the whole population of China", (in Thompson, 1929). Checks, however, do occur and it has been the subject of much controversy to determine how these checks operate. Certain general principles—the density-dependence concept of Smith (1955) , the competition theory of Nicholson (1933)—have been proposed both verbally and mathematically, but because they have been based in part upon untested and restrictive

assumptions they have been severelv criticized (e.g. Andrewartha and Birch 1954). These problems could be considerably clarified if we knew the mode of operation of each process that affects numbers, if we knew its basic and subsidiary components. predation, one such process, forms the subject of the present paper.

Hostetter, N. J. (2009). *Susceptibility of Juvenile Salmonids to Avian Predation: Are Caspian Terns and Double-crested Cormorants Only Taking the Sick and Injured?* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/3197xr26d
The ability to non-destructively assess fish condition and subsequently track fish behavior and survival can be vital in understanding natural and anthropogenic stressors and sources of mortality, especially in populations of fish listed as threatened or endangered. I investigated the use of a quick, non-lethal, external examination technique to assess general health status of run-of-the-river juvenile steelhead (Oncorhynchus mykiss) migrating from the Snake River basin. The relationship between external symptoms of captured fish (including body injuries, de-scaling, external symptoms of disease, fin damage, and ectoparasite infestations) and their health status was investigated through pathology analysis of a euthanized subsample of fish. I assessed the relative fitness of steelhead smolts assigned to various categories of health status by measuring the subsequent survival and susceptibility to avian predation of fish that were tagged with passive integrated transponder (PIT) tags and released unharmed. Histological analysis was conducted on 222 steelhead sacrificed at the juvenile collection facility of Lower Monumental Dam (LMN) on the lower Snake River during steelhead out-migration in 2008; results indicated that external symptoms of disease, body injuries, de-scaling, and fin damage were all associated with increased prevalence of infectious pathogens. Capture-recapture models for 14,177 steelhead PIT-tagged and released at LMN in 2007 and 2008 indicated that the presence of external symptoms of disease, body injuries, or de-scaling, but not fin damage, were associated with significantly reduced survival probabilities during either short-distance (ca. 119 Rkm) or long-distance (ca. 354 Rkm) migration. PIT tags from 3.0% and 1.9% of all released steelhead (n = 16,258) were recovered on a Caspian tern (Hydroprogne caspia) colony and a double-crested cormorant (Phalacrocorax auritus) colony, respectively, located < 79 Rkm downstream of release locations. A consistent factor relating susceptibility of steelhead to predation by both bird species was compromised health, particularly steelhead with external symptoms of disease and body injuries. River conditions, including decreased discharge and elevated water temperatures at the time of release, were also associated with increased susceptibility of steelhead to avian predation, but the strength of these explanatory factors differed between species of avian predator. These results support the conclusion that external condition, measured nondestructively on individual fish, is associated with quantifiable differences in general health status and fitness of fish. Results also indicate that some reduction in avian predation on juvenile salmonids (Oncorhynchus spp.) may be accomplished by modifying hydrosystem operations. The higher susceptibility of unhealthy steelhead to avian predation suggests that a portion of any reduction in mortality due to avian predation will be compensated for by other sources of smolt mortality. The portion of juvenile steelhead that are at greater risk of avian predation is small, however, based on the small proportion of steelhead that exhibited visible symptoms of compromised health.

Hostetter, N. J., Evans, A. F., Cramer, B. M., Collis, K., Lyons, D. E., & Roby, D. D. (2015). Quantifying Avian Predation on Fish Populations: Integrating Predator-Specific Deposition

Probabilities in Tag Recovery Studies. *Transactions of the American Fisheries Society*, *144*(2), 410–422. https://doi.org/10.1080/00028487.2014.988882
Accurate assessment of specific mortality factors is vital to prioritize recovery actions for threatened and endangered species. For decades, tag recovery methods have been used to estimate fish mortality due to avian predation. Predation probabilities derived from fish tag recoveries on piscivorous waterbird colonies typically reflect minimum estimates of predation due to an unknown and unaccounted-for fraction of tags that are consumed but not deposited on-colony (i.e., deposition probability). We applied an integrated tag recovery modeling approach in a Bayesian context to estimate predation probabilities that accounted for predator-specific tag detection and deposition probabilities in a multiple-predator system. Studies of PIT tag deposition were conducted across three bird species nesting at seven different colonies in the Columbia River basin, USA. Tag deposition probabilities differed significantly among predator species (Caspian terns Hydroprogne caspia: deposition probability D 0.71, 95% credible interval [CRI] D 0.51–0.89; double-crested cormorants Phalacrocorax auritus: 0.51, 95% CRI D 0.34–0.70; California gulls Larus californicus: 0.15, 95% CRI D 0.11–0.21) but showed little variation across trials within a species or across years. Data from a 6-year study (2008–2013) of PIT-tagged juvenile Snake River steelhead Oncorhynchus mykiss (listed as threatened under the Endangered Species Act) indicated that colony-specific predation probabilities ranged from less than 0.01 to 0.17 and varied by predator species, colony location, and year. Integrating the predator-specific deposition probabilities increased the predation probabilities by a factor of approximately 1.4 for Caspian terns, 2.0 for double-crested cormorants, and 6.7 for California gulls compared with traditional minimum predation rate methods, which do not account for deposition probabilities. Results supported previous findings on the high predation impacts from strictly piscivorous waterbirds nesting in the Columbia River estuary (i.e., terns and cormorants), but our findings also revealed greater impacts of a generalist predator species (i.e., California gulls) than were previously documented. Approaches used in this study allow for direct comparisons among multiple fish mortality factors and considerably improve the reliability of tag recovery models for estimating predation probabilities in multiple-predator systems.

Hostetter, N. J., Evans, A. F., Loge, F. J., O’Connor, R. R., Cramer, B. M., Fryer, D., & Collis, K. (2015). The Influence of Individual Fish Characteristics on Survival and Detection: Similarities across Two Salmonid Species. *North American Journal of Fisheries Management*, *35*(5), 1034–1045. https://doi.org/10.1080/02755947.2015.1077176
Trait-selective mortality is of considerable management and conservation interest, especially when trends are similar across multiple species of conservation concern. In the Columbia River basin, thousands of juvenile Pacific salmonids Oncorhynchus spp. are collected each year and are tagged at juvenile bypass system (JBS) facilities located at hydroelectric dams, thus allowing the tracking of population-level performance metrics (e.g., juvenile survival and juvenile-to-adult survival). Several studies have suggested that juvenile salmonid survival is both size dependent and condition dependent, but little is known about trait-selective collection at JBS facilities. Trait-selective collection (e.g., length-based or condition-based selectivity) is particularly important, as inferences to population-level performance metrics may be biased if both the survival and collection processes are influenced by similar characteristics. We used a capture–mark–recapture study to investigate length- and condition-selective survival and detection probabilities for two salmonid species in the Columbia River basin. In 2014, juvenile steelhead O. mykiss (n = 11,201) and yearling Chinook Salmon O. tshawytscha (n = 7,943) were PIT-

tagged, measured (FL), examined for external condition characteristics (descaling, body injuries, fin damage, or disease symptoms), and released into the Lower Granite Dam JBS facility on the Snake River to continue seaward migration. Results indicated similar trends in both length- and condition-selective juvenile survival and detection probabilities. For both species, survival probability was higher for longer, nondegraded individuals (those without descaling, body injuries, or fin damage). Trends in detection probability were also consistent across species: shorter, degraded individuals were more likely to be detected at downstream JBS facilities than longer, healthier individuals. These results suggest that similar characteristics (FL and external condition) affect survival and detection processes for PIT-tagged steelhead and yearling Chinook Salmon and that JBS facilities may selectively collect smaller, degraded individuals with lower probabilities of survival. The consistency in trait-selective survival and detection results has important management implications for several species of conservation concern.

Hostetter, N. J., Evans, A. F., Roby, D. D., & Collis, K. (2012). Susceptibility of Juvenile Steelhead to Avian Predation: The Influence of Individual Fish Characteristics and River Conditions. *Transactions of the American Fisheries Society*, *141*(6), 1586–1599. https://doi.org/10.1080/00028487.2012.716011

Identification of the factors that influence susceptibility to predation can aid in developing management strategies to recover fish populations of conservation concern. Predator–prey relationships can be influenced by numerous factors, including prey condition, prey size, and environmental conditions. We investigated these factors by using juvenile steelhead Oncorhynchus mykiss from the Snake River (Pacific Northwest, USA), a distinct population segment that is listed as threatened under the U.S. Endangered Species Act. During 2007–2009, steelhead smolts (n = 25,909) were captured, examined for external condition characteristics (e.g., body injuries, descaling, external signs of disease, fin damage, and ectoparasite infestations), marked with passive integrated transponder (PIT) tags, and released to continue their out-migration. Recoveries of PIT tags on a downstream colony of Caspian terns Hydroprogne caspia (n = 913 tags) indicated that steelhead susceptibility to Caspian tern predation increased significantly with decreases in steelhead external condition, decreased water discharge, and decreased water clarity. Susceptibility to Caspian tern predation also increased with increasing steelhead fork length up to 202 mm but then decreased for longer steelhead. Recoveries of PIT tags on a downstream colony of double-crested cormorants Phalacrocorax auritus (n = 493 tags) indicated that steelhead susceptibility to double-crested cormorant predation increased significantly with declining external condition of steelhead, and that steelhead of hatchery origin were more susceptible than their wild counterparts. Results indicate that steelhead susceptibility to avian predation is dependent on fish condition and length and is influenced by river conditions and rearing environment.

Hostetter, N. J., Evans, A. F., Roby, D. D., Collis, K., Hawbecker, M., Sandford, B. P., Thompson, D. E., & Loge, F. J. (2011). Relationship of External Fish Condition to Pathogen Prevalence and Out-Migration Survival in Juvenile Steelhead. *Transactions of the American Fisheries Society*, *140*(5), 1158–1171. https://doi.org/10.1080/00028487.2011.613303

Understanding how the external condition of juvenile salmonids is associated with internal measures of health and subsequent out-migration survival can be valuable for population monitoring programs. This study investigated the use of a rapid, nonlethal, external examination to assess the condition of run-of-the-river juvenile steelhead Oncorhynchus mykiss migrating from the

Snake River to the Pacific Ocean. We compared the external condition (e.g., body injuries, descaling, external signs of disease, fin damage, and ectoparasite infestations) with (1) the internal condition of a steelhead as measured by the presence of selected pathogens detected by histopathology and polymerase chain reaction analysis and (2) out-migration survival through the Snake and Columbia rivers as determined by passive integrated transponder (PIT) tag technology. The results from steelhead captured and euthanized (n = 222) at Lower Monumental Dam on the lower Snake River in 2008 indicated that external condition was significantly correlated with selected measures of internal condition. The odds of testing positive for a pathogen were 39.2, 24.3, and 5.6 times greater for steelhead with severe or moderate external signs of disease or more than 20% descaling, respectively. Capture–recapture models of 22,451 PIT-tagged steelhead released at Lower Monumental Dam in 2007–2009 indicated that external condition was significantly correlated with juvenile survival. The odds of out-migration survival for steelhead with moderate or severe external signs of disease, more than 20% descaling, or severe fin damage were 5.7, 4.9, 1.6, and 1.3 times lower, respectively, than those for steelhead without these external conditions. This study effectively demonstrated that specific measures of external condition were associated with both the internal condition and out-migration survival of juvenile steelhead.

Hostetter, N. J., Gardner, B., Evans, A. F., Cramer, B. M., Payton, Q., Collis, K., & Roby, D. D. (2018). Wanted dead or alive: A state-space mark–recapture–recovery model incorporating multiple recovery types and state uncertainty. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(7), 1117–1127. https://doi.org/10.1139/cjfas-2016-0246

We developed a state-space mark–recapture–recovery model that incorporates multiple recovery types and state uncertainty to estimate survival of an anadromous fish species. We apply the model to a dataset of outmigrating juvenile steelhead trout (Oncorhynchus mykiss (Walbaum, 1792)) tagged with passive integrated transponders, recaptured during outmigration, and recovered on bird colonies in the Columbia River basin (2008–2014). Recoveries on bird colonies are often ignored in survival studies because the river reach of mortality is often unknown, which we model as a form of state uncertainty. Median outmigration survival from release to the lower river (river kilometre 729 to 75) ranged from 0.27 to 0.35, depending on year. Recovery probabilities were frequently ≥0.20 in the first river reach following tagging, indicating that one out of five fish that died in that reach was recovered on a bird colony. Integrating dead recovery data provided increased parameter precision, estimation of where birds consumed fish, and survival estimates across larger spatial scales. More generally, these modeling approaches provide a flexible framework to integrate multiple sources of tag recovery data into mark–recapture studies.

Hughes, J. S., Weiland, M. A., Woodley, C. M., Ploskey, G. R., Carpenter, S. M., Hennen, M. J., Fischer, E. S., Batton, G., Carlson, T. J., Cushing, A. W., Deng, Z., Etherington, D. J., Fu, T., Greiner, M. J., Ingraham, J. M., Kim, J. A., Li, X., Martinez, J. J., Mitchell, T. D., … Zimmerman, S. A. (2013). *Survival and Passage of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead at McNary Dam, 2012* (PNNL-22788 FINAL, 1113605; p. 246). https://doi.org/10.2172/1113605

Researchers at the Pacific Northwest National Laboratory (PNNL) collaborated with the Pacific States Marine Fisheries Commission (PSMFC), U.S. Army Corps of Engineers Portland District and Walla Walla District, and the University of Washington to conduct a 2012 study to estimate dam passage survival and other performance metrics for yearling and subyearling Chinook salmon

(Oncorhynchus tshawytscha) and juvenile steelhead (O. mykiss) at McNary Dam. The study addressed the 2008 Biological Opinion (BiOp) stipulations and 2008 Columbia Basin Fish Accords on the operation of the Federal Columbia River Power System (FCRPS). Under the 2008 FCRPS BiOp, dam passage survival should be ≥0.96 for yearling Chinook salmon and steelhead, and >0.93 for subyearling Chinook salmon, with standard error (SE) values of ≤0.015. Results presented focus on performance measures, route-specific survival, and horizontal and vertical distributions of yearling and subyearling Chinook salmon and juvenile steelhead surgically implanted with Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic micro-transmitters (AMTs). A virtual/paired-release (VPR) design was used to estimate dam passage survival at McNary Dam (MCN). The approach relied on releases of yearling and subyearling Chinook salmon and juvenile steelhead implanted with AMTs at Port Kelley, Washington, upriver from MCN, that contributed to the formation of a virtual-release group at the face of the dam and a paired-release group below the dam. Dam passage survival was estimated as the quotient of the survival estimates for the virtual release to that of the paired release. A total of 3,797 yearling Chinook salmon, 3,797 steelhead, and 6,501 subyearling Chinook salmon were implanted with AMTs and released for this study. This report is a comprehensive summary of 2012 results.

Hupp, J. W., Pearce, J. M., Mulcahy, D. M., & Miller, D. A. (2006). Effects of Abdominally Implanted Radiotransmitters with Percutaneous Antennas on Migration, Reproduction, and Survival of Canada Geese. *Journal of Wildlife Management*, *70*(3), 812–822. https://doi.org/10.2193/0022-541X(2006)70[812:EOAIRW]2.0.CO;2

Abdominally implanted radiotransmitters with percutaneous antennas are increasingly used to monitor movements, survival, and reproduction of waterbirds. However, there has been relatively little assessment of the effects of such radios on avian demographic parameters or migration. We implanted either a 26- or 35-g abdominal transmitter with percutaneous antenna in 198 adult female lesser Canada geese (Branta canadensis parvipes) in Anchorage, Alaska during 2000 and 2001. We compared migration chronology, reproductive effort, and survival of radiomarked females to 118 control females marked with leg bands. Arrival dates following spring migration were similar among females in different treatments in 2001. However, in 2002, wind direction during late migration was less favorable, and arrival of females with 35-g radiotransmitters lagged 1–2 days behind that of control females. Nest initiation dates, clutch size, and mean egg volume were similar for 152 nests of females that lacked radios and 62 nests of radiomarked females. Estimated nesting propensity for females with operable radiotransmitters was 61% and 72% in 2001 and 2002, respectively. Apparent annual survival ($\varphi = 0.82$, 95% confidence interval: 0.76 to 0.87) was similar among treatments in the first year after geese were marked. In the second and third years after marking, model-averaged estimates for survival of females with large radiotransmitters were 10% lower than estimates for control females. However, the effect of large radios on long-term survival was equivocal because of uncertainty surrounding treatment estimates. We conclude that abdominally implanted radiotransmitters with percutaneous antennas had small effects on migration chronology but no apparent effects on fecundity. Abdominal transmitters can provide unbiased estimates of anserine survival in the first year after deployment. Because of the potentially greater effects of larger transmitters on migration and long-term survival, we recommend that biologists minimize the size of implanted transmitters and deploy radios with caution if long-term survival of marked birds is a concern.

Ims, R. A. (1990). On the Adaptive Value of Reproductive Synchrony as a Predator-Swamping Strategy. *The American Naturalist*, *136*(4), 485–498. JSTOR.

The logic behind the hypothesis explaining reproductive synchrony as a strategy for reducing the predation of vulnerable offspring (predator swamping) is evaluated by means of two simple models. Predator swamping was found to be an adequate explanation for the occurrence of within-season reproductive synchrony when the predator exhibits a Holling type-II functional response (specialist predator). However, in the case of a generalist predator switching from alternative prey (Holling type-III functional response), which is expected to be a common functional-response type when particular prey are unavailable at certain times of the year, highly asynchronous reproduction may be the best reproductive strategy. In particular, when prey switching occurs at high offspring densities and/or the satiation density of the predator is high relative to the total reproduction of the prey population, the peak predation rate is expected to occur when reproduction is completely synchronous. Spatially clumped prey populations are expected to experience a dramatically increased predation rate if reproduction is synchronized within clumps but not between them. Hence, it is predicted that mechanisms promoting within-group reproductive synchrony are even less likely to have evolved as a predator-swamping strategy in patchily distributed populations, in which reproduction cannot be synchronized between groups. It is argued that the present models also may serve as a theoretical framework for studies on the evolution of fruiting synchrony in animal-dispersed plants.

Isaacs, F. B., & Anthony, R. G. (2011). *Bald eagles (Haliaeetus leucocephalus) nesting in Oregon and along the lower Columbia River, 1978-2007.* (p. 242) [Final Report]. Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University. https://fw.oregonstate.edu/sites/agscid7/files/be30yearfinal.pdf

We surveyed the breeding population of bald eagles (Haliaeetus leucocephalus) in Oregon and along the lower Columbia River from 1978–2007. Surveys were conducted annually by aircraft, boat, and/or afoot from 1 February–31 August to determine occupancy and productivity of breeding areas. We divided the study area into ten watersheds based on Recovery Plan management zones. Overall, the minimum size of the breeding population increased from 66 occupied breeding areas in 1978 (65 in Oregon and 1 in Washington) to 553 in 2007 (496 in Oregon and 57 in Washington). Population growth rate (r) was exponential for all areas combined, but varied among the nine watersheds from 0.048 for the Deschutes to 0.147 for the Willamette. The average increase in the breeding population was 0.073 or a 7.3% increase per year for the study area. At the beginning of the study, the breeding population was located primarily in the Deschutes, Klamath, Pacific, and Columbia watersheds with dispersed breeding areas elsewhere. By the end of the study, the population was concentrated in those four areas plus the Willamette, Rogue, and Umpqua watersheds, and additional breeding areas were dispersed throughout most of the state except for the Owyhee watershed of southeast Oregon. We documented breeding phenology over the 30-year period and discovered an approximately five-day advance in the egg-laying period for breeding areas west of the Cascades, which may have been a result of warmer late-winter and spring temperatures in the region during the latter part of the study. Nesting success, productivity (number of young produced per occupied breeding area), and brood size increased significantly from 1978–2007, and productivity was correlated positively with breeding success over the 30 years of the study. Overall, average annual productivity was >1.0 young per occupied breeding area during the last decade of the study, which was indicative of a healthy population. However, productivity on segment 2 of the lower Columbia River (river

miles 13–31 or km 21–50) was low throughout the study indicating that the effects of environmental contaminants still persist in that area. Reduced productivity with increasing population indicated that breeding populations at Odell Lake and the west side of Upper Klamath Lake were at or near carrying capacity. Overall, our data suggest that the breeding population of the study area has the potential to double or triple in the future based on the amount of shoreline habitat present and assuming unchanged environmental conditions. Recoveries of bald eagles banded as nestlings in Oregon (n = 22) provided a longevity record for the study area of 26-years-3-months and indicated that subadults moved further from natal areas than adults (438 km vs. 153 km or 272 mi vs. 95 mi, respectively). Seven banded nestlings that were recovered as adults during the breeding season were 59 km (37 mi) on average from their natal areas, providing evidence of natal philopatry. Encounters in the study area with marked bald eagles from outside Oregon were common (n = at least 62), involved eagles from 6 western states and Mexico, occurred throughout Oregon (20 or 22 of 36 counties), and were concentrated in Klamath, Lake, and Deschutes counties (53%). Movements of resident and non-resident bald eagles that utilized the study area delineated a complex web of overlapping ranges extending from northwestern Mexico to Alaska and northwestern Canada and included Oregon, Washington, Idaho, Montana, Wyoming, Utah, Nevada, California, and Arizona. The breeding population (n = 553) was associated with estuaries (31%), rivers (22%), reservoirs (21%), and natural lakes (15%), and 90% of occupied breeding areas were within 3,200 m (2 mi) of shorelines. Breeding areas were distributed bi-modally relative to elevation because of concentrations at rivers and estuaries at low elevations west of the Cascades and at lakes or reservoirs at higher elevations east of the Cascades. Productivity decreased with increasing elevation. Although that correlation was weak overall (r = -0.111), it was prominent on the west slope of the Cascade Mountains. Lower productivity at high elevations likely was due to severe weather in some years that resulted in cold and wet conditions during egg-laying and incubation periods. We also found that low productivity coincided with mate changes (0.36 young per occupied breeding area) and establishment of new territories (0.29 young per occupied breeding area), which indicated that inexperience of first-time breeders was a likely reason for failure of nesting attempts. Our analysis of nesting success within breeding areas indicated that successful nesting attempts were followed by successes 69% of the time (n = 4,498) and that failed attempts followed failures 47% of the time (n = 2,793). Primary nest tree species were Douglas-fir (Pseudotsuga menziesii), Sitka spruce (Picea sitchensis), and black cottonwood (Populus trichocarpa) west of the Cascades, and ponderosa pine (Pinus ponderosa) and Douglas-fir east of the Cascades. In general, nest trees used by bald eagles in the study area were the dominant individuals in forest stands located near water bodies with an abundant food supply and some degree of isolation from human activity, although there were notable exceptions to this latter generality. The cumulative number of bald eagle nest trees within breeding areas increased with time (r = 0.928, p <0.01) from approximately one the first year a breeding area was known to approximately five after 30 years. Nest and nest tree "survival" averaged 97% per year over 28 years, and 16% of nest trees discovered in 1978 still held nests in 2007. We observed use of bald eagle nests by seven other avian species: red-tailed hawk (Buteo jamaicensis), osprey (Pandion haliaetus), great horned owl (Bubo virginianus), peregrine falcon (Falco peregrinus), Canada goose (Branta canadensis), common raven (Corvus corax), and golden eagle (Aquila chrysaetos), with most use by Canada goose. We provided several recommendations for monitoring and documenting nesting and wintering populations, managing nest trees and forests within breeding areas, and future research topics for bald eagles in Oregon and the Pacific Northwest. Our primary recommendations were: 1) implement a more intensive nest monitoring plan for Oregon than is provided by the nation-wide, post-delisting monitoring plan of the U.S. Fish & Wildlife Service, 2) develop a centralized data base and tracking system for breeding and wintering locations and results of nest and winter monitoring, 3) manage for and conserve nesting habitat, especially the preservation of existing nest trees and management of forest stands to replace nest trees, following the approaches established when the species was listed under the Endangered Species Act, 4) continue periodic research on the effects of contaminants on nesting bald eagles on the lower Columbia River, 5) study movements and survival of resident bald eagles, 6) coordinate research and management with other western states, Mexico, and Canada, and 7) monitor nesting phenology for evidence of long-term change.

Jepsen, N., Aarestrup, K., Økland, F., & Rasmussen, G. (1998). Survival of radiotagged Atlantic salmon (Salmo salar L.) – and trout (Salmo trutta L.) smolts passing a reservoir during seaward migration. *Hydrobiologia*, *371*(0), 347. https://doi.org/10.1023/A:1017047527478

High mortality-rates of seaward migrating salmonid smolts when passing reservoirs and lakes have earlier been found in the Danish River Gudenå watershed. To reveal the causes of mortality of migrating smolts in Lake Tange, a 12 km long, shallow reservoir, 50 salmon smolts and 24 trout smolts were tagged with internal miniature radio-transmitters, and released in the river just upstream the reservoir on May 1, 1996. The salmon smolts were hatchery-reared, while the trout smolts were wild fish, caught in a smolt trap. The tagged smolts were tracked daily for 3 weeks, and when possible the cause of death was determined. During the 3-week period, 90% of the tagged smolts died. The main cause of death for both trout and salmon was predation from fish and birds. The most important predator was pike (Esox lucius L.), being responsible for 56% of the observed mortality. Avian predators were assumed to be responsible for 31% of the observed mortality. No trout smolts left the reservoir, but 5 salmon-smolts got out through the turbines. Others did traverse the reservoir, but were unable to enter the river downstream, and were later eaten. The present results suggest that mortalities for migrating smolts through Lake Tange are of such a magnitude, that stocking of juveniles in the river upstream is futile, and further, that the establishment of a natural population of salmon or sea-trout in river Gudenå, upstream Tange, is unrealistic under present conditions.

Jepsen, N., Klenke, R., Sonnesen, P., & Bregnballe, T. (2010). The use of coded wire tags to estimate cormorant predation on fish stocks in an estuary. *Marine and Freshwater Research*, *61*(3), 320–329. https://doi.org/10.1071/MF09038

One of the main obstacles to resolving the conflict between an increasing population of cormorants, Phalacrocorax carbo sinensis, and the fishing industry is the lack of documentation of the effect of the birds' predation on fish stocks. Tagging and releasing fish with coded wire tags followed by intensive cormorant pellet sampling may be a viable method to measure the impact of cormorants on fish populations. To test this new method, we studied cormorant predation in a shallow estuary, where nearly 100 000 fish were tagged and more than 10 000 cormorant pellets were collected over a 3-year study period. A total of 112 tags were recovered from the collected pellets. Analyses of tag recovery data indicated considerable cormorant predation on tagged flounder, eel and salmon smolts, but the method did not deliver high-quality documentation, mainly because of limitations in pellet sampling. We conclude with recommendations to enhance the value of this method.

Jewett, S. G. (1936). Bird Notes from Harney County, Oregon, during May 1934. *The Murrelet*, *17*(2/3), 41–47. JSTOR. https://doi.org/10.2307/3535822

Johnsgard, P. A. (1956). Effects of Water Fluctuation and Vegetation Change on Bird Populations, Particularly Waterfowl. *Ecology*, *37*(4), 689–701. https://doi.org/10.2307/1933059

Johnson, G. E., Carlson, T. J., & Skalski, J. R. (2010). *Compliance Monitoring of Juvenile Subyearling Chinook Salmon Survival and Passage at The Dalles Dam, Summer 2010* (PNNL-20042, 1001510; p. 54). https://doi.org/10.2172/1001510

The purpose of this compliance study was to estimate dam passage survival of subyearling Chinook salmon smolts at The Dalles Dam during summer 2010. Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival should be greater than or equal to 0.93 and estimated with a standard error (SE) less than or equal 0.015. The study also estimated smolt passage survival from the forebay 2 river kilometers (rkm) upstream of the dam to the tailrace 2 rkm below the dam1 , forebay residence time, tailrace egress time, and fish passage efficiency, as required in the Columbia Basin Fish Accords, as well as spill passage efficiency. A virtual/paired-release design was used to estimate dam passage survival at The Dalles Dam. The approach included releases of acoustic-tagged smolts above John Day Dam that contributed to the formation of a virtual release at the face of The Dalles Dam. A survival estimate from this release was adjusted by a paired release below The Dalles Dam. A total of 4,449 subyearling Chinook salmon smolts were tagged and released in the study. The Juvenile Salmon Acoustic Telemetry System (JSATS) tag model number ATS-156dB, weighing 0.430 g in air, was used in this investigation.

Källo, K., Baktoft, H., Jepsen, N., & Aarestrup, K. (2020). Great cormorant (Phalacrocorax carbo sinensis) predation on juvenile down-migrating trout (Salmo trutta) in a lowland stream. *ICES Journal of Marine Science*, *77*(2), 721–729. https://doi.org/10.1093/icesjms/fsz227

Since in 1980s, the number of great cormorants (Phalacrocorax carbo sinensis) has increased all over its European distribution area. This has led to conflicts between bird conservation and fisheries. Mariager fjord in Denmark is an important feeding and transition area for a large population of migrating seatrout (Salmo trutta), but it also provides resting and breeding places for cormorants. Thus, juvenile anadromous salmonids migrating from the river to the sea may be exposed to high predation risk during a critical and vulnerable time in their development. A total of 31 123 down-migrating wild seatrout were tagged with Passive Integrated Transponder (PIT) tags in 2008, 2009, 2015, and 2016 in river Villestrup, the main tributary flowing into Mariager fjord. Tagged fish were measured and grouped by their developmental stage as parr, pre-smolt, or smolt. To quantify cormorant predation, nearby cormorant colonies and roosting sites were repeatedly scanned for PIT tags with a manual antenna to record tags from predated fish. Minimum predation rate was 27% but varied among years. Body length of the fish and predation risk were negatively correlated and the latter was dependent on the group of the fish. This study demonstrates a potential negative effect of predation by great cormorants on an important population of wild trout.

Karasov, W. H. (1990). Digestion in birds: Chemical and physiological determinants and ecological implications. *Studies in Avian Biology*, *13*, 25.

I review the utilization efficiencies of wild birds on various foods. Average apparent metabolizable energy coefficients (MEC*; [food energy - excreta energy]/food energy) according to type of food consumed are: nectar. 0.98; arthropods. 0.77; vertebrate prey, 0.75; cultivated seeds, 0.80; wild seeds, 0.62; fruit pulp and skin, 0.64;-whole fruits (including seeds), 0.5 1; herbage, 0.35. The observed differences in MEC* can be explained largely on the basis of differences in food composition. Fruits and herbage were utilized less efficiently than predicted on the basis of composition alone, possibly because of (1) underestimation of the refractory component of food (i.e., cell wall), (2) the presence of plant secondary chemicals, or (3) features of the digestive system, such as short digesta retention time and/or low enzyme levels. The digestive system's efficiency in extracting food energy or nutrients is directly related to three variables: (1) digesta retention time; (2) rates of hydrolysis, fermentation, and absorption; and (3) digestive tract surface area and volume. Because these components act in concert, it is best to evaluate digestive system function in an integrated fashion. I present three examples: (1) efficiency is apparently depressed in frugivores because digesta retention time is relatively short and no compensation occurs in rates of hydrolysis and absorption; (2) herbivores must eat large amounts of food, but a compensation appears to be an increase in digestive tract volume; and (3) the presence of caeca in herbivores enhances extraction efficiency by affecting all three variables. Digestion is important in avian ecology at the level of individuals, populations, and community structure by affecting resource removal rate, and possibly by constraining the rate of production and affecting niche width.

Kareiva, P., Marvier, M., & McClure, M. (2000). Recovery and Management Options for Spring/Summer Chinook Salmon in the Columbia River Basin. *Science*, *290*(5493), 977–979. https://doi.org/10.1126/science.290.5493.977

Construction of four dams on the lower Snake River (in northwestern United States) between 1961 and 1975 altered salmon spawning habitat, elevated smolt and adult migration mortality, and contributed to severe declines of Snake River salmon populations. By applying a matrix model to long-term population data, we found that (i) dam passage improvements have dramatically mitigated direct mortality associated with dams; (ii) even if main stem survival were elevated to 100%, Snake River spring/summer chinook salmon (Oncorhynchus tshawytscha) would probably continue to decline toward extinction; and (iii) modest reductions in first-year mortality or estuarine mortality would reverse current population declines.

Karppinen, P., Jounela, P., Huusko, R., & Erkinaro, J. (2014). Effects of release timing on migration behaviour and survival of hatchery-reared Atlantic salmon smolts in a regulated river. *Ecology of Freshwater Fish*, *23*(3), 438–452. https://doi.org/10.1111/eff.12097

In this study, 221 two-year-old hatchery-reared salmon, Salmo salar, smolts were tagged with radio transmitters over a period of three consecutive years and released in the river in groups of 20–21 fish in various dates between late April and early June. Tagged smolts were tracked during their downstream migration in the lower 36-km stretch of the regulated River Oulujoki, with the focus on the effects of release date, water temperature and river flow on migration behaviour and survival. The results indicate that release timing and river temperature have profound effects on the initiation of migration, swimming speed and survival of released S. salar smolts. Smolts released early in the spring in cold waters ceased migration after brief downstream movement and were vulnerable to predation, whereas the migration speed and survival rates increased markedly for smolts released later in the spring.

Keller, T. M., & Visser, G. H. (1999). Daily energy expenditure of great cormorants Phalacrocorax carbo sinensis wintering at Lake Chiemsee, Southern Germany. *Ardea*, *87*(1), 61–69.

In the winters of 1993/94 and 1994/95 the daily energy expenditure (DEE) of Great Cormorants Phalacrocorax carbo sinensis was measured using the doubly labelled water technique (DLW). This was the first time the method has been used on a Phalacrocoracid species. DLW trials were carried out on 5 caged birds and on 5 free-ranging wild birds at Lake Chiemsee. The mean body mass of the captive birds (2079 g) was not significantly different from and that of wild birds (2122 g). There was no significant difference in the total body water (TBW) of the two Cormorant groups (55.9% in captive birds and 56.7% in free-ranging birds). Estimated DEE (+/- SD) averaged 1325 +/- 130 kJ day(-1) (n = 5) in the caged birds and 2094 +/- 174 kJ day(-1) (n = 5) in the free-ranging ones, a highly signficant difference. To match their DEE, it was calculated that the Cormorants had to consume 341 g of fish per day under aviary conditions and 539 g in the wild.

Kennedy, B. M., Gale, W. L., & Ostrand, K. G. (2007). Relationship between smolt gill Na+, K+ ATPase activity and migration timing to avian predation risk of steelhead trout (Oncorhynchus mykiss) in a large estuary. *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(11), 1506–1516. https://doi.org/10.1139/f07-117

We examined avian predation risk of juvenile steelhead trout (Oncorhynchus mykiss) migrating through the Columbia River Estuary in relation to their osmoregulatory physiology, body length, rearing conditions (hatchery or wild), migration timing, and migration year. From 2003 to 2006, mean gill Na+, K+ ATPase activity of migrating wild steelhead was greater than hatchery steelhead. Hatchery steelhead were always longer than wild steelhead. Wild steelhead never had higher plasma [Na+] or osmolality levels than hatchery fish after seawater challenge trials conducted in 2004, 2005, and 2006. More passive integrated transponder (PIT) tags from hatchery fish (19%; 126 of 678 fish) were detected on East Sand Island among bird nesting colonies than PIT tags of wild fish (14%; 70 of 509 fish), presumably consumed by birds. As gill Na+, K+ ATPase activity and migration date within a year increased, the probability of an individual fish being eaten by an avian predator decreased. Length, rear type, and year were not related to predation risk. These results show that physiology and migration timing of juvenile steelhead play an important role in a migrant’s risk to avian predation within an estuary.

King, D. T., & Tobin, M. E. (2000). Capture and telemetry techniques for double-crested cormorants (Phalacrocorax auritus). *Proceedings of the 19th Vertebrate Pest Conference*, *19*. https://doi.org/10.5070/V419110002

Double-crested Cormorants (Phalacrocorax auritus) often roost in cypress oxbows and nest on islands making their capture for research studies difficult. In the southeastern United States we used a capture technique involving a boat equipped with flood lights, flushing the birds out of their roost trees, and capturing them with a landing net. On the Great Lakes we devised a capture technique using modified padded leg-hold traps placed in nest trees or on the ground in the colony. We captured >250 cormorants using these two techniques with very few injuries to the birds. In a study with captive birds, we evaluated the short-term effects of backpack and patagial tag VHF transmitters and their attachment techniques for use on cormorants. We conclude that backpack VHF transmitters are applicable for use on double-crested cormorants and that patagial solar powered transmitters should be further tested. We also tested two methods

for simultaneously attaching a VHF transmitter and a backpack satellite transmitter to cormorants. Birds with the VHF patagial tag attachment showed moderate to heavy feather wear and abrasions on the ventral surface of the patagium. We recommend gluing the VHF transmitter to the backpack satellite transmitter for attaching both VHF and satellite transmitters to double-crested cormorants. These adaptable cormorant capture and telemetry techniques should prove suitable for use in other habitats and situations.

Kitchin, E. A. (1930). Nesting Observations at Moses Lake in May. *The Murrelet*, *11*(3), 55–59. JSTOR. https://doi.org/10.2307/3535493

Klaassen, M., Zwaan, B., Heslenfeld, P., Lucas, P., & Luijckx, B. (1992). Growth-rate associated changes in the energy-requirements of tern chicks. *Ardea*, *80*(1), 19–28.
To obtain infonnation on the energetic implications of intraspecific growth rate differences we measured the energy requirement for development in chicks of Common Tern Sterna hirundo and Sandwich Tern S. sandvicensis under laboratory conditions. Both maximum (kJ.day-l) and total gross energy intake for development (kJ during prefledging period) increased with growth rate and were reduced by almost 40% and 25%, respectively, in the slowest compared to the fastest growing individuals in each of the two species. These results imply that the range of food availability within which a chick can grow to adulthood, is wider than hitherto believed. However, one should bear in mind that slow growth also may result in higher nestling and postfledging mortality.

Knopf, F. L., & Evans, R. M. (2004). *American White Pelican—Pelecanus erythrorhynchos—Birds of the World*. https://birdsoftheworld.org/bow/species/amwpel/cur/introduction

Koed, A., Jepsen, N., Aarestrup, K., & Nielsen, C. (2002). Initial mortality of radio-tagged Atlantic salmon (Salmo salar L.) smolts following release downstream of a hydropower station. *Hydrobiologia*, *483*(1), 31–37. https://doi.org/10.1023/A:1021390403703
The fate of radio-tagged hatchery-reared salmon smolts (Salmo salar L.) was investigated in the tailrace of a hydropower station in the Danish River Gudenaa during 2 years. Seventeen and 27 smolts were tagged and released in late May 1996 and during April 1999, respectively. Out of the total of 44 smolts, only two were recorded to leave the river and enter the estuary. In both years of study, electrofishing was used to sample tagged smolts. In 1996, these attempts were unsuccessful, while in 1999, 19 (70% of total) transmitters were retrieved in the stomachs of pikeperch (Stizostedion lucioperca (L.)) and pike (Esox lucius L.), and in grey heron (Ardea cinerea L.) nests. The present study demonstrates that the physical condition of the watershed, with respect to spawning and rearing, may not be the only crucial determining factors of the success of reintroduction of Atlantic salmon. Hydropower plants not only block the free movement of migratory fish, hence preventing the utilisation of spawning and rearing areas, but also form the basis of areas with increased mortality.

Koed, Anders, Baktoft, H., & Bak, B. D. (2006). Causes of mortality of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) smolts in a restored river and its estuary. *River Research and Applications*, *22*(1), 69–78. https://doi.org/10.1002/rra.894
During October 2000 to August 2002, the River Skjern Nature Project was implemented by removing dykes and re-meandering 20.5 km of the lower canalized river. As a consequence the length of

the river stretch increased to 23 km. A lake of 250 ha developed in the river valley 5 km upstream from the river mouth because of subsiding soils caused by reclamation and drainage since the 1960s. Using radiotelemetry, the mortality of wild Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) smolts in the River Skjern and its estuary was investigated prior to and after the implementation of the project. Altogether, 77 Atlantic salmon and 66 brown trout smolts were caught, tagged and released in the river upstream of the restoration project during the spring of 2000 and 2002. The in-river smolt mortality was more than double in 2002 for both Atlantic salmon and brown trout compared with 2000. This was primarily due to bird predation in 2002 which was not observed in 2000. The in-river bird predation in 2002 was mediated by the new lake, which quickly became an important bird rest area. Estuarine mortality mainly caused by cormorants (Phalacrocorax carbo sinensis) differed significantly between species, but was high for both Atlantic salmon (39%) and brown trout (12%) in both years of investigation. The aggregated smolt mortality in the river and in the estuary (48%) may threaten an indigenous self-sustaining Atlantic salmon population in the River Skjern. When planning river restoration projects, caution should be used, especially where permanently flooded floodplains (lakes) develop due to subsiding soil. In situations where rivers pass directly through newly developed lakes, migratory species such as Atlantic salmon and brown trout may be severely affected due to increased exposure to predation from predatory fish and birds.

Kress, S. W. (1983). The Use of Decoys, Sound Recordings, and Gull Control for Re-Establishing a Tern Colony in Maine. *Colonial Waterbirds*, *6*, 185–196. JSTOR. https://doi.org/10.2307/1520987

To re-establish breeding Arctic Terns, (Sterna paradisaea) on Eastern Egg Rock (Knox Co., Maine), breeding populations of Great Black-backed Gulls (Larus marinus) and Herring Gulls (L. argentatus) were eliminated and social attractants (Arctic Tern decoys and sound recordings of nonaggressive tern vocalizations) were used to attract terns to this former nesting site. Herring Gull populations were significantly reduced after the first summer of control efforts and Great Black-backed Gulls were significantly reduced after three summers of control by poisoning, shooting, egg and chick destruction and human disturbance. Common Eider (Somateria mollissima) and Black Guillemot (Cepphus grylle) populations have remained constant despite nine years of gull control and human occupation on the island. In the first year of using decoys and sound recordings, tern sightings nearly doubled in frequency and in the third year of using these attractants, Arctic Terns and Common Terns (Sterna hirundo) nested in the immediate vicinity of the decoys and playback speaker. Roseate Terns (S. dougallii) joined the colony in 1981. By 1982 Eastern Egg Rock supported the largest Common Tern colony in Maine. The relative importance of gull control, decoys, and sound recordings cannot be determined from this study, however, the re-establishment of breeding terms on Eastern Egg Rock demonstrates that tern populations may be restored through an integrated program of gull control and social attractants. These techniques offer opportunities for re-establishing terns on historic, remote locations where they are safer from the increased predation, flooding, and human disturbance often characteristic of sites adjacent to mainlands.

Kuiken, T. (1999). Review of Newcastle Disease in Cormorants. *Waterbirds: The International Journal of Waterbird Biology*, *22*(3), 333–347. JSTOR. https://doi.org/10.2307/1522109

Pathogenic Newcastle disease virus (NDV) caused wide-spread mortality of Double-crested Cormorants (Phalacrocorax auritus) in Canada in 1990 and in Canada and the USA in 1992.

Presence of pathogenic NDV in Double-crested Cormorants is important because of the potential risk of spread to other wild birds and domestic poultry, and the effect on population dynamics of Double-crested Cormorants. The first isolation of NDV from a member of the Phalacrocoracidae was from European Shags (P. aristotelis) in Scotland in 1949. It was found in Great Cormorants (P. carbo) from the Volga Delta in 1974, and in Double-crested Cormorants from Quebec in 1975. From 1990 to 1997, pathogenic NDV was isolated from Double-crested Cormorants in different parts of North America in five of eight years. Newcastle disease may cause high mortality of juvenile Double-crested Cormorants; affected birds typically have wing or leg paralysis, loss of balance, and non-suppurative inflammation of brain and spinal cord. There are no reports of extensive mortality from Newcastle disease in wild birds cohabiting with Double-crested Cormorants; however, it is likely that commercial range turkeys contracted Newcastle disease from Double-Crested Cormorants in North Dakota in 1992. Newcastle disease virus isolates from Double-crested Cormorants from widely separated breeding sites and from different years have the same predicted amino acid sequence of the fusion protein cleavage site. This sequence includes the substitution of arginine for glutamine at position 110 of the fusion protein, which appears to be unique for NDV isolates obtained from cormorants and associated species since 1990.

Lampman, K. P., Taylor, M. E., & Blokpoel, H. (1996). Caspian Terns (Sterna caspia) Breed Successfully on a Nesting Raft. *Colonial Waterbirds*, *19*(1), 135–138. JSTOR. https://doi.org/10.2307/1521819

The Caspian Tern (Sterna caspia) occurs in Ontario on Lake Ontario and Lake Huron, where its provincial status is rare. The colony at Hamilton Harbour is one of five Lake Ontario colonies, but its present location within the harbor is threatened by development plans. In an effort to determine the feasibility of relocating Caspian Terns, a raft was built and installed as an alternative nesting site during the 1993-1995 breeding seasons. In 1993, one pair established a nest and raised two chicks to at least 25 days, in 1994, six pairs nested and six chicks fledged and in 1995, 50 pairs nested and raised 97 chicks to fledging. In 1993, colonization of the raft by one pair occurred within 11 days of removal of a tarpaulin put in place to discourage nesting by gulls. In 1994, the raft was not colonized until late in the breeding season, some 42 days after it became available. Factors influencing the late nesting in 1994 are unclear, but may relate to either a renesting of failed pairs from mainland sites, or a loss of habitat in the mainland sub-colonies due to encroachment by Ring-billed Gulls (Larus delawarensis) and increasing vegetation. In 1995, the raft was colonized by 8 May and at least 50 pairs nested, raising approximately two young per nest. Heavy predation by red fox (Vulpes vulpes) on mainland sub-colonies resulted in the raft providing the majority of fledged young in 1995.

Lebreton, J.-D., Burnham, K. P., Clobert, J., & Anderson, D. R. (1992). Modeling Survival and Testing Biological Hypotheses Using Marked Animals: A Unified Approach with Case Studies. *Ecological Monographs*, *62*(1), 67–118. https://doi.org/10.2307/2937171

The understanding of the dynamics of animal populations and of related ecological and evolutionary issues frequently depends on a direct analysis of life history parameters. For instance, examination of trade—offs between reproduction and survival usually rely on individually marked animals, for which the exact time of death is most often unknown, because marked individuals cannot be followed closely through time. Thus, the quantitative analysis of survival studies and experiments must be based on capture—recapture (or resighting) models which

consider, besides the parameters of primary interest, recapture or resighting rates that are nuisance parameters. Capture—recapture models oriented to estimation of survival rates are the result of a recent change in emphasis from earlier approaches in which population size was the most important parameter, survival rates having been first introduced as nuisance parameters. This emphasis on survival rates in capture—recapture models developed rapidly in the 1980s and used as a basic structure the Cormack—Jolly—Seber survival model applied to an homogeneous group of animals, with various kinds of constraints on the model parameters. These approaches are conditional on first captures; hence they do not attempt to model the initial capture of unmarked animals as functions of population abundance in addition to survival and capture probabilities. This paper synthesizes, using a common framework, these recent developments together with new ones, with an emphasis on flexibility in modeling, model selection, and the analysis of multiple data sets. The effects on survival and capture rates of time, age, and categorical variables characterizing the individuals (e.g., sex) can be considered, as well as interactions between such effects. This "analysis of variance" philosophy emphasizes the structure of the survival and capture process rather than the technical characteristics of any particular model. The flexible array of models encompassed in this synthesis uses a common notation. As a result of the great level of flexibility and relevance achieved, the focus is changed from fitting a particular model to model building and model selection. The following procedure is recommended: (1) start from a global model compatible with the biology of the species studied and with the design of the study, and assess its fit; (2) select a more parsimonious model using Akaike's Information Criterion to limit the number of formal tests; (3) test for the most important biological questions by comparing this model with neighboring ones using likelihood ratio tests; and (4) obtain maximum likelihood estimates of model parameters with estimates of precision. Computer software is critical, as few of the models now available have parameter estimators that are in closed form. A comprehensive table of existing computer software is provided. We used RELEASE for data summary and goodness—of—fit tests and SURGE for iterative model fitting and the computation of likelihood ratio tests. Five increasingly complex examples are given to illustrate the theory. The first, using two data sets on the European Dipper (Cinclus cinclus), tests for sex—specific parameters, explores a model with time—dependent survival rates, and finally uses a priori information to model survival allowing for an environmental variable. The second uses data on two colonies of the Swift (Apus apus), and shows how interaction terms can be modeled and assessed and how survival and recapture rates sometimes partly counterbalance each other. The third shows complex variation in survival rates across sexes and age classes in the roe deer (Capreolus capreolus), with a test of density dependence in annual survival rates. The fourth is an example of experimental density manipulation using the common lizard (Lacerta vivipara). The last example attempts to examine a large and complex data set on the Greater Flamingo (Phoenicopterus ruber), where parameters are age specific, survival is a function of an environmental variable, and an age × year interaction term is important. Heterogeneity seems present in this example and cannot be adequately modeled with existing theory. The discussion presents a summary of the paradigm we recommend and details issues in model selection and design, and foreseeable future developments.

Ledgerwood, R. D., Ryan, B. A., Dawley, E. M., Nunnallee, E. P., & Ferguson, J. W. (2004). A Surface Trawl to Detect Migrating Juvenile Salmonids Tagged with Passive Integrated

Transponder Tags. *North American Journal of Fisheries Management*, *24*(2), 440–451. https://doi.org/10.1577/M0-071.1

We developed a surface pair-trawl system to detect juvenile Pacific salmon Oncorhynchus spp. marked with passive integrated transponder (PIT) tags as they migrate through the upper Columbia River estuary. The trawl was fitted with a detection antenna in its cod end and was deployed by two vessels. Fish entering the trawl body exit after passing by the detection antenna. Detection data were recorded by electronic components housed in a small boat tethered to the trawl. The system was modified extensively after its first deployment in 1995 and by 2001 was performing reliably under a variety of weather conditions and river flows. From 1995 to 2001 the device detected 29,699 PIT-tagged juvenile salmon. During extended daily sampling periods, we detected nearly 2% of all PIT tags previously detected at Bonneville Dam, which is located 159 rkm upstream from the study area.

Leopold, A. (1933). *Game Management*. C. Scribner's Sons.

Lichatowich, J., Mobrand, L., & Lestelle, L. (1999). Depletion and extinction of Pacific salmon (Oncorhynchus spp.): A different perspective. *ICES Journal of Marine Science*, *56*(4), 467–472. https://doi.org/10.1006/jmsc.1999.0457

Conventional wisdom holds that the depletion of Pacific salmon is a consequence of the economic development and exploitation of Pacific Northwest ecosystems, including fur trade, mining, timber harvest, grazing, irrigation, dams, municipal and industrial development, pollution, and excessive harvest. An attempt to support the fishery through artificial propagation is also recognized as a contributor to the decline. However, those proximal causes of depletion fail to adequately explain the current status of the stocks. Fishery managers have known for at least 122 years what would destroy the Pacific salmon, but having possession of that knowledge, and adding more to it, did not prevent depletion. The decline and local extinction is also a consequence of the implementation of management programmes based on assumptions that have proven to be wrong. If the century of decline is to be halted and reversed, biologists, politicians, and the public will have to undertake the difficult task of evaluating and revising those assumptions and the management programmes derived from them.

Litz, M. N. C., Emmett, R. L., Bentley, P. J., Claiborne, A. M., & Barceló, C. (2014). Biotic and abiotic factors influencing forage fish and pelagic nekton community in the Columbia River plume (USA) throughout the upwelling season 1999–2009. *ICES Journal of Marine Science*, *71*(1), 5–18. https://doi.org/10.1093/icesjms/fst082

Large river plumes modify coastal environments and can impact production across multiple trophic levels. From 1999 to 2009, the assemblages of forage fish, predator fish, and other pelagic nekton were monitored in coastal waters associated with the Columbia River plume. Surveys were conducted at night to target vertically migrating species, and community structure evaluated to better understand ecological interactions. Distinct inshore and offshore communities were identified during spring and summer that were correlated with ocean temperature, salinity, plume volume, and upwelling intensity. Resident euryhaline forage fish species, such as smelts, anchovy, herring, market squid, juvenile salmon, and spiny dogfish, showed a high affinity for inshore habitat and the lower salinity plume during spring. Highly migratory species, such as sardine, piscivorous hake, sharks, and mackerels, were associated with warmer, saltier waters offshore, during strong upwelling periods in summer. Overall, our study of pelagic nekton revealed that temporal dynamics in abundance and community composition were associated with seasonal abiotic phenomenon, but not interannual, large-scale oceanographic processes. Forage fish assemblages differed seasonally and spatially from the assemblages of major piscivorous predators. This finding suggests a potential role of the plume as refuge for forage fish from predation by piscivorous fish in the northern California Current.

Lohse, T. G., Lohse, T. K., Lohse, T. W., & Lang, A. (2008). First Documented Breeding Colony of Caspian Terns on the Copper River Delta, Alaska. *Western Birds*, *39*, 94–96.

Lyons, D.E., Evans, A. F., Hostetter, N. J., Piggott, A., Weitkamp, L., Good, T. P., Roby, D. D., Collis, K., Loschl, P. J., & Cramer, B. (2014). *Factors Influencing Predation on Juvenile Salmonids by Double-crested Cormorants in the Columbia River Estuary: A Retrospective Analysis* (p. 38). http://www.birdresearchnw.org/ESI%20DCCO%20Revised%20Retrospective%20Analysis%202014%2011%2007.pdf

Enhancing the survival of juvenile salmonid (Oncorhynchus spp.) is a priority objective to recover populations of Columbia River salmonids listed under the U.S. Endangered Species Act (ESA). In the Columbia River estuary, a significant mortality factor for juvenile salmonids is predation by double-crested cormorants (Phalacrocorax auritus) nesting at East Sand Island. The U.S. Army Corps of Engineers is considering management alternatives to reduce this mortality. Understanding the factors that influence cormorant predation is important to understanding the potential consequences of various management strategies. We used principal components regression (PCR) to evaluate the relationship between several annual measures of cormorant predation and a combination of colony size and environmental covariates. The environmental factors considered included large-scale climate indices (Pacific Decadal Oscillation, El Nino/Southern Oscillation Index, North Pacific Gyre Oscillation, Pacific Northwest Index), regional climate measures (sea surface temperature, upwelling strength, upwelling timing), and variables describing conditions during freshwater and estuarine outmigration (river discharge, spill at hydroelectric dams, measures of salmonid smolt survival to the estuary). These covariates potentially influenced both the susceptibility of salmonids to cormorant predation and the abundance and distribution of marine forage fish and their availability as alternative prey for cormorants nesting in the estuary. Measures of cormorant predation spanned a 15-year period (1999 – 2013) and included (1) predation probabilities for multiple steelhead (O. mykiss) and Chinook salmon (O. tshawytscha) populations derived from recoveries of salmonid passive integrated transponder (PIT) tags at the cormorant colony, (2) estimates of annual consumption of steelhead and yearling Chinook by cormorants derived using bioenergetics modelling, and (3) the observed percentage of the cormorant diet that consisted of salmonids. We also related cormorant diet composition to purse seine catches in the estuary during 2007 – 2012 to assess how predation on salmonids is related to availability of alternative, non-salmonid prey and to examine cormorant selectivity of salmonids relative to other available prey. PCR analyses indicated that environmental factors explain a substantial proportion of the annual variability seen in several measures of cormorant predation on Columbia River juvenile salmonids. Cormorant colony size was an important explanatory factor in most regressions; however, it never explained more than 17% of the variability in any annual measure of cormorant predation on salmonids. In aggregate, environmental factors explained a greater proportion of the annual variability in cormorant predation than did colony size; in particular, river discharge and the

North Pacific Gyre Oscillation (NPGO) were prominent environmental explanatory factors. Based on comparisons to estuary purse seine catches, cormorants appeared to take salmonids in proportion to their relative availability in the Columbia River estuary, not their absolute abundance. Conversely, changes in absolute abundance of alternative prey, both marine and freshwater/estuarine forage fishes, did influence how much cormorants relied on salmonids as prey. While colony size is an important determinant of cormorant impacts on salmonid populations, environmental conditions that regulate the availability of alternative prey might outweigh the effects of changing colony size in any given year. Potential management efforts to reduce the size of the double-crested cormorant colony on East Sand Island to benefit ESA-listed salmonids would best be evaluated in the context of environmental conditions, particularly if evaluation occurs on an annual basis, with special attention given to river discharge and the NPGO. Multiyear data sets following any implementation of management would likely be more useful to evaluate potential benefits.

Lyons, Donald E. (2004). *Foraging Ecology of Caspian Terns and Double-crested Cormorants in the Columbia River Estuary* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/vm40xv63m

A detailed understanding of the foraging ecology of species preying upon threatened or endangered prey may contribute to identifying and evaluating management options to reduce predation, when such management is deemed appropriate. In the Columbia River estuary, Caspian terns (Sterna caspia) and double-crested cormorants (Phalacrocorax auritus) have been identified as significant predators on juvenile salmonids (Oncorhynchus spp.), many populations of which are listed under the U.S. Endangered Species Act. In 1998 and 1999, we studied the foraging ecology of Caspian terns and double-crested cormorants in the estuary using point count surveys. We also flew aerial strip transect surveys throughout the estuary for terns, and in 1999 we used radiotelemetry to track terns during the chick-rearing period. Terns and cormorants generally used habitat in relation to availability, with tidal flats and deep water channels both important foraging habitats, while tributaries, sloughs, and areas near ocean jetties were less important. Higher densities of cormorants were observed foraging in locations with pile dikes and/or pilings in 1999. More terns foraged in the freshwater portion of the estuary in 1998, than in 1999, when some terns nested on East Sand Island in the marine zone of the estuary. During the latter half of both seasons, use of upriver foraging sites became less prevalent for both terns and cormorants and use of sites in the marine and mixing zone more prevalent. Terns were observed foraging ≥ 50 km from the Rice Island colony (where all terns nested in 1998, and most did in 1999); however, ≤ 5% of foraging occurred ≥ 27 km from this colony in both years. In 1999, we compared the foraging ecology of radio-tagged Caspian terns raising young at the main estuary colony on Rice Island, in the freshwater zone of the estuary, to terns raising young at a newly restored colony site at East Sand Island in the marine zone. Early in the chick-rearing period, radio-tagged terns nesting at Rice Island (river km 34) foraged close to the colony in the freshwater zone of the estuary, while terns nesting on East Sand Island (river km 8) foraged in the marine or estuarine mixing zones close to that colony. Late in the chick- rearing period, Rice Island terns shifted their foraging to the marine and mixing zones lower in the estuary; East Sand Island terns continued to forage in these areas. Tern diets at each colony corresponded to foraging location (freshwater zone vs. marine/mixing zone) of radio-tagged individuals: Rice Island terns relied heavily on juvenile salmonids (71% of identified prey) early in chick-rearing but this declined late in chick-rearing (46%). East Sand Island terns relied less upon salmonids

(42% and 16%, respectively), instead utilizing marine fishes such as anchovy (Engraulis mordax) and herring (Clupea pallasi). Throughout chick-rearing, Rice Island terns foraged farther from the colony (median distance: 12.3 km during early chick-rearing and 16.9 km during late chick-rearing) than did East Sand Island terns (9.6 and 7.7 km, respectively). Colony attendance decreased for terns at both sites from similar high levels during early chick-rearing (60-70% of daylight hours) to lower levels (40-50%) during late chick-rearing, with attendance decreasing significantly more at Rice Island. We conclude that Caspian terns and double-crested cormorants are generalist foragers and make use of the forage fish resources most available near the breeding colony. Predation rates on salmonids should decline if terns are attracted to colony sites, such as East Sand Island, where alternative prey are readily available. Precluding cormorant roosting at pile dikes and pilings, if feasible, might reduce consumption of salmonids, but additional studies would be required for verification.

Lyons, Donald E. (2010). *Bioenergetics-based Predator-prey Relationships Between Piscivorous Birds and Juvenile Salmonids in the Columbia River Estuary* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/08612r341

This dissertation focuses on the predator-prey relationship between two species of avian predators, Caspian terns (Hydroprogne caspia) and double-crested cormorants (Phalacrocorax auritus), and one of their important prey types, juvenile salmonids (Oncorhynchus spp.), in the Columbia River estuary of Oregon and Washington states during the period 1998 – 2007. I used a data-rich bioenergetics framework to estimate juvenile salmonid consumption by these two avian predators, assessed impacts to at-risk salmonid populations by estimating salmonid mortality rates due to avian predation, and estimated potential demographic benefits to salmonids if avian predation were reduced. The managed relocation of the Caspian tern colony from Rice Island to East Sand Island, lower in the Columbia River estuary, reduced tern predation on salmonids from over 11 million smolts consumed annually to 4 – 7 million, but those benefits accrued primarily to sub-yearling Chinook salmon (O. tshawytscha). Combined consumption of juvenile salmonids by Caspian terns and double-crested cormorants in the Columbia River estuary was ca. 7 – 15 million smolts per year during 2006-2007, causing an 8 – 17% mortality rate among smolts migrating through the estuary, with higher mortality rates for steelhead (O. mykiss) and coho salmon (O. kisutch). Under a potential management scenario to reduce avian predation by both species, improvements in the average annual population growth rate (λ) of salmonids ranged from 0.4% for sub-yearling Chinook to 3.1% for coho. These improvements are generally less than what is possible from altered hydropower system operation within the Columbia Basin for salmonid populations that are more severely affected by dams. For a few salmonid populations, reduced avian predation might contribute to stabilizing the population ($\lambda = 1$), but would need to be part of a broader recovery strategy to ensure population growth and recovery ($\lambda > 1$). Climate was an important factor modulating Caspian tern predation on salmonids, with greater consumption of smolts occurring in years of cooler ocean conditions and higher Columbia River flows. Climate did not contribute to variation in consumption of salmonids by cormorants, perhaps due to the larger effect of growth in the size of the cormorant colony during the study period. Due to current trends in colony size (terns: stable, cormorants: increasing) and the planned dispersal of a portion of the tern population, cormorant predation will likely be a more significant mortality factor for Columbia Basin salmonids in the future than will tern predation. A critical unknown factor remains; that is the degree to which reductions in avian predation on salmonids might be compensated for by other salmonid mortality factors.

Lyons, Donald E., Patterson, A. G. L., Tennyson, J., Lawes, T. J., & Roby, D. D. (2018). The Salton Sea: Critical Migratory Stopover Habitat for Caspian Terns (Hydroprogne caspia) in the North American Pacific Flyway. *Waterbirds*, *41*(2), 154–165. https://doi.org/10.1675/063.041.0206

For migratory waterbirds, the availability and quality of suitable stopover habitat can affect body condition and demographic parameters throughout the annual cycle. This study investigates the importance of the Salton Sea, a large saline lake located in the southwestern United States near the USA-Mexico border, for migrating Caspian Terns (Hydroprogne caspia) fitted with long-duration satellite telemetry tags in the northwest contiguous USA. During fall migration, 100% (n = 25) in 2014 and 98% (n = 63) in 2015 of all tagged individuals were tracked to the Salton Sea, with median durations of stay lasting 36 and 25 days, respectively. Use of the Salton Sea during subsequent spring migrations was less consistent than in fall, but still substantial, with 91% (n = 23) and 68% (n = 53) of all birds conducting brief stops there during 2015 and 2016, respectively. The future of the Salton Sea as suitable habitat for fish and piscivorous birds is uncertain due to rising salinity levels caused by reduced input flows. It is also uncertain if other wetlands in the region can serve as replacement habitat for Caspian Terns and other migratory piscivorous species should the Salton Sea cease to provide fish prey.

Lyons, Donald E., & Roby, D. D. (2011). Validating growth and development of a seabird as an indicator of food availability: Captive-reared Caspian Tern chicks fed ad libitum and restricted diets: Tern Chick Growth and Food Availability. *Journal of Field Ornithology*, *82*(1), 88–100. https://doi.org/10.1111/j.1557-9263.2010.00311.x

For seabirds raising young under conditions of limited food availability, reducing chick provisioning and chick growth rates are the primary means available to avoid abandonment of a breeding effort. For most seabirds, however, baseline data characterizing chick growth and development under known feeding conditions are unavailable, so it is difficult to evaluate chick nutritional status as it relates to foraging conditions near breeding colonies. To address this need, we examined the growth and development of young Caspian Terns (Hydroprogne caspia), a cosmopolitan, generalist piscivore, reared in captivity and fed ad libitum and restricted (ca. one-third lower caloric intake) diets. Ad libitum-fed chicks grew at similar rates and achieved a similar size at fledging as previously documented for chicks in the wild and had energetic demands that closely matched allometric predictions. We identified three general characteristics of food-restricted Caspian Tern chicks compared to ad libitum chicks: (1) lower age-specific body mass, (2) lower age-specific skeletal and feather size, such as wing chord length, and (3) heightened levels of corticosterone in blood, both for baseline levels and in response to acute stress. Effects of diet restriction on feather growth (10–11% slower growth in diet-restricted chicks) were less pronounced than effects on structural growth (37–52% slower growth) and body mass (24% lower at fledging age), apparently due to preferential allocation of food resources to maintain plumage growth. Our results suggest that measurements of chick body mass and feather development (e.g., wing chord or primary length) or measurement of corticosterone levels in the blood would allow useful evaluation of the nutritional status of chicks reared in the wild and of food availability in the foraging range of adults. Such evaluations could also inform demography studies (e.g., predict future recruitment) and assist in evaluating designated piscivorous waterbird conservation (colony) sites.

Lyons, Donald E., Roby, D. D., & Collis, K. (2005). Foraging Ecology of Caspian Terns in the Columbia River Estuary, USA. *Waterbirds*, *28*(3), 280–291. https://doi.org/10.1675/1524-4695(2005)028[0280:FEOCTI]2.0.CO;2

Comparisons were made of the foraging ecology of Caspian Terns (Sterna caspia) nesting on two islands in the Columbia River estuary using radio telemetry and observations of prey fed to chicks and mates at each colony. Early in the chick-rearing period, radio-tagged terns nesting at Rice Island (river km 34) foraged mostly in the freshwater zone of the estuary close to the colony, while terns nesting on East Sand Island (river km 8) foraged in the marine or estuarine mixing zones close to that colony. Late in the chick-rearing period, Rice Island terns moved more of their foraging to the two zones lower in the estuary, while East Sand Island terns continued to forage in these areas. Tern diets at each colony corresponded to the primary foraging zone (freshwater vs. marine/mixing) of radio-tagged individuals: Early in chick-rearing, Rice Island terns relied heavily on juvenile salmonids (Oncorhynchus spp., 71% of identified prey), but this declined late in chick-rearing (46%). East Sand Island terns relied less on salmonids (42% and 16%, early and late in chick-rearing), and instead utilized marine fishes such as Anchovy (Engraulis mordax) and Herring (Clupea pallasi). Throughout chick-rearing, Rice Island terns foraged farther from their colony (median distance: 12.3 km during early chick-rearing and 16.9 km during late chick-rearing) than did East Sand Island terns (9.6 and 7.7 km, respectively). The study leads to the conclusion that Caspian Terns are generalist foragers and make use of the most proximate available forage fish resources when raising young.

Lyons, Donald E., Roby, D. D., & Collis, K. (2007). Foraging Patterns of Caspian Terns and Double-crested Cormorants in the Columbia River Estuary. *Northwest Science*, *81*(2), 91–103. https://doi.org/10.3955/0029-344X-81.2.91

We examined spatial and temporal foraging patterns of Caspian terns and double-crested cormorants nesting in the Columbia River estuary, to potentially identify circumstances where juvenile salmonids listed under the U.S. Endangered Species Act might be more vulnerable to predation by these avian piscivores. Data were collected during the 1998 and 1999 breeding seasons, using point count surveys of foraging birds at 40 sites along the river's banks, and using aerial strip transect counts throughout the estuary for terns. In 1998, terns selected tidal flats and sites with roosting beaches nearby for foraging, making greater use of the marine/mixing zone of the estuary later in the season, particularly areas near the ocean jetties. In 1999, cormorants selected foraging sites in freshwater along the main channel with pile dikes present, particularly early in the season. Foraging trends in the other year for each species were generally similar to the above but usually not significant. During aerial surveys we observed 50% of foraging and commuting terns within 8 km of the Rice Island colony, and < 5% of activity occurred > 27 km from this colony in both years. Disproportionately greater cormorant foraging activity at pile dikes may indicate greater vulnerability of salmonids to predation at those features. Colony relocations to sites at sufficient distance from areas of relatively high salmonid abundance may be a straightforward means of reducing impacts of avian predation on salmonids than habitat alterations within the Columbia River estuary, at least for terns.

Lyons, Donald E., Roby, D. D., Evans, A. F., Hostetter, N. J., & Collis, K. (2011). *Benefits to Columbia River Anadromous Salmonids from Potential Reductions in Avian Predation on the Columbia Plateau* (p. 78). http://www.birdresearchnw.org/inland%20avian%20predation%20benefits%20analysis.pdf

Predation on juvenile salmonids (Oncorhynchus spp.) during out-migration to the Pacific Ocean is considered potentially limiting to the recovery of anadromous salmonid populations from the Columbia River basin that are listed under the U.S. Endangered Species Act. We examined the potential benefits of reducing avian predation associated with five colonies of piscivorous waterbirds in the Columbia Plateau region for three evolutionarily significant units (ESUs) of Chinook salmon (O. tshawytscha), one ESU of sockeye salmon (O. nerka), and two distinct population segments (DPSs) of steelhead trout (O. mykiss) from the Upper Columbia River and Snake River basins. Using predation rate data based on recoveries of smolt passive integrated transponder (PIT) tags at bird colonies and the framework of a simple deterministic, age-structured, matrix population growth model, we translated potential changes in smolt survival due to reductions in avian predation into increases in the average annual population growth rate (λ) at the ESU/DPS level. Estimates were produced for a range of reductions in avian predation and for a range of levels of compensatory mortality. The greatest potential benefit from reductions in predation by birds from a single colony in the Columbia Plateau region was for Upper Columbia River steelhead when predation by Caspian terns (Hydroprogne caspia) nesting at Goose Island (in Potholes Reservoir near Othello, WA) was reduced; up to a 4.2% (hatchery-raised smolts) or 3.2% (wild smolts) increase in λ was possible if predation were completely eliminated and compensatory mortality did not occur. Potential benefits for Snake River ESUs were lower, in part because significant portions of those ESUs are transported and thus inaccessible to avian predators in the Columbia Plateau region. The greatest potential benefit possible for a Snake River salmonid ESU/DPS resulting from reductions in predation by birds from a single colony was for steelhead, if predation by Caspian terns nesting at the Crescent Island colony (near Pasco, WA) was eliminated (0.5% increase in λ if no compensatory mortality occurred). Management to reduce predation on salmonids by Caspian terns nesting at the Goose Island colony would offer the greatest benefits per managed bird. Management to reduce predation by Caspian terns from two other colonies in the Columbia Plateau region (Crescent Island and the Blalock Island Complex) would provide the next largest incremental benefit. Adding reductions in predation by double-crested cormorants (Phalacrocorax auritus) nesting on Foundation Island (near Pasco, WA) and gulls (Larus spp.) nesting on Miller Rocks (near Maryhill, WA) to reductions in Caspian tern predation would somewhat enhance benefits to salmonids, but at a much lower marginal benefit rate per managed bird. Cumulative potential benefits for eliminating predation by birds nesting at all five colonies in the Columbia Plateau region considered here were generally comparable to estimates of benefits from dispersing approximately two thirds of the large Caspian tern colony in the Columbia River estuary (USFWS 2005); benefits were greater, however, for Upper Columbia River steelhead from eliminating predation by birds nesting at the five Columbia Plateau colonies. Our analysis indicates that, at current bird colony sizes, actions to reduce avian predation on juvenile salmonids in the Columbia Plateau region will not by themselves recover any ESA-listed population of anadromous salmonids. Reductions in avian predation in this region could, however, result in increases in salmonid population growth rates comparable to some other salmonid recovery efforts in the Columbia Basin, particularly for Upper Columbia River and Snake River steelhead populations.

Lyons, Donald E., Roby, D. D., Evans, A. F., Hostetter, N. J., & Collis, K. (2014). *Benefits to Columbia River Anadromous Salmonids from Potential Reductions in Predation by Double-*

crested Cormorants Nesting at the East Sand Island Colony in the Columbia River Estuary (p. 64). http://www.birdresearchnw.org/final%20esi%20dcco%20benefits%20analysis.pdf

Predation on juvenile salmonids (Oncorhynchus spp.) during out-migration to the Pacific Ocean is considered a factor potentially limiting the recovery of threatened and endangered anadromous salmonid populations from the Columbia River basin. We examined the potential benefits of reductions in predation by double-crested cormorants (Phalacrocorax auritus) nesting at the large colony on East Sand Island (rkm 8) in the Columbia River estuary to three distinct population segments (DPSs) of steelhead (O. mykiss), four evolutionarily significant units (ESUs) of Chinook salmon (O. tshawytscha), and one ESU of sockeye salmon (O. nerka). All eight of these salmonid populations originate from either the Columbia Basin upstream of Bonneville Dam (rkm 235) or the Upper Willamette Basin, and are listed as either threatened or endangered under the U.S. Endangered Species Act. The East Sand Island double-crested cormorant colony, averaging ca. 12,600 breeding pairs during 2007 – 2012, is the largest colony for this species in western North America, and cormorants from this colony have been documented to consume millions of salmonid smolts per year. We estimated cormorant predation rates using recoveries of smolt passive integrated transponder (PIT) tags on the East Sand Island cormorant colony. Under the framework of a simple deterministic, age-structured, matrix population growth model for salmonid populations, we translated potential changes in smolt survival due to reductions in cormorant predation into increases in the average annual population growth rate (λ) at the level of the salmonid distinct population segment (DPS) or evolutionarily significant unit (ESU). Estimates were produced for a range of reductions in cormorant predation and for a range of levels of compensatory mortality for smolts. Potential increases in λ ($\Delta\lambda$) for complete elimination of predation on smolts by East Sand Island double-crested cormorants, assuming no other mortality factors would compensate for this reduction in predation, ranged from 0.4 – 1.1% for Chinook salmon ESUs originating upstream of Bonneville Dam or from the Upper Willamette Basin, was 1.6% for the Snake River sockeye salmon ESU, and ranged from 1.8 – 2.1% for steelhead DPSs originating upstream of Bonneville Dam. If a moderate level of compensatory smolt mortality (e.g., 50%) occurred in response to a complete elimination of mortality due to cormorant predation, $\Delta\lambda$ values would drop below 1% for Chinook and sockeye salmon ESUs, but remain 0.9 – 1.1% for steelhead DPSs. In general, a two-thirds reduction in predation by double-crested cormorants nesting at the East Sand Island colony would produce similar levels of benefit for salmonids originating upstream of Bonneville Dam to benefits projected for the ongoing management to reduce by two-thirds the predation by Caspian terns nesting at the East Sand Island colony (USFWS 2005). Management to reduce cormorant predation would not be as efficient, however, as management to reduce Caspian tern predation in terms of benefits per managed bird due to the lower per capita impacts of cormorants on survival of salmonids originating upstream of Bonneville Dam. As seen with other analyses of avian predation, potential benefits to ESA-listed DPSs/ESUs of Columbia Basin salmonids from reductions in predation by East Sand Island double-crested cormorants are smaller than the total expected benefits projected from all recovery actions included in the proposed management of the Federal Columbia River Power System (FCRPS). Benefits from cormorant management would not ensure recovery of any of the eight ESA-listed salmonid populations analyzed here, but are comparable to other individual recovery actions included in the 2008 Biological Opinion on the management of the FCRPS. The robustness of these analyses would be strengthened by additional information on the degree to which other smolt mortality factors may compensate for reductions in mortality from cormorant predation. Also, the impacts of cormorant predation on

survival of ESA-listed salmonids from populations originating downstream of Bonneville Dam remain poorly understood. Finally, additional measurements of on-colony deposition rates of PIT tags from PIT-tagged salmonids consumed by cormorants would further reduce uncertainty in the results presented here.

MacFarlane, R. B. (2010). Energy dynamics and growth of Chinook salmon (Oncorhynchus tshawytscha) from the Central Valley of California during the estuarine phase and first ocean year. *Canadian Journal of Fisheries and Aquatic Sciences*, *67*(10), 1549–1565. https://doi.org/10.1139/F10-080

The greatest rates of energy accumulation and growth in subyearling Chinook salmon (Oncorhynchus tshawytscha) occurred during the first month following ocean entry, supporting the importance of this critical period. Data from an 11-year study in the coastal ocean off California and the San Francisco Estuary revealed that juvenile salmon gained 3.2 kJ·day–1 and 0.8 g·day–1, representing 4.3%·day–1 and 5.2% day–1, respectively, relative to estuary exit values. Little gain in energy (0.28 kJ·day–1) or size (0.07 g·day–1) occurred in the estuary, indicating that the nursery function typically ascribed to estuaries can be deferred to initial ocean residence. Calculated northern anchovies (Engraulis mordax) equivalents to meet energy gains were one anchovy per day in the estuary (8% body weight·day–1) and about three per day immediately following ocean entry (15% body weight·day–1). Energy content in the estuary was positively related to higher salinity and lower freshwater outflow, whereas in the ocean, cooler temperatures, lower sea level, and greater upwelling resulted in greater gains. These results suggest that greater freshwater flows, warmer sea temperatures, and reduced or delayed upwelling, all of which are indicated by some (but not all) climate models, will likely decrease growth of juvenile Chinook salmon, leading to reduced survival.

Madenjian, C. P., & Gabrey, S. W. (1995). Waterbird Predation on Fish in Western Lake Erie: A Bioenergetics Model Application. *The Condor*, *97*(1), 141–153. https://doi.org/10.2307/1368992

To better understand the role of piscivorous waterbirds in the food web of western Lake Erie, we applied a bioenergetics model to determine their total fish consumption. The important nesting species included the Herring Gull (Larus argentatus), Ring-billed Gull (L. delawarensis), Double-crested Cormorant (Phalacrocorax auritus), Great Blue Heron (Ardea herodias), Black-crowned Night-Heron (Nycticorax nycticorax), and Great Egret (Casmerodius albus). The impact of migrant waterbirds, including the Red-breasted Merganser (Mergus serrator), on western Lake Erie fish biomass was also considered in the analysis. According to the modeling results, during the early 1990s, piscivorous waterbirds consumed 13,368 tonnes of fish from western Lake Erie each year. This tonnage was equivalent to 15.2% of the prey fish biomass needed to support the walleye (Stizostedion vitreum) population in western Lake Erie during a single growing season. The model application was useful in quantifying energy flow between birds and fish in a large lake ecosystem.

Major, W. W., Grassley, J. M., Ryding, K. E., Grue, C. E., Pearsons, T. N., Tipton, D. A., & Stephenson, A. E. (2005). Abundance and Consumption of Fish by California Gulls and Ring-billed Gulls at Water and Fish Management Structures within the Yakima River, Washington. *Waterbirds*, *28*(3), 366–377. https://doi.org/10.1675/1524-4695(2005)028[0366:AACOFB]2.0.CO;2

During 1999-2002, we studied the abundance of fish-eating birds, primarily Ring-billed Gulls (Larus delawarensis) and California Gulls (L. californicus), and estimated their consumption of fish at Horn Rapids Dam and the Chandler Irrigation Canal return pipe on the Yakima River in eastern Washington. Earlier observations of gulls at these structures suggested a high level of predation of juvenile salmonids. The relationship between river flow, gull use at the sites and fish taken was also examined. Numbers of gulls (instantaneous counts of foraging and non-foraging individuals) at the structures varied daily between their arrival in late March-early April and departure in late June. Daily averages across the four years were 9.8 (SE ± 1.5) and 19.1 (SE ± 2.5) gulls at Horn Rapids and Chandler, respectively. Gull numbers at Horn Rapids peaked dramatically during the last two weeks in May, reaching maxima of 37 (SE ± 2.2) to 133 (SE ± 4.2) gulls/day. This increase appeared to be associated with the hatchery release of one to two million juvenile autumn Chinook (Oncorhynchus tshawytscha) above the dam. A comparable peak in gull abundance was not observed at Chandler. Diurnal patterns of gull abundance differed between sites and among years. Relationships between fish take and water flow also varied within and among years at the two sites. Low seasonal flows were associated with increased predation at Chandler, whereas high seasonal flows were associated with increased predation at Horn Rapids. Assuming all fish taken were salmonids, consumption at both sites combined was estimated to be ≤10.3% of the juvenile salmonids passing the two sites.

Malevich, S. B., Woodhouse, C. A., & Meko, D. M. (2013). Tree-ring reconstructed hydroclimate of the Upper Klamath basin. *Journal of Hydrology*, *495*, 13–22. https://doi.org/10.1016/j.jhydrol.2013.04.048

This work presents the first tree-ring reconstructions of hydroclimate for the Upper Klamath River basin, which stretches from northern California into southern Oregon. The extended record provides a centuries-long perspective on the region's hydroclimatic variability and context for water-related political issues that have erupted in recent years. Reconstructions of water-year precipitation for Klamath Falls, Oregon (extending 1564–2004 and 1000–2010 CE) were developed to compare past drought severity with drought severity of the instrumental record (extending 1896–2011). The reconstructions suggest that variability exhibited during the instrumental period captures extremes of moderate-to-long-duration (6-, 10-, and 20-year) droughts, but not of short (single-year and 3-year) and very long (50-year) droughts, which were more severe during the 11th–13th centuries. The late-16th-century "mega drought" is present in the Klamath River basin, though with less strength than in the neighboring Sacramento River basin. Cool-season storm tracks appear to be a direct driver of hydroclimatic variability, leading to instances of see-saw like relationships with neighboring regions, such as in the mid-14th century. In contrast, the larger area of drought in the 12th century is suggestive of a long-term northward shift in cool-season storm tracks.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., & Francis, R. C. (1997). A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production. *Bulletin of the American Meteorological Society*, *78*(6), 1069–1080. https://doi.org/10.1175/1520-0477(1997)078<1069:APICOW>2.0.CO;2

Evidence gleaned from the instrumental record of climate data identifies a robust, recurring pattern of ocean-atmosphere climate variability centered over the midlatitude North Pacific basin. Over the past century, the amplitude of this climate pattern has varied irregularly at interannual-to-interdecadal timescales. There is evidence of reversals in the prevailing polarity of the oscillation occurring around 1925, 1947, and 1977; the last two reversals correspond to dramatic shifts in salmon production regimes in the North Pacific Ocean. This climate pattern also affects coastal sea and continental surface air temperatures, as well as streamflow in major west coast river systems, from Alaska to California.

Maranto, C. J., Good, T. P., Wiese, F. K., & Parrish, J. K. (2010). Impact of the Potholes Reservoir Caspian Tern Breeding Colony on Out-Migrating Juvenile Salmonids in the Mid-Columbia River. *Transactions of the American Fisheries Society*, *139*(2), 362–381. https://doi.org/10.1577/T09-095.1

We examined the foraging behavior and diet of Caspian terns Hydroprogne caspia breeding at Potholes Reservoir, Washington, in 2003, 2005, and 2006, and we developed a bioenergetics model to estimate impacts on juvenile salmonids Oncorhynchus spp. from Columbia River stocks. Potholes Reservoir Caspian terns mostly foraged on local fish (68–97% of tern bill loads) rather than traveling to the Columbia River. Our model suggested that only 8,913–94,139 juvenile salmonids were consumed, representing 0.02–0.38% of the salmonids available to Caspian terns. Local foraging is probably explained by higher net profitability of Potholes Reservoir fish prey. Columbia River steelhead O. mykiss were the only juvenile salmonids that were energetically comparable with local Potholes Reservoir fish, mostly due to their high energy density and relatively large size. Passive integrated transponder tag analyses showed that Potholes Reservoir Caspian terns preferred steelhead (predation rates = 0.42–1.06%) to all other salmonid stocks (coho salmon O. kisutch = 0.09–0.36%; subyearling Chinook salmon O. tshawytscha = 0.009–0.040%; yearling Chinook salmon = 0.05–0.17%). Given the proposed reduction in nesting habitat at East Sand Island (ESI; where the current Caspian tern population consumes 3.6–5.3 million juvenile salmonids annually), we estimated the impact on salmonid stocks that would occur if ESI Caspian terns relocated to Potholes Reservoir. Depending on diet scenario, 100% relocation could result in juvenile salmonid consumption between 2.2 and 6.6 million fish, with lower values being much more likely, making Potholes Reservoir the colony location of least likely impact among all sites within the Columbia River drainage. We suggest that selection of sites for ESI relocation should be based on scientific evidence combining a quantitative approach, such as bioenergetics modeling linked to prey population growth rate.

Maranto, C. J., Parrish, J. K., Herman, D. P., Punt, A. E., Olden, J. D., Brett, M. T., & Roby, D. D. (2011). Use of Fatty Acid Analysis to Determine Dispersal of Caspian Terns in the Columbia River Basin, U.S.A. *Conservation Biology*, *25*(4), 736–746. https://doi.org/10.1111/j.1523-1739.2011.01706.x

Lethal control, which has been used to reduce local abundances of animals in conflict with humans or with endangered species, may not achieve management goals if animal movement is not considered. In populations with emigration and immigration, lethal control may induce compensatory immigration, if the source of attraction remains unchanged. Within the Columbia River Basin (Washington, U.S.A.), avian predators forage at dams because dams tend to reduce rates of emigration of juvenile salmonids (Oncorhynchus spp.), artificially concentrating these prey. We used differences in fatty acid profiles between Caspian Terns (Hydroprogne caspia) at coastal and inland breeding colonies and terns culled by a lethal control program at a mid-Columbia River dam to infer dispersal patterns. We modeled the rate of loss of fatty acid biomarkers, which are fatty acids that can be traced to a single prey species or groups of species, to infer whether and when terns foraging at dams had emigrated from the coast. Nonmetric multidimensional scaling showed that coastal terns had high levels of C20 and C22 monounsaturated fatty acids, whereas fatty acids of inland breeders were high in C18:3n3, C20:4n6, and C22:5n3. Models of the rate of loss of fatty acid showed that approximately 60% of the terns collected at Rock Island Dam were unlikely to have bred successfully at local (inland) sites, suggesting that terns foraging at dams come from an extensive area. Fatty acid biomarkers may provide accurate information about patterns of dispersal in animal populations and may be extremely valuable in cases where populations differ demonstrably in prey base.

Markle, D. F., Cavalluzzi, M. R., & Simon, D. C. (2005). Morphology and taxonomy of Klamath Basin suckers (Catostomidae). *Western North American Naturalist*, *65*(4), 473–489.

We examined morphology of 4 sucker species (Catostomidae) from Klamath and Rogue River basins, Oregon and California. Different pairs of these species have been suspected of hybridizing, and field biologists have experienced difficulty identifying individuals in some areas. The suite of morphological characters used for initial identification was poorly supported by other morphometric characters but well supported by meristic characters, especially when analyses were restricted geographically. In some species sexual dimorphism was evident, with males having longer pectoral fins and females having longer pre-anal counts and measurements. Each species showed geographic differentiation, either between the Lost River subbasin and other Klamath subbasins or between Klamath and Rogue basins. Classification was most difficult for Catostomus snyderi, which was frequently misclassified as all other species, but especially as Chasmistes brevirostris. Despite this, the 2 species are ecologically segregated in the upper subbasins with lake-spawning Ch. brevirostris spatially segregated and river-spawning Ch. brevirostris temporally segregated from river-spawning C. snyderi. We discuss the possibility that a large-headed, thin-lipped species has become extinct in Upper Klamath Lake and alternatively suggest that the form could represent an ecophenotype of Ch. brevirostris that is no longer produced in hypereutrophic Upper Klamath Lake.

Marsh, D. M., Matthews, G. M., Achord, S., Ruehle, T. E., & Sandford, B. P. (1999). Diversion of Salmonid Smolts Tagged with Passive Integrated Transponders from an Untagged Population Passing through a Juvenile Collection System. *North American Journal of Fisheries Management*, *19*(4), 1142–1146. https://doi.org/10.1577/1548-8675(1999)019<1142:DOSSTW>2.0.CO;2

We evaluated a system to divert salmonid smolts tagged with passive integrated transponders (PIT) from the general migrant population as they passed through a juvenile collection system at a hydroelectric dam on the Snake River. Our goal was to maximize the diversion of PIT-tagged fish while simultaneously minimizing the diversion of untagged fish. The slide-gate system that was tested diverted 81% of PIT-tagged fish detected. The number of untagged fish entering the diversion system with every PIT-tagged fish was proportional to fish abundance and averaged one untagged fish for every PIT-tagged fish. Measures of descaling, injury, and mortality for all fish in the diversion system were similar to those for fish that were not diverted. These results established our basic PIT-tag diversion system as a major tool for conducting research on Snake River anadromous salmonids.

Martin, T. E. (1993). Nest Predation and Nest Sites: New perspectives on old patterns. *BioScience*, *43*(8), 523–532. https://doi.org/10.2307/1311947

Thomas E. Martin; Nest Predation and Nest Sites: New perspectives on old patterns, BioScience, Volume 43, Issue 8, 1 September 1993, Pages 523–532, https://doi

Mather, M. E. (1998). The role of context-specific predation in understanding patterns exhibited by anadromous salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, *55*(S1), 232–246. https://doi.org/10.1139/d98-002
Predation is frequently studied in aquatic systems that contain salmon. Because these systems are difficult to manipulate and replicate, rigorous across-system comparisons are essential. Herein I review the literature on factors that may influence predation across systems. Specifically, I evaluated how often predation on salmonids was important across prey taxa, life stage, habitat, predator taxa, methodology, and spatial scale. Further, I examined what factors were influential in systems where predation was important. In nine journals from 1959-1996, 45 field studies explicitly tested the importance of direct effects of predation on anadromous salmonid prey. Authors of 36 (80%) studies concluded that predation was important. More studies in which predation was deemed important focused on smolts subjected to fish predation in the transitional river and estuary habitats. Furthermore, field surveys at larger spatial scales were most often used. Finally, most studies reported little information on confounding factors that complicate predation. If we are to learn from these complex systems, we need to collect, analyze, and report similar types of information that are collected across systems and years using rigorous and systematic methods.

Mathews, S. E., Craig, D. P., Collis, K., & Roby, D. D. (2006). Double-crested Cormorant (Phalacrocorax auritus). In *Birds of Oregon: A General Reference* (2nd ed., pp. 56–58). Oregon State University Press.
Adaptable and opportunistic, this species is the most abundant and widespread of the three cormorant species found in Oregon, occurring inland and on the coast (Brand 1982, Harrison 1983). Adults have deep, coppery feathers, bordered in black, that glisten with a green iridescence and offset a rich orange throat atop a long curved neck. The bird earns its name from plumes, ranging from white to black, that crown either side of the head during the breeding season (Gabrielson and Jewett 1940, Brand 1982, Harrison 1983, Hatch and Weseloh 1999).

Mathur, D., Heisey, P. G., Euston, E. T., Skalski, J. R., & Hays, S. (1996). Turbine passage survival estimation for chinook salmon smolts (Oncorhynchus tshawytscha) at a large dam on the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences*, *53*(3), 542–549. https://doi.org/10.1139/f95-206
The short-term survival rate of hatchery-reared fall yearling chinook salmon smelts (On,corhynchus tshawytscha) introduced at 3.1 m below the turbine intake ceiling (N = 350) at a large Columbia River hydroelectric dam relative to the survival. rate of controls (released in the discharge) was estimated at 93.0% (90% profile CI = 90.1-95.5%); among those introduced at 9.3 m depth (N = 250) the survival rate was 94.7% (90% CI = 91.9-97.0%). Differences were not significant, and the pooled estimate of 93.9% (90% CI = 91.9-95.7%) is higher than is generally assumed or reported (70-89%) for salmonids. Unlike the prevailing models based on recovery ratios of alive fish only, our likelihood model included the capture probabilities of both the alive and dead fish for estimation of parameters and their standard errors. Survival rates reported herein refer to the direct effects of turbine passage; those reported in the literature, however, do not make a clear distinction between direct (immediately upon turbine passage) and indirect effects that may

occur over time. The types of fatal injuries observed suggested that a reduction or elimination of gaps between the hub and runner blades may enhance fish survival.

Mayer, T. D. (2005). Water-quality impacts of wetland management in the Lower Klamath National Wildlife Refuge, Oregon and California, USA. *Wetlands*, *25*(3), 697–712. https://doi.org/10.1672/0277-5212(2005)025[0697:WIOWMI]2.0.CO;2

Insufficient water supply and poor water quality are major problems in the Klamath Basin of southern Oregon and northern California, USA. Various land-management practices and competing demands for water in much of the basin have led to degraded environmental conditions and poor water quality (excessive nutrients, warn temperatures, high pH, low dissolved oxygen). Of particular interest are the water quality impacts of wetland management at Lower Klamath National Wildlife Refuge. Wetlands in the refuge are intensely managed through a system of canals, drains, and water-control structures, but the impacts of this management are not known. Data for inflows, outflows, field water-quality parameters, and nutrient concentrations were collected and analyzed in 1999 and 2000. Water budgets and nutrient loads were developed for the refuge. Water-quality impacts from wetland management include higher conductivity and water temperatures but lower turbidity. Outflow nutrient concentrations of N and P are generally increased relative to inflow concentrations, but nutrient loads are reduced. From 55 to 77% of the mass of N and 19 to 51% of the mass of P entering the refuge wetlands is retained. Seasonal wetlands retain less P than permanent wetlands or farmed units, possibly because of the annual drying cycle, the later drainage dates, and predominance of annual vegetation. For all refuge wetlands, dissolved inorganic N is retained more efficiently than particulate N, and particulate P is retained more efficiently than soluble reactive P. The ultimate effect of refuge wetland management is to decrease net N and P loads but increase the ratio of bioavailable P to bioavailable N in the refuge outflow.

Maynard, D. J., Flagg, T. A., & Mahnken, C. V. W. (1995). *A review of innovative culture strategies for enhancing the postrelease survival of anadromous salmonids*. *15*, 307–314. https://www.nwfsc.noaa.gov/assets/11/6716_12142010_101043_Maynard.et.al.1994a-rev.pdf

The unnatural behavioral and morphological conditioning that occurs in the fish culture environment reduces the postrelease survival of hatchery-reared salmonids compared to their wild-reared counterparts. We review innovative culture techniques that offer development of fish with more "wild-like" behavior and morphology, and higher postrelease survival. These techniques include rearing fish over natural substrates that promote the development of proper camouflage coloration, training them to avoid predators, exercising them to enhance their ability to escape from predators, supplementing diets with natural live foods to improve foraging ability, reducing rearing densities, and utilizing oxygen-supplementation technology. In addition to enhancing postrelease survival, these seminatural culture strategies will minimize the shift in selection pressures associated with the artificial rearing environment. We conclude that these innovative culture techniques are effective and should be used in both enhancement and conservation hatcheries.

McCann, J., Chockley, B., Cooper, E., Hsu, B., Scheer, G., Haeseker, S., Lessard, R., Copeland, T., Tinus, E., Storch, A., & Rawding, D. (2019). *Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye* (p. 850). https://www.fpc.org/documents/CSS/2019CSSAnnualReport.pdf

The 2019 Comparative Survival Study Annual Report continues to update the historical time series life-cycle monitoring data and includes enhancements to analyses based upon review comments and recommendations from the fishery management agencies, tribes, and the Northwest Power and Conservation Council's Independent Scientific Advisory Board (ISAB). This CSS Annual Report includes 24 years of SAR data for wild Snake River spring/summer Chinook (1994–2017), 21 years of SAR data for Snake River hatchery spring/summer Chinook (1997–2017), 20 years of SAR data for Snake River wild and hatchery steelhead (1997–2016), and eight years of SAR data for Snake River sockeye (2009–2017). There are eleven years of SAR data for Snake River hatchery fall Chinook (2006–2016), and six years of Snake River wild fall SAR data spanning the years 2006–2011. For mid-Columbia and upper-Columbia fall Chinook there are varying numbers of years available. There are 17 years of SAR data for Hanford Reach wild fall Chinook (2000–2016), six years of SAR data for wild Deschutes River fall Chinook (2011–2016), and nine years of SAR data for both Spring Creek NFH and Little White Salmon NFH fall Chinook (2008–2016). Spring and summer Chinook and sockeye returns from outmigration year 2017 should be considered preliminary, as they include only 2-salt returns and may change with the addition of 3-salt returns next year. Similarly, 2016 migration year fall Chinook returns include only 2-salt adults. The CSS has actively provided Passive Integrated Transponder (PIT) tags for most of these groups since outmigration year 1997. Mark groups in 2019 were consistent with groups utilized in past years. In addition to overall smolt-to-adult return rates (SARs) for aggregate Snake River wild steelhead and Chinook salmon, the CSS has continued to pursue the development of SAR and life cycle metrics at the Major Population Group (MPG) level when sample size was adequate. These MPG-level SARs are provided for Lower Granite to Lower Granite and from Lower Granite to Bonneville with and without jacks (1-salt) for Chinook salmon. In addition, Chapter 4 continues to include estimates of overall SARs (MCN-to-MCA) for Yakima River wild Chinook salmon, Yakima River hatchery Chinook salmon (i.e., Cle Elum Hatchery), and Yakima River wild steelhead. The CSS continues to strive to improve life cycle monitoring metrics for wild populations of salmon and steelhead, and continue to work with fishery managers to improve tagging coverage of wild populations from tributary traps. In the Introductory chapter of this report a discussion of the PITPH indicator variable has been included to provide clarity to the management decision process which includes discussion of PITPH at times. During 2019 the CSS Oversight Committee and the Fish Passage Center invested a considerable effort providing CSS life Cycle analyses and CSS Cohort model analyses of Columbia River System Review (CRSO) Environmental Impact Statement operations alternatives. This work was completed under a non-disclosure agreement between the Pacific States Marine Fisheries Commission and the Bonneville Power Administration. Under the NonDisclosure Agreement, these analyses cannot be distributed to the public until the draft CRSOEIS is distributed for public review. The Grande Ronde Life cycle model analyses and the Cohort model analyses comprise Chapter 2 of this 2019 CSS Annual Report. Chapter 2 will be available to the public in February 2020 when the draft EIS is released for public review. New in this report is a summary of analyses of delayed mortality, in Chapter 6. Response to review comments on Chapter 6 necessitated a review of Faulkner et al. (2019), which had not been previously included in the Chapter. The review of Faulkner et al. (2019), was so extensive that the detailed review has been included as Appendix G, in this report. The 2019 report includes a continuation of Upper Columbia live cycle survival of spring Chinook in Chapter 9. The juvenile migration analyses evaluate the effects of management actions on fish travel times and in-river juvenile survival probabilities, while directly accounting for model uncertainty, measurement uncertainty, and environmental variation. The data collected and analyzed over 1998-2018 juvenile migration years showed considerable variation both withinand across-years in fish travel time, instantaneous mortality rates, and survival rates. Combinations of managed factors such as water transit time and spill proportions, and unmanaged factors such as Julian Day and water temperature were found to be important for explaining the variability in juvenile migration characteristics. Results indicate that improvements to fish travel time, mortality rates, and survival may be possible through management actions that reduce WTT and increase spill percentages. Concerns have been raised over the poor condition and survival of sockeye released from the Springfield Hatchery in 2015 through 2017. Snake River hatchery sockeye released in 2016 and 2017 had the highest instantaneous mortality rates observed over the time series and survival probabilities were about half of average. However, the estimated fish travel time, instantaneous mortality rate, and survival probability from the 2018 releases were all consistent with model predictions based on the environmental conditions that were present in 2018, indicating that the issues that impacted Snake River hatchery sockeye during 2015-2017 did not appear to affect sockeye performance in 2018. Overall PIT-tag SARs for Snake River wild spring/summer Chinook and wild steelhead fell well short of the Northwest Power and Conservation Council (NPCC) SAR objectives of a 4% average for recovery and 2% minimum. PIT-tag SARs for Mid-Columbia wild spring Chinook (John Day and Yakima rivers) and wild steelhead (Umatilla, John Day, Deschutes and Yakima rivers) generally fell within the 2%–6% range of the NPCC SAR objectives. PIT-tag SARs for Upper Columbia wild spring Chinook and steelhead have fallen short of the NPCC 2%-6% objectives since CSS monitoring began in 2006. Due to limited juvenile detection capability in the Columbia River mainstem upstream of MCN, previous Upper Columbia SAR time series have been presented as MCN-to-BOA, which overstated life cycle survival by excluding mortality within the migration corridor upstream of MCN. The CSS has begun to estimate SARs beginning with smolts at Rocky Reach Dam to address this issue. The 2018 adult returns documented in this CSS Annual Report are consistent with past reported trends. The overall SARs for Upper Columbia and Snake River populations of salmon and steelhead are not meeting the regional goal, while middle Columbia populations are meeting the regional SAR goals in most years. The analyses of SARs relative to estimates of population productivity which began in the 2015 CSS Annual Report has been expanded and is presented in Chapter 5. For this report, we extend two of the previous analyses. For this report, we extend the previous steelhead analyses. In 2016, the CSS began a comparison of Snake River steelhead SARs to population productivity for Fish Creek (Clearwater Major Population Group (MPG)), Rapid River (Salmon MPG). Pahsimeroi River (Salmon River MPG) was added in 2017 and Joseph Creek (Grande Ronde River MPG) in 2018. The observations reported in this chapter to date are relevant to, and generally support, the NPCC (2014) 2%–6% SAR objectives. We observed major population declines associated with SARs (LGR-GRA) less than 1%, and increased life-cycle productivity as SARs exceeded 2%. Review of literature on delayed mortality (Chapter 6) concludes that delayed mortality is occurring and is associated with passage through the hydrosystem. A detailed review of Faulkner et, al. (2019) is presented in Appendix G of this report. This extensive review found that when fish size was considered in conjunction with other environmental covariates, fish size explained relatively little of the variation between survival rates or bypass detection probability. While size may help improve some models fit, the a vast majority of the variability in survival is explained by other variables that were not explicitly examined in the Faulkner analysis, indicating that size is likely not the main driver of observed delayed mortality While competing hypotheses relating to specific causes of delayed mortality remain somewhat unresolved, there is broadly acknowledged that delayed mortality is occurring. Furthermore, the evidence confirms that powerhouse passed fish experience delayed mortality and have lower smolt to adult return rates compared to their spillway passed counterparts. Regardless of which specific mechanism is responsible, there is general consensus that some of the management actions likely to reduce delayed mortality include reducing turbine and bypass encounters, decreasing water transit time, and maximizing spill. In the analyses of adult salmon and steelhead upstream migration in Chapter 7, our model indicated that adult fish migrants were subjected to a higher migratory cost between Bonneville and McNary Dams compared to McNary and Lower Granite Dams, probably reflecting managed harvest. In the McNary-Lower Granite reach, where migratory cost was modest for Chinook and steelhead, prolonged travel time seemed mostly inconsequential to conversion probability. Sockeye had a higher mortality compared to other species in both reaches; prolonged travel time could have a devastating effect on conversion probability for sockeye. Chapter 8 continues to develop and refine an approach to estimate detection probability and total passage of spring migrating Chinook at Bonneville Dam. The overall goal of this work is to generate passage estimates at Bonneville Dam that can be used to assess population dynamics across time and inform management decisions, or can be applied in broader contexts to elucidate factors (e.g., density dependence) that may affect survival. In 2019 the primary focus was to address and pursue recommendations from the ISAB from the 2018 report. The work presented here represents a continuation in development of a framework to estimate total passage at Bonneville Dam. Preliminarily, we focused on yearling Chinook salmon as a "test" group to assess various methods and template for further development. Further development of this approach will incorporate groups of fish beyond yearling Chinook and seek to address the many complications associated with estimating passage abundance at Bonneville Dam; some of which have been discussed above and others that will inevitably arise. Nonetheless, we view previous and these additional results as a promising basis upon which to further expand. We agree with the ISAB that a metric characterizing total passage dynamics Bonneville Dam will be useful in elucidating unexplored questions.

McClure, M. M., Holmes, E. E., Sanderson, B. L., & Jordan, C. E. (2003). A Large-Scale, Multispecies Status Assessment: Anadromous Salmonids in the Columbia River Basin. *Ecological Applications*, *13*(4), 964–989. https://doi.org/10.1890/1051-0761(2003)13[964:ALMSAA]2.0.CO;2

Twelve salmonid evolutionarily significant units (ESUs) throughout the Columbia River Basin are currently listed as threatened or endangered under the Endangered Species Act; these ESUs are affected differentially by a variety of human activities. We present a standardized quantitative status and risk assessment for 152 listed salmonid stocks in these ESUs and 24 nonlisted stocks. Using data from 1980–2000, which represents a time of stable conditions in the Columbia River hydropower system and a period of ocean conditions generally regarded as poor for Columbia Basin salmonids, we estimated the status of these stocks under two different assumptions: that hatchery-reared spawners were not reproducing during the period of the censuses, or that hatchery-reared spawners were reproducing and thus that reproduction from hatchery inputs was masking population trends. We repeated the analyses using a longer time period containing both "good" and "bad" ocean conditions (1965–2000) as a first step toward determining whether recent apparent declines are a result of sampling a period of poor ocean conditions. All the listed ESUs except Columbia River chum showed declining trends with estimated long-term

population growth rates (λ's) ranging from 0.85 to 1.0, under the assumption that hatchery fish were not reproducing and not masking the true λ. If hatchery fish were reproducing, the estimated λ's ranged from 0.62 to 0.89, indicating extremely low natural reproduction and survival. For most ESUs, there was no significant decline in population growth rates calculated for the 1980–2000 vs. 1965–2000 time periods, suggesting that the current population status for most ESUs is not solely a result of changes in ocean conditions, and that without other changes, risks will persist even during upturns in ocean conditions. However, estimated population growth rates for the Snake River spring–summer chinook salmon and steelhead ESUs were significantly lower during the longer time period. This difference may be due to a period of dam building on the Snake River during the 1960s and 1970s. For 33 stocks and seven ESUs, the probability of extinction could be estimated. The estimates were generally low for all ESUs with the exception of Upper Columbia River spring chinook and Upper Willamette River steelhead. The probability of 90% decline could be estimated for all stocks. The mean probability of 90% decline in 50 years was highest for Upper Columbia River spring chinook (95% mean probability across all stocks within the ESU) and Lower Columbia River steelhead (80% mean probability). We estimated the effects of two different management actions on long-term growth rates for the ESUs. Harvest reductions offer a means to mitigate risks for ESUs that bear substantial harvest pressure, but they are unlikely to increase population growth rates enough to produce stable or increasing trends for all ESUs. Similarly, anticipated improvements to passage survival through the Snake and mainstem Columbia hydropower systems may be important, but additional actions are likely to be necessary to recover affected ESUs.

McMahon, B. F., & Evans, R. M. (1992). Foraging Strategies of American White Pelicans. *Behaviour*, *120*(1/2), 69–89. JSTOR.

Foraging strategies employed by American white pelicans were studied at a riverine site in Manitoba, Canada, during the breeding season in 1985 and 1986. Six strategies were identified during both diurnal and nocturnal foraging periods. Sit-and-wait was the least common strategy (four instances). Mobile individuals were common but had low rates of bill dipping and prey capture, as did relatively rare and uncoordinated aggregations. A degree of flock coordination occurred in following flocks, characterized by foragers following one after the other, with occasional synchronization of bill dipping among flock members. The largest number of pelicans foraged within more or less circular groups called nuclei. Synchronous bill dipping and apparent herding of prey towards shore were common within nuclei. The most highly coordinated strategy, semicircles, involved small numbers of foragers (2 to 30 birds) that maintained their positions relative to one another, usually in a semicircle but sometimes moving to a closed circular pattern. The greatest degree of synchronized bill dipping occurred in semicircles. Small inter-bird distances and synchronized bill dipping in nuclei and semicircles may enhance their effectiveness in driving or herding clumped fish prey. Foraging strategies could be arranged along a continuum based on degree of coordination, ranging from mobile individuals, then uncoordinated aggregations, through increasing degrees of coordination in following, nuclei, and semicircles. Along this continuum, prey size and capture rats were greatest for the more highly coordinated strategies, while less coordinated strategies appeared to be involved primarily in searching. Switching among strategies fit along the same continuum, with a tendency to switch from less to more coordinated strategies when prey were located and to return to less coordinated search when capture rates declined. Video analysis of captures within large nuclei and observations of positional shifts among foragers in nuclei and following flocks indicated that all individuals within a coordinated group potentially benefited from the presence of others, supporting the view that coordinated foraging strategies in this species are examples of true cooperative foraging. The range of strategies, and interplay among them, appear to provide the American white pelican with a highly effective group foraging system for harvesting mobile, clumped fish prey.

McMichael, G. A., Eppard, M. B., Carlson, T. J., Carter, J. A., Ebberts, B. D., Brown, R. S., Weiland, M., Ploskey, G. R., Harnish, R. A., & Deng, Z. D. (2010). The Juvenile Salmon Acoustic Telemetry System: A New Tool. *Fisheries*, *35*(1), 9–22. https://doi.org/10.1577/1548-8446-35.1.9

Limitations of biotelemetry technology available in 2001 prompted the U.S. Army Corps of Engineers Portland District to develop a new acoustic telemetry system to monitor survival of juvenile salmonids through the Columbia River to the Pacific Ocean. Eight years later, the Juvenile Salmon Acoustic Telemetry System (JSATS) consists of microacoustic transmitters (12 mm long, 0.43 g weight in air), autonomous and cabled receiving systems, and data management and processing applications. Transmitter pulse rate can be user-defined and as configured for this case study was set at 5 seconds, with an estimated tag life of 30 days and detection range of 300 m. Before JSATS development, no technology existed to study movement and survival of fish smaller than 10 g migrating long distances from freshwater and into saltwater. In a 2008 study comparing detection probabilities, travel times, and survival of 4,140 JSATS-tagged and 48,433 passive integrated transponder (PIT)-tagged yearling Chinook salmon (Oncorhynchus tshawytscha; mean fork length 133.9 and 135.3 mm, for JSATS and PIT-tagged fish, respectively) migrating the Snake and Columbia rivers to the Pacific, the JSATS provided survival estimates at more locations with greater precision, using less than one-tenth as many tagged fish as the traditional PIT-tag system. While designed to be optimized for juvenile salmonid survival assessment in the Columbia River basin, JSATS technology may be used in a variety of environments. Information regarding different acoustic telemetry systems from various vendors is presented and discussed relative to the nonproprietary JSATS.

McNatt, R. A., Bottom, D. L., & Hinton, S. A. (2016). Residency and Movement of Juvenile Chinook Salmon at Multiple Spatial Scales in a Tidal Marsh of the Columbia River Estuary. *Transactions of the American Fisheries Society*, *145*(4), 774–785. https://doi.org/10.1080/00028487.2016.1172509

Use of the Columbia River estuary by juvenile Pacific salmon Oncorhynchus spp. is garnering more attention as managers look to improve salmon survival through estuary restoration. Studies have shown that juvenile salmon are abundant in shallow-water habitats within the Columbia River estuary, but information on how juveniles exploit specific estuarine habitats is lacking. We used a combination of physical marks and PIT tag technology to record residence time, movement, and growth of juvenile Chinook Salmon O. tshawytscha, particularly subyearlings, within an emergent marsh of the Columbia River estuary during 2005, 2006, and 2008. We documented marsh-scale residency and movement within the marsh complex and channel-scale residency and movement within two small secondary channels. Many juvenile Chinook Salmon remained in the marsh for 2–4 weeks and increased in FL by 10–20 mm, with an average growth rate of 0.53 mm/d. Chinook Salmon entered secondary channels most frequently in late afternoon and occasionally did so against the tide. Our results indicate that subyearling Chinook Salmon take

advantage of shallow estuarine habitat in the Columbia River to a greater extent than previously documented.

McNeil, R., & Léger, C. (1987). Nest-Site Quality and Reproductive Success of Early- and Late-Nesting Double-Crested Cormorants. *The Wilson Bulletin*, *99*(2), 262–267. JSTOR.

Meng, L., Moyle, P. B., & Herbold, B. (1994). Changes in Abundance and Distribution of Native and Introduced Fishes of Suisun Marsh. *Transactions of the American Fisheries Society*, *123*(4), 498–507. https://doi.org/10.1577/1548-8659(1994)123<0498:CIAADO>2.3.CO;2

Overall fish abundance, abundance of introduced, native, and seasonal fish groups, and species diversity declined over a 14-year period in Suisun Marsh, a portion of the San Francisco Bay estuary, and were associated with decreases in freshwater outflow and increases in salinity. Fish groups showed different patterns of abundance; large fluctuations in introduced and seasonal fish groups contrasted with a steady decline in native fish. Native species were found more often in small, dead-end sloughs, seasonal species were found in larger sloughs, and introduced species were found in both habitats. Fish assemblage structure was less predictable than in an earlier (and shorter) study of the same community. Mixed groups of native and introduced species with similar freshwater and seasonal needs reflected effects of drought and increasing water diversions from the estuary. Chameleon goby Tridentiger trigonocephalus and yellowfin goby Acanthogobius flavimanus, two introduced species, fluctuated greatly in abundance in recent years, whereas other species declined steadily. Changes in fish abundance in the marsh reflect estuary-wide changes and suggest that environmental disturbances coupled with introduced species are altering fish communities and hastening native fish declines.

Mercer, D. M. (2008). *Phylogeography and Population Genetic Structure of Double-crested Cormorants (Phalacrocorax auritus)* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/wd376009h

The Double-crested Cormorant (Phalacrocorax auritus) is a widespread, colonial, North American waterbird with bicoastal and inland distributions. Four subspecies have been described within North America corresponding to five geographic breeding regions: Interior and North Atlantic cormorants (P. a. auritus); Southeastern cormorants (P. a. floridanus); Alaskan cormorants (P. a. cincinnatus); and Pacific cormorants (P. a. albociliatus). Management strategies vary widely across the species' range according to local perceptions rather than relative population status. An understanding of population genetic structure is necessary for delineating appropriate management units. We examined the genetic structure of Double-crested Cormorants across their range in the United States and Canada to quantify variation within and among breeding sites and to assess the status of traditional geographically defined subspecies. Sequences (700bp) from domains I and II of the mitochondrial control region were analyzed for 234 Double-crested Cormorants from 23 breeding sites. Variation was also examined at 8 microsatellite loci for 395 cormorants from the same 23 breeding sites. The mtDNA and microsatellite data provided strong evidence that the Alaskan subspecies is genetically divergent from other populations in North America (net sequence divergence = 6.72%; ΦST for mtDNA control region = 0.738; FST for microsatellite loci = 0.05). Our data also suggested strong genetic divergence in the southwestern U.S.; southern California may represent a zone of introgression resulting from a northward expansion of a unique lineage from the species' range in northwestern Mexico. In contrast, there was little support for recognition of subspecies within the conterminous U.S. and Canada,

outside of Alaska. Rather than genetically distinct regions corresponding to the putative subspecies, we observed a distribution of genetic variation consistent with a pattern of gradual isolation by distance. This pattern implies that genetic differences across the range are due to geographic distance rather than discrete subspecific breaks. Although three of the four subspecies were not genetically distinct, potential demographic separation, habitat differences, and recent declines at some colonies within the regions, suggests that the Pacific and possibly the North Atlantic breeding regions may still warrant consideration as distinct populations. This thesis provides the first species-wide assessment of the phylogeography and population genetic structure of the Double-crested Cormorant. It further resulted in the first microsatellite markers developed specifically for a North American pelecaniform. The mitochondrial and microsatellite data provide a comprehensive assessment of the four putative subspecies described for the species. Given the highly varying conservation status of Double-crested Cormorants throughout their range, results of this study provide guidance for conservation and management practices on their behalf in North America.

Mercer, D. M., Haig, S. M., & Roby, D. D. (2013). Phylogeography and population genetic structure of double-crested cormorants (Phalacrocorax auritus). *Conservation Genetics*, *14*(4), 823–836. https://doi.org/10.1007/s10592-013-0477-8
We examined the genetic structure of double-crested cormorants (Phalacrocorax auritus) across their range in the United States and Canada. Sequences of the mitochondrial control region were analyzed for 248 cormorants from 23 breeding sites. Variation was also examined at eight microsatellite loci for 409 cormorants from the same sites. The mitochondrial and microsatellite data provided strong evidence that the Alaskan subspecies (P. a. cincinnatus) is genetically divergent from other populations in North America (net sequence divergence = 5.85 %; ΦST for mitochondrial control region = 0.708; FST for microsatellite loci = 0.052). Historical records, contemporary population estimates, and field observations are consistent with recognition of the Alaskan subspecies as distinct and potentially of conservation interest. Our data also indicated the presence of another divergent lineage, associated with the southwestern portion of the species range, as evidenced by highly unique haplotypes sampled in southern California. In contrast, there was little support for recognition of subspecies within the conterminous U.S. and Canada. Rather than genetically distinct regions corresponding to the putative subspecies [P. a. albociliatus (Pacific), P. a. auritus (Interior and North Atlantic), and P. a. floridanus (Southeast)], we observed a distribution of genetic variation consistent with a pattern of isolation by distance. This pattern implies that genetic differences across the range are due to geographic distance, rather than discrete subspecific breaks. Although three of the four traditional subspecies were not genetically distinct, possible demographic separation, habitat differences, and documented declines at some colonies within the regions, suggests that the Pacific and possibly North Atlantic portions of the breeding range may warrant differential consideration from the Interior and Southeast breeding regions.

Mesa, M G, & Warren, J. J. (1997). Predator avoidance ability of juvenile chinook salmon (Oncorhynchus tshawytscha) subjected to sublethal exposures of gas-supersaturated water. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(4), 757–764. https://doi.org/10.1139/f96-326
To assess the effects of gas bubble trauma (GBT) on the predator avoidance ability of juvenile chinook salmon (Oncorhynchus tshawytscha), we created groups of fish that differed in

prevalence and severity of gas emboli in their lateral lines, fins, and gills by exposing them to 112% total dissolved gas (TDG) for 13 days, 120% TDG for 8 h, or 130% TDG for 3.5 h. We subjected exposed and unexposed control fish simultaneously to predation by northern squawfish (Ptychocheilus oregonensis) in water of normal gas saturation in 6, 18, and 10 tests using prey exposed to 112, 120, and 130% TDG, respectively. Only fish exposed to 130% TDG showed a significant increase in vulnerability to predation. The signs of GBT exhibited by fish sampled just prior to predator exposure were generally more severe in fish exposed to 130% TDG, which had the most extensive occlusion of the lateral line and gill filaments with gas emboli. Fish exposed to 112% TDG had the most severe signs of GBT in the fins. Our results suggest that fish showing GBT signs similar to those of our fish exposed to 130% TDG, regardless of their precise exposure history, may be more vulnerable to predation.

Mesa, Matthew G. (1994). Effects of Multiple Acute Stressors on the Predator Avoidance Ability and Physiology of Juvenile Chinook Salmon. *Transactions of the American Fisheries Society*, *123*(5), 786–793. https://doi.org/10.1577/1548-8659(1994)123<0786:EOMASO>2.3.CO;2

Northern squawfish Ptychocheilus oregonensis are the predominant predators of juvenile Pacific salmonids Oncorhynchus spp. inthe Columbia River, and their predation rates are greatest just below dams. Because juvenile salmonids are commonly subjected to multiple stressors at dams in the course of their seaward migration, high predation rates below dams may be due in part to an increase in the vulnerability of stressed fish. I conducted laboratory experiments to examine the predator avoidance ability and physiological stress responses of juvenile chinook salmon O. tshawytscha subjected to treatments (stressors) designed to simulate routine hatchery practices (multiple handlings) or dam passage (multiple agitations). Both stressors resulted in lethargic behavior in the fish, and agitation also caused disorientation and occasional injury. When equal numbers of stressed and unstressed fish were exposed to northern squawfish for up to 1 h, significantly more stressed fish were eaten, but this effect was not evident during longer exposures. The lack of differential predation in trials lasting up to 24 h can be explained by the rapid development of schooling behavior in the prey, but other possibilities exist, such as changing ratios of stressed and unstressed prey over time. Concentrations of plasma cortisol, glucose, and lactate in fish subjected to multiple stressors were similar and sometimes cumulative, returned to prestress levels within 6–24 h, and correlated poorly with predator avoidance ability. My results suggest that juvenile salmonids are capable of avoiding predators within 1 h after being subjected to multiple acute stressors even though physiological homeostasis may be altered for up to 24 h. Therefore, because juvenile salmonids typically reside in tailrace areas for only a short time after dam passage, measures aimed at reducing physical stress or protecting them as they migrate through dam tailraces may help alleviate the relatively intense predation in these areas.

Mesa, Matthew G, Poe, T. P., Maule, A. G., & Schreck, C. B. (1998). Vulnerability to predation and physiological stress responses in juvenile chinook salmon (Oncorhynchus tshawytscha) experimentally infected with Renibacterium salmoninarum. *Canadian Journal of Fisheries and Aquatic Sciences*, *55*(7), 1599–1606. https://doi.org/10.1139/f98-049

We experimentally infected juvenile chinook salmon (Oncorhynchus tshawytscha) with Renibacterium salmoninarum (Rs), the causative agent of bacterial kidney disease (BKD), to examine the vulnerability to predation of fish with differing levels of Rs infection and assess physiological change during progression of the disease. Immersion challenges conducted during

1992 and 1994 produced fish with either a low to moderate (1992) or high (1994) infection level of Rs during the 14-week postchallenge rearing period. When equal numbers of treatment and unchallenged control fish were subjected to predation by either northern squawfish (Ptychocheilus oregonensis) or smallmouth bass (Micropterus dolomieui), Rs-challenged fish were eaten in significantly greater numbers than controls by nearly two to one. In 1994, we also sampled fish every 2 weeks after the challenge to determine some stressful effects of Rs infection. During disease progression in fish, plasma cortisol and lactate increased significantly whereas glucose decreased significantly. Our results indicate the role that BKD may play in predator-prey interactions, thus ascribing some ecological significance to this disease beyond that of direct pathogen-related mortality. In addition, the physiological changes observed in our fish during the chronic progression of BKD indicate that this disease is stressful, particularly during the later stages.

Meyer, K. A., Sullivan, C. L., Kennedy, P., Schill, D. J., Teuscher, D. M., Brimmer, A. F., & King, D. T. (2016). Predation by American White Pelicans and Double-Crested Cormorants on Catchable-Sized Hatchery Rainbow Trout in Select Idaho Lentic Waters. *North American Journal of Fisheries Management*, *36*(2), 294–308. https://doi.org/10.1080/02755947.2015.1120835

In southern Idaho, population growth of American white pelicans Pelecanus erythorhynchos at the Blackfoot Reservoir and Lake Walcott colonies since the early 1990s has generated concerns about whether pelican predation is impacting angler catch of hatchery trout stocked in Idaho waters. To evaluate this concern, we estimated rates of pelican predation (i.e., the proportion of fish consumed by pelicans) and angler catch (i.e., the proportion of fish caught by anglers) for 19 unique springtime fish stocking events over 3 years across 12 study waters; where feasible we also estimated double-crested cormorant Phalacrocorax auritus predation. Stocked Rainbow Trout Oncorhynchus mykiss averaged 247 mm in length and were internally PIT-tagged (to monitor bird predation) and externally anchor-tagged (to monitor angler catch) before stocking. Additional hatchery trout were PIT-tagged, euthanized, and fed directly to pelicans to estimate PIT tag deposition rates at the colonies; feeding was unsuccessful for cormorants. After the juvenile pelicans and cormorants fledged in the fall, we recovered PIT tags from stocked and fed fish that were deposited at the two colonies. Deposition rates for pelican-consumed tags averaged 21% and declined exponentially as distance increased from the colonies. Pelican predation on hatchery trout averaged 18% and ranged from 0 to 48%, whereas angler catch averaged 21% and ranged from 0 to 82%. Mean angler catch was nearly four times higher when pelican predation was low (i.e., <25%) than when pelican predation was high (≥25%). Cormorant predation estimates (available for seven stocking events) were minimum estimates only (i.e., they assumed 100% of tags consumed by cormorants were recovered) and averaged 14% (range, 2–38%). Our results suggest that predation by American white pelicans and double-crested cormorants on catchable-sized hatchery Rainbow Trout stocked in southern Idaho waters often exceeds the total catch of those fish by anglers who compete directly with avian predators for use of stocked trout.

Miller, D. A., Grand, J. B., Fondell, T. F., & Anthony, M. (2006). Predator functional response and prey survival: Direct and indirect interactions affecting a marked prey population. *Journal of Animal Ecology*, *75*(1), 101–110. https://doi.org/10.1111/j.1365-2656.2005.01025.x

1 Predation plays an integral role in many community interactions, with the number of predators and the rate at which they consume prey (i.e. their functional response) determining interaction strengths. Owing to the difficulty of directly observing predation events, attempts to determine

the functional response of predators in natural systems are limited. Determining the forms that predator functional responses take in complex systems is important in advancing understanding of community interactions. 2 Prey survival has a direct relationship to the functional response of their predators. We employed this relationship to estimate the functional response for bald eagle Haliaeetus leucocepalus predation of Canada goose Branta canadensis nests. We compared models that incorporated eagle abundance, nest abundance and alternative prey presence to determine the form of the functional response that best predicted intra-annual variation in survival of goose nests. 3 Eagle abundance, nest abundance and the availability of alternative prey were all related to predation rates of goose nests by eagles. There was a sigmoidal relationship between predation rate and prey abundance and prey switching occurred when alternative prey was present. In addition, predation by individual eagles increased as eagle abundance increased. 4 A complex set of interactions among the three species examined in this study determined survival rates of goose nests. Results show that eagle predation had both prey- and predator-dependent components with no support for ratio dependence. In addition, indirect interactions resulting from the availability of alternative prey had an important role in mediating the rate at which eagles depredated nests. As a result, much of the within-season variation in nest survival was due to changing availability of alternative prey consumed by eagles. 5 Empirical relationships drawn from ecological theory can be directly integrated into the estimation process to determine the mechanisms responsible for variation in observed survival rates. The relationship between predator functional response and prey survival offers a flexible and robust method to advance our understanding of predator–prey interactions in many complex natural systems where prey populations are marked and regularly visited.

Miller, M. R., & Reinecke, K. J. (1984). Proper Expression of Metabolizable Energy in Avian Energetics. *The Condor*, *86*(4), 396–400. https://doi.org/10.2307/1366814

We review metabolizable energy (ME) concepts and present evidence suggesting that the form of ME used for analyses of avian energetics can affect interpretation of results. Apparent ME (AME) is the most widely used measure of food energy available to birds. True ME (TME) differs from AME in recognizing fecal and urinary energy of nonfood origin as metabolized energy. Only AME values obtained from test birds fed at maintenance levels should be used for energy analyses. A practical assay for TME has shown that TME estimates are less sensitive than AME to variation in food intake. The TME assay may be particularly useful in studies of natural foods that are difficult to obtain in quantities large enough to supply test birds with maintenance requirements. Energy budgets calculated from existence metabolism should be expressed as kJ of AME and converted to food requirements with estimates of metabolizability given in kJ AME/g. Energy budgets calculated from multiples of basal metabolic rate (a component of maintenance energy), however, should be expressed as kJ of either TME or net energy depending on ambient temperature. Energy units should be stated explicitly to improve comparability and in some cases accuracy of energy analyses.

Miyamoto, K., Squires, T. E., & Araki, H. (2018). Experimental evaluation of predation of stocked salmon by riparian wildlife: Effects of prey size and predator behaviours. *Marine and Freshwater Research*, *69*(3), 446–454. https://doi.org/10.1071/MF17215

Predation after release is one of the major concerns of hatchery fish conservation and propagation. However, the relationships between the size of hatchery fish, the predator species and their behaviours in natural environments are largely unknown. To understand these relationships, we

conducted predation experiments in outdoor tanks and a seminatural stream with exposure to local predators. Masu salmon (Oncorhynchus masou) of two different size classes were used as experimental prey fish in the present study. Camera trap data showed that grey herons (Ardea cinerea) were the primary predator in the experimental system, and that most herons used shallow areas in the morning or evening while feeding. Increasing the density of stocked salmon led to increases in the number of occurrences of grey heron. More importantly, predation by grey herons resulted in a significantly lower survival rate of larger salmon compared with smaller salmon. The results indicate that it is important to understand local predators, adjust the optimum body size of hatchery fish at release and choose the appropriate stocking site and time of day for maximising the effectiveness of fish stocking.

Montevecchi, W. A., Cairns, D. K., & Birt, V. L. (1988). Migration of Postsmolt Atlantic Salmon, Salmo salar , Off Northeastern Newfoundland, As Inferred by Tag Recoveries in a Seabird Colony. *Canadian Journal of Fisheries and Aquatic Sciences*, *45*(3), 568–571. https://doi.org/10.1139/f88-068

Northern gannets, Sula bassanus, and possibly other seabird species nesting on Funk Island off northeastern Newfoundland preyed on postsmolt Atlantic salmon, Salmo salar. Salmon comprised less than 1% of 2928 regurgitated food samples collected from gannets at the colony. Ten smolt tags were recovered in and near the gannetry during August or September in 1984 through 1986. The tags were from smolts released 3–4 mo earlier in the Penobscot River (Maine) (n = 7) and one each from the Saint John River (New Brunswick) and the Lower Clyde and LaHave rivers (Nova Scotia). These recoveries provide evidence that postsmolt Atlantic salmon from rivers in New England, the Bay of Fundy, and the Atlantic coast of Nova Scotia migrate off eastern Newfoundland This migratory pattern contrasts with that of postsmolts from the Gulf of St. Lawrence, which tend to move northwards along Newfoundland's west coast and through the Strait of Belle Isle.

Montevecchi, W. A., & Piatt, J. (1984). Composition and energy contents of mature inshore spawning capelin (mallotus villosus): Implications for seabird predators. *Comparative Biochemistry and Physiology Part A: Physiology*, *78*(1), 15–20. https://doi.org/10.1016/0300-9629(84)90084-7

1. Lipid levels of capelin are highest in late fall and lowest during the summer spawning season; protein levels are constant at 13–14% body wt throughout the year. 2. Ovid females contained significantly more lipid and protein and less water and had higher energy densities than males and spent females. 3. Surgically-removed egg masses made up 34.2 ± 10.3% female body wt and were very similar in composition and energy density to gravid females, differing from spent females and males in similar respects. Owing to the ovarian development of females, sexes differ in energy density only during the spawning season. 4. Sexes were similar in amino acid composition. Analysis of capelin and three other seabird forage species revealed that isoleucine levels were lower than minimum avian maintenance and growth requirements. 5. Implications for the foraging behaviour and food preferences of diving seabird predators (murres, puffins) are discussed.

Muir, W. D., Marsh, D. M., Sandford, B. P., Smith, S. G., & Williams, J. G. (2006). Post-Hydropower System Delayed Mortality of Transported Snake River Stream-Type Chinook Salmon: Unraveling the Mystery. *Transactions of the American Fisheries Society*, *135*(6), 1523–1534. https://doi.org/10.1577/T06-049.1

Past research indicates that on an annual basis, smolts of stream-type Chinook salmon Oncorhynchus tshawytscha collected at Snake River dams and transported by barge to below Bonneville Dam have greater post-hydropower system mortality than smolts that migrate in-river. To date, this difference has most commonly been attributed to stress from collection and transportation, leading to decreased disease resistance or predator avoidance ability. Using both hatchery and wild passive integrated transponder (PIT) tagged Chinook salmon, we explored two mechanisms that either separately or jointly contributed to an alternative explanation: Altered timing of ocean entry and lost growth opportunity leading to size-selective predation. Based on weekly estimates of in-river survival and adult return rates of smolts that were transported or that migrated in-river between Lower Granite and Bonneville dams, we found greater post-hydropower system mortality for smolts transported early in the season but greater mortality for in-river migrating smolts later in the season. Migrants took 2–4 weeks to travel between the two dams, while transported fish took less than 2 d. Thus, fish leaving Lower Granite Dam under the two transit modes encountered different conditions downstream from Bonneville Dam. Further, wild and hatchery migrants grew 6–8 and 5–6 mm, respectively, while transported fish had no apparent growth in the less than 2-d barge ride. Using length data and regression equations of size selectivity, we found that transported smolts were more vulnerable to predation by northern pikeminnow Ptychocheilus oregonensis (freshwater) and Pacific hake Merluccius productus (marine) than were migrants; this was particularly true for the smaller wild smolts transported early in the season. We concluded that the most parsimonious explanation for differential post-hydropower system mortality of transported Chinook salmon smolts related not to effects of stress but to differential size and timing of ocean entry.

Muir, W. D., Smith, S. G., Williams, J. G., Hockersmith, E. E., & Skalski, J. R. (2001). Survival Estimates for Migrant Yearling Chinook Salmon and Steelhead Tagged with Passive Integrated Transponders in the Lower Snake and Lower Columbia Rivers, 1993–1998. *North American Journal of Fisheries Management*, *21*(2), 269–282. https://doi.org/10.1577/1548-8675(2001)021<0269:SEFMYC>2.0.CO;2

Precise, up-to-date survival estimates for salmonids that migrate through reservoirs, hydroelectric dams, and free-flowing sections of the Snake and Columbia rivers are essential to develop effective strategies for recovering depressed stocks. To provide this information, survival was estimated for yearling chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss with passive integrated transponder (PIT) tags that migrated through Snake River dams and reservoirs from 1993 through 1998. A multiple-recapture model for single release groups was used to estimate survival from detections of PIT-tagged fish at dams. The stretch of river over which survival was estimated varied between years, depending on the release site, the number of dams with the capability to detect and rerelease PIT-tagged fish back to the river, the total number of fish marked, and the efficiency of detecting PIT-tagged fish at each dam. Precision of survival estimates varied with the number of fish PIT-tagged and released and the amount of spill at dams with PIT-tag detectors. When spill levels were high, detection probabilities were lower, as was precision. Mortality at bypass outfall sites was not significant at any Snake River dam investigated. Estimated annual average per-project (combined reservoir and dam passage) survival ranged from 86% to 94% for yearling chinook salmon and from 88% to 92% for steelhead. Survival estimates were higher for both species in years when spill was used specifically to pass fish through nonturbine routes. Over the same stretches of river in years with similar flow conditions from 1970 through 1975, per-project survival estimates typically averaged 57–71% for yearling chinook salmon and 77–90% for steelhead. From 1993 to 1998, survival estimates for fish released from Snake River basin hatcheries to the Lower Granite Dam tailrace indicated that substantial smolt mortality occurred before fish entered the hydropower system. For each hatchery, estimated survival varied each year, and estimates from different hatcheries to Lower Granite Dam varied inversely with the distance fish traveled.

Muir, W. D., Smith, S. G., Williams, J. G., & Sandford, B. P. (2001). Survival of Juvenile Salmonids Passing through Bypass Systems, Turbines, and Spillways with and without Flow Deflectors at Snake River Dams. *North American Journal of Fisheries Management*, *21*(1), 135–146. https://doi.org/10.1577/1548-8675(2001)021<0135:SOJSPT>2.0.CO;2

Using yearling chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss tagged with passive integrated transponders (PITs), we estimated passage survival through bypass systems, turbines, and spill bays with and without flow deflectors at Snake River dams relative to survival of fish released into the tailrace below the dam. Actively migrating fish were collected and marked with PIT tags at Snake River dam smolt collection facilities. Groups of tagged fish were then released through hoses into different passage routes; releases were coincident with a tailrace release approximately 1–2 km below the dam. Relative survival was estimated by the use of tag–recapture models for paired releases from detections of individual PIT-tagged fish at juvenile collection or detection facilities at downstream dams. Detection sites included Little Goose, Lower Monumental, McNary, John Day, and Bonneville dams, depending on the release location and year. Standard errors of relative survival probability estimates were generally less than 3.0% through all potential passage routes. The estimated relative survival was highest through spill bays without flow deflectors (98.4–100%), followed by spill bays with flow deflectors (92.7–100%), bypass systems (95.3–99.4%), and turbines (86.5–93.4%). These estimates of relative survival, which include both the direct and indirect effects of passage, are generally higher than past estimates but similar to other recent estimates determined with modern techniques under present dam configurations and operating conditions.

Myers, A. M. (2007). *Evaluating the Fatty Acid Signature Technique for Studies of Diet Composition in Piscivorous Waterbirds* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/cz30pw84g

This research was designed to evaluate the Fatty Acid Signature (FAS) technique as a non-lethal alternative to more traditional, and sometimes destructive, methods of studying the diet composition of piscivorous birds. Specifically we tested the technique with Caspian terns (Hydroprogne caspia) which currently nest in large numbers in the Columbia River estuary and are known to consume juvenile salmonids (Oncorhynchus spp.) listed under the U.S. Endangered Species Act. From captive feeding trials conducted with Caspian tern chicks, we determined that FASs of the birds reflected differences in their diets. After 20 days of being fed consistently mixed or monotypic diets of two fish types, chicks displayed different adipose tissue FASs between all 4 diet treatments. When diets were changed, adipose tissue FASs reflected the shift in diet treatments within two weeks. Fatty acid (FA)- specific calibration coefficients (FA level in the consumer divided by FA level in the food) were calculated for Caspian terns fed monotypic diets for 34 days; some calibration coefficients varied in association with diet and age of the terns, and also differed between terns and common murres (Uria aalge), whose calibration coefficients were measured in a separate study. Variation in FA-specific calibration coefficients may be problematic for obtaining accurate estimates of diet composition in piscivorous birds using the Quantitative Fatty Acid Signature (QFASA) technique. We advocate sensitivity analysis to test whether the QFASA models are robust to the magnitude of variation in calibration coefficients detected in this study. FASs differed among the 3 major fish prey types observed in diets of Caspian terns nesting in the Columbia River estuary during the 2003 breeding season: juvenile salmonids, surf smelt (Hypomesus pretiosus), and northern anchovy (Engraulis mordax). We detected differences in FASs of nesting Caspian terns between early and late in the nesting season of 2003; these differences were associated with a shift in diet composition from a diet dominated by juvenile salmonids to a diet dominated by northern anchovy. The FASs of several species of juvenile salmonids, however, exhibited little inter-specific variation, especially between species raised in hatcheries, which comprise the majority of smolts consumed by Caspian terns in the estuary. We found levels of highly-unsaturated FAs (HUFAs) to be higher in wild steelhead smolts than in hatchery-reared steelhead smolts, but HUFA levels in terns did not reflect the changing prevalence of wild steelhead in their diets. This is likely due to contribution of HUFAs to the diets of terns from marine forage fishes. Thus, HUFAs do not appear to be useful indicators of wild steelhead in the diets of these birds. If the QFASA technique can be validated, it has the potential to provide general information on diet composition for piscivorous birds foraging on broadly different prey types over extended periods. However, due to similarities in FASs of key prey types consumed by Caspian terns in the Columbia River estuary, namely salmonids, obtaining the precise estimates of diet composition and consumption of different species of salmonids that are requested by resource managers does not seem feasible using the QFASA technique alone. Consequently, more traditional methods of diet composition analysis for Caspian terns (bill load identification, stomach contents analysis) can not be replaced by the FAS analysis technique.

Myrvold, K. M. (2018). Shifts in Great Blue Heron Habitat use Following Nest Site Usurpation: Implications for Salmonids. *The American Midland Naturalist*, *179*(1), 105–125. https://doi.org/10.1674/0003-0031-179.1.105

Interactions among predators can have important consequences for lower trophic levels. Here, we use individual tag data on juvenile salmonids to quantify how their geographic, taxonomic, and life-history representation in the diets of great blue herons (Ardea herodias) changed after a pair of bald eagles (Haliaeetus leucocephalus) usurped the colony's nesting site, forcing the colony to relocate. Heron diet composition changed significantly despite the short relocation distance (4.1 km). This was driven by a shift in space use, as herons to a greater extent began consuming fish from a river basin farther away from the bald eagle nest. As a consequence the species composition in heron diets changed significantly, with the largest increase in coho (Oncorhynchus kisutch) and largest decrease in Chinook salmon (O. tshawytscha). The representation of Chinook life-history types in the diets also shifted. Fall Chinook was the numerically dominant life-history type in the diets but decreased relative to spring and summer Chinook following relocation, accounting for differences in availability. Expressed by rearing type (natural or hatchery-produced), the prevalence of natural-origin Chinook in the diets increased whereas hatchery-origin Chinook decreased. For steelhead rearing type there were no significant changes. Finally, herons increased their use of a nearby tributary watershed following the relocation. Notwithstanding the potential confounding factors inherent to natural experiments, our results demonstrated marked shifts in space use among herons in response to the relocation and continued presence of bald eagles, which in turn shifted their predation pressure to other salmonid species.

Naughton, M. B., Pitkin, D. S., Lowe, R. W., So, K. J., & Strong, C. S. (2007). *Catalog of Oregon Seabird Colonies* (Biological Technical Publication BTP-R1009-2007; p. 489). U.S. Fish and Wildlife Service. https://tethys.pnnl.gov/sites/default/files/publications/Naughtonetal2007.pdf

The rocky islands and rugged habitats of the outer Oregon coast and the low flat islands of the Columbia River estuary provide habitat for approximately 1.3 million nesting seabirds representing 15 species. Current and historical information on colony locations and estimates of breeding seabirds were compiled into databases, for all known seabird colonies in Oregon. A total of 393 colonies were identified, and maps and data tables for each colony are presented in this catalog. The data tables include counts of nests and birds, where available, and estimates of the number of breeding birds for each species at a colony. Specific information regarding date, observers, type of survey, quality of the estimate, and source of the data are provided for each record. The geographic scope of this catalog encompasses seabird colonies in marine and estuarine environments. Marbled Murrelets, which nest solitarily in habitats distinctly different from the rest of the seabird community, are not included in this catalog

Neuenhoff, R. D., Swain, D. P., Cox, S. P., McAllister, M. K., Trites, A. W., Walters, C. J., & Hammill, M. O. (2018). Continued decline of a collapsed population of Atlantic cod (Gadus morhua) due to predation-driven Allee effects. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*(1), 168–184. https://doi.org/10.1139/cjfas-2017-0190

Most stocks of Atlantic cod (Gadus morhua) in the Northwest Atlantic collapsed in the early 1990s, with little sign of recovery since then. In the southern Gulf of St. Lawrence (sGSL), the failed recovery is due to severe increases in the natural mortality of adult Atlantic cod. We examined the role of predation by grey seals (Halichoerus grypus) in this failed recovery by directly incorporating grey seal predation in the population model for Atlantic cod via a functional response. Estimated predation mortality of adult Atlantic cod increased sharply during the cod collapse and has continued to increase, comprising the majority of mortality since the late 1990s. While predation by grey seals appeared to play a minor role in the collapse of Atlantic cod, we found it to be the main factor preventing recovery. Our results are consistent with the hypothesis that failed recovery is due to predation-driven Allee effects, a demographic effect due to the decline in cod abundance and an emergent effect resulting from increasing grey seal abundance. Under current conditions, extirpation of sGSL Atlantic cod appears likely unless there is a large decline in the abundance of grey seals.

Neuman, J., Pearl, D. L., Ewins, P. J., Black, R., Weseloh, D. V., Pike, M., & Karwowski, K. (1997). Spatial and temporal variation in the diet of double-crested cormorants (Phalacrocorax auritus) breeding on the lower Great Lakes in the early 1990s. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(7), 1569–1584. https://doi.org/10.1139/f97-064

We sampled 1573 pellets and 560 boli regurgitated at double-crested cormorant (Phalacrocorax auritus) colonies on the three lower Laurentian Great Lakes (Lake Ontario, Lake Huron, and Lake Erie) during the breeding season in 1992 and 1994. This constitutes the first extensive study of cormorant diet in this region. We found significant spatial and temporal heterogeneity in diet among colonies within a lake. Differences in diet among colonies were usually consistent with knowledge of changes in fish behaviour during the cormorant breeding season, differences in the surrounding bathymetry among breeding colonies, and the proximity of colonies to the preferred habitat of prey species. Our results indicate that temporal and spatial variation, as well

as the technique for diet determination, are very important factors that must be considered when assessing the effects of double-crested cormorant predation on fisheries.

Nisbet, I. C. T. (1975). Selective Effects of Predation in a Tern Colony. *The Condor*, *77*(2), 221–226. https://doi.org/10.2307/1365803

NOAA, Peterson, W. T., Fisher, J. L., Peterson, J. O., Morgan, C. A., Burke, B. J., & Fresh, K. L. (2014). Applied Fisheries Oceanography: Ecosystem Indicators of Ocean Conditions Inform Fisheries Management in the California Current. *Oceanography*, *27*(4), 80–89. https://doi.org/10.5670/oceanog.2014.88
Fisheries oceanography is the study of ecological relationships between fishes and the dynamics of their marine environments and aims to characterize the physical, chemical, and biological factors that affect the recruitment and abundance of harvested species. A recent push within the fisheries management community is toward ecosystem-based management. Here, we show how physical and biological oceanography data can be used to generate indicators of ocean conditions in an ecosystem context, and how these indicators relate to the recruitment of salmonids, sablefish, sardines, and rockfish in the California Current.

Olla, B. L., & Davis, M. W. (1989). The role of learning and stress in predator avoidance of hatchery-reared coho salmon (Oncorhynchus kisutch) juveniles. *Aquaculture*, *76*(3), 209–214. https://doi.org/10.1016/0044-8486(89)90075-6
The possibility of conditioning hatchery-reared coho salmon (Oncorhynchus kisutch) juveniles to avoid predation, and the role of learning and stress in predator avoidance was investigated under controlled laboratory conditions. When coho that had survived predation (experienced) by lingcod (Ophiodon elongatus) were mixed with equal numbers of naive coho and exposed to predation, experienced fish consistently survived in greater numbers than did naive ones. When examined separately, experienced coho were able to avoid predation longer than naive coho. Coho exposed to stimuli associated with predation for two, 15-min bouts were better able to avoid capture by lingcod than naive fish, demonstrating that learning may play a major role in the development of predator avoidance. Salmon raised in the psychosensory-deprived environment of hatcheries appear to suffer from a decrement in predator avoidance which may be readily improved with conditioning. Coho stressed by handling showed a decreased ability to avoid predators, but recovered from this effect in 90 min.

Osterback, A.-M. K., Frechette, D. M., Hayes, S. A., Bond, M. H., Shaffer, S. A., & Moore, J. W. (2014). Linking individual size and wild and hatchery ancestry to survival and predation risk of threatened steelhead (Oncorhynchus mykiss). *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(12), 1877–1887. https://doi.org/10.1139/cjfas-2014-0097
We examined the role of individual size and origin (wild versus hatchery) to predation risk and marine survival for threatened juvenile steelhead (Oncorhynchus mykiss) in a coastal California watershed. In this study, we found that individual size and origin were strongly associated with increased predation risk of steelhead by a generalist avian predator (western gull, Larus occidentalis) and associated with survival to reproduction by tracking the fate of juvenile steelhead tagged with passive integrated transponder (PIT) tags. Across six cohorts (2005–2010), larger steelhead (>170 mm fork length (FL)) experienced marine survival rates at least 60 times higher than the smallest individuals. Predation risk by western gulls was highest for

intermediate-sized fish (145–190 mm FL), which was at least ten times higher than the predation risk of the smallest individuals and four times higher than the predation risk of the largest individuals. Wild steelhead experienced both higher predation risk and higher survival rates than hatchery fish of the same size. Although gulls disproportionately remove intermediate-sized wild steelhead from the population, they also remove large wild individuals that may otherwise experience the highest adult return rates. Instead of focusing on population size alone, conservation measures could also be guided towards the recovery of larger and wild individuals, whose survival is paramount for population recovery.

Osterback, A.-M. K., Frechette, D. M., Shelton, A. O., Hayes, S. A., Bond, M. H., Shaffer, S. A., & Moore, J. W. (2013). High predation on small populations: Avian predation on imperiled salmonids. *Ecosphere*, *4*(9), art116. https://doi.org/10.1890/ES13-00100.1
Generalist predators can contribute to extinction risk of imperiled prey populations even through incidental predation. Quantifying predation on small populations is important to manage their recovery, however predation is often challenging to observe directly. Recovery of prey tags at predator colonies can indirectly provide minimum estimates of predation, however overall predation rates often remain unquantifiable because an unknown proportion of tags are deposited off-colony. Here, we estimated overall predation rates on threatened wild juvenile steelhead (Oncorhynchus mykiss) by generalist adult Western Gulls (Larus occidentalis) in six central California (USA) watersheds. We estimated predation rates by gulls from the recapture of PIT (passive integrated transponder) tags that were originally inserted into steelhead and were subsequently deposited at a Western Gull breeding colony, Año Nuevo Island (ANI). We combined three independent datasets to isolate different processes: (1) the probability a tagged steelhead was consumed during predation, (2) the probability a consumed tag was transported to ANI, and (3) the probability a transported tag was detected at ANI. Together, these datasets parameterized a hierarchical Bayesian model to quantify overall predation rates while accounting for tag loss between when prey were tagged and subsequent tag detection at ANI. Results from the model suggest that low recovery rates of PIT tags from steelhead at ANI were mostly driven by low probabilities of transportation (≤0.167) of consumed tags to ANI. Low transportation probabilities equate to high per-capita probabilities of predation (≥0.306/yr) at the three watersheds in closest proximity to ANI, whereas predation rates were uncertain at watersheds farther from ANI due to very low transportation rates. This study provides the first overall estimate of Western Gull predation rates on threatened wild juvenile steelhead and suggests gull predation on salmonids is a larger source of mortality than was previously estimated from minimum predation rates. This study thus represents an important example of high rates of incidental predation by a generalist consumer on an imperiled prey and provides a quantitative framework to inform robust estimates of predation rates on small populations that can be applied to other systems where direct observation of predation is not feasible.

Pacific Flyway Council. (2012). *Pacific Flyway Plan: A framework for the management of double-crested cormorant depredation on fish resources in the Pacific Flyway.* (p. 62). Pacific Flyway Council, U.S. Fish and Wildlife Service. http://pacificflyway.gov/Documents/Dcc_plan.pdf
The Double-crested Cormorant (Phalacrocorax auritus; DCCO) is the most abundant of the six cormorant species in North America and has the broadest distribution, ranging across the entire continent. DCCOs were reduced in numbers and range during the 19th and early 20th centuries due to human encroachment and persecution, and widespread use of chlorinated hydrocarbons

(e.g., DDT and its metabolites). Since the 1960s, DCCO numbers have increased with better environmental regulations and protection under the Migratory Bird Treaty Act. This plan pertains to all DCCOs within the Pacific Flyway, which includes the Alaska Population, Western Population, Mexico/Southern California Population, and portion of Montana east of the continental divide. Colony sizes and distribution of DCCOs fluctuate considerably across the Pacific Flyway. Population growth within the Pacific Flyway is largely attributed to the population increase of the East Sand Island colony in the Columbia River estuary, now the largest DCCO colony in the world. However, declines of DCCO colonies have been documented over much of southern Alaska, British Columbia, Washington, and southern California. Overall DCCO abundance in the Pacific Flyway is much smaller than it was historically. DCCO depredation at localized areas within the Pacific Flyway is creating conflicts with federal Endangered Species Act (ESA)-listed and special status fish and supplemental fisheries. This plan was developed to address these localized conflicts while managing DCCO numbers and distributions at the Flyway scale. The goal of this plan is to maintain DCCOs as a natural part of the waterbird biodiversity of the Pacific Flyway, while minimizing substantial negative ecological, economic, and social impacts of DCCOs. This plan provides a synopsis of DCCO biology, status, resources conflicts, management options, regulatory requirements, and recommended management strategies. Three objectives were developed to achieve the overarching goal: a Population Assessment Objective, an Impact Reduction Objective, and a Flyway Coordination Objective. The purpose of this plan is to provide agencies with information and guidance to facilitate management of DCCOs in the Pacific Flyway. This plan provides a framework for states and other entities to follow when addressing fish depredation issues involving DCCO and is not intended to dictate specific management actions or policies. Management of DCCOs will be best achieved through coordinated, collaborative, and broad-scale management efforts, as outlined in this plan. This plan is a working document and should be reviewed regularly (every 5 years) and revised as needed to incorporate new information and concerns.

Pacific Flyway Council. (2013). *A Monitoring Strategy for the Western Population of Double-crested Cormorants within the Pacific Flyway* (p. 45). Pacific Flyway Council, U.S. Fish and Wildlife Service. http://www.pacificflyway.gov/Documents/Dcc_monitoring.pdf

Localized depredation issues within the Pacific Flyway prompted the Pacific Flyway Council to develop a management framework for the Double-crested Cormorant (Phalacrocorax auritus; herein cormorant). In July 2012, A Framework for the Management of Double-crested Cormorant Depredation on Fish Resources in the Pacific Flyway was approved and adopted by the Pacific Flyway Council (Pacific Flyway Council 2012). The highest priority strategy under the Population Assessment Objective in the Management Framework called for developing and implementing a monitoring strategy for cormorants at the flyway scale to guide and assess management actions. The goal of the monitoring strategy is to establish a coordinated, long-term monitoring effort to estimate the breeding population size, trend, and distribution of the Western Population of cormorants. This information is fundamental for developing effective management recommendations, and for guiding and assessing management actions pertaining to cormorant depredation on fish resources. The monitoring objective is to have the ability to detect a 5% change/year in the Western Population of cormorants with 80% power ($\beta = 0.20$) and a 10% Type I error rate ($\alpha = 0.10$). A sample of locations was randomly selected using a modified dual-frame sampling approach. Active nests will be counted at these sample locations and will provide an index to estimate the total number of breeding adults in the Western Population. A power analyses was conducted to identify the most cost effective sampling scheme that achieved the monitoring objective. In total, 44 locations will be monitored per monitoring year. Monitoring will begin in 2014 and occur every third year thereafter for at least 10 years (i.e., 2014, 2017, 2020, 2023). Surveys will consist of a combination of existing monitoring efforts, which are funded by other entities, as well as new locations that will require additional funding. Thirty of the 44 locations selected for monitoring in 2014 are included in existing monitoring efforts. Estimated additional cost to implement the monitoring strategy will be $14,500 per monitoring year to cover additional surveys and enumerate cormorant nests from aerial photographs.

Patterson, A. (2012). *Breeding and Foraging Ecology of Caspian Terns Nesting on Artificial Islands in the Upper Klamath Basin, California* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/pv63g325b

Availability of suitable nesting habitat that is free of nest predators and provides access to adequate prey resources within commuting distance is a major factor limiting seabird populations. Caspian terns (Hydroprogne caspia) in western North America have shifted their breeding habitat from naturally occurring habitats in interior wetlands, lakes, and rivers to primarily human-created habitats in coastal bays and estuaries. This shift has brought Caspian terns into conflict with fisheries of conservation concern, in particular anadromous salmonids. Prior to the 2010 breeding season, three artificial islands were built in the Klamath Basin National Wildlife Refuge (NWR) Complex as alternative nesting habitat for Caspian terns currently nesting at the world's largest colony for the species, near the mouth of the Columbia River, Oregon. I investigated the efficacy of habitat creation (island building) and social attraction (decoys and recorded vocalizations) for establishing new breeding colonies in the Upper Klamath Basin, California. In 2010, approximately 258 pairs of Caspian terns attempted to nest on the new islands and raised an average of 0.65 fledglings/breeding pair; in 2011, 222 pairs attempted to nest and raised an average of 0.11 fledglings/breeding pair. Competition with California and ring-billed gulls (Larus californicus and L. delawarensis) for nesting space, gull predation on Caspian tern eggs and chicks, low water levels, and depredation by great horned owls (Bubo virginianus) were the primary factors limiting colony development and productivity, especially in 2011. The immediate response by Caspian terns to habitat creation and social attraction in the Upper Klamath Basin demonstrates that these can be effective restoration techniques to establish new breeding colonies where nesting habitat is a major limiting factor; however, continued management of other limiting factors (e.g., control of on-colony predators and competitors) will likely be necessary to promote the development of established, self-sustaining breeding colonies on these artificial islands. Efforts to conserve and restore seabird colonies can be compromised by low prey availability within foraging distance of the breeding colony. I used GPS telemetry to study the fine-scale foraging behavior of Caspian terns nesting at two newly established colonies and cluster analysis to discriminate behavioral states based on movement characteristics. Terns breeding at the Sheepy Lake colony spent less time at the colony (52% of the day) than terns breeding at the Tule Lake colony (74%). Caspian terns breeding at Sheepy Lake foraged more extensively than terns breeding at Tule Lake; the foraging trips of Sheepy Lake terns lasted longer (median = 186 min) and were longer-distance (27 km) compared to those of Tule Lake terns (55 min and 6 km, respectively). Between-colony differences in foraging behavior corresponded to 5% lower average body mass of breeding adults and significantly lower size-adjusted body mass of chicks at the Sheepy Lake colony compared to the Tule Lake colony. Proximity to high-quality foraging areas influenced the foraging behavior and parental care of breeding Caspian terns, which in turn had effects on nesting success. The successful use of GPS telemetry to study the fine-scale foraging behavior of Caspian terns represents a significant advance in our ability to investigate the foraging ecology of this species and other moderate-sized seabirds.

Paullin, D. G., Ivey, G. L., & Littlefield, C. D. (1988). The Re-Establishment of American White Pelican Nesting in the Malheur-Harney Lakes Basin, Oregon. *The Murrelet*, *69*(3), 61–64. JSTOR. https://doi.org/10.2307/3534030

American White Pelicans (Pelecanus erythroryhnchos) re-established nesting in the Malheur-Harney Lakes Basin in 1985 when seven pairs fledged three young on a small greasewood (Sarcobatus vermiculatus) island. In 1986, nesting efforts increased to an estimated 140 nests in four colonies with a total production of 125 young. Nesting islands were less than 1 ha in size, apparently free from mammalian predators, and occupied by other bird species which had poineered the island before pelicans initiated nesting. On three islands greasewood shrubs dominated the vegetation, providing shade for the prefledged young. On the shrubless island shade was provided by tall forbs.

Payton, Q., Evans, A., & Cramer, B. (2016). *Effects of Biotic and Abiotic Factors on Juvenile Steelhead Survival in the Middle Columbia River, 2008-2015* (p. 26). http://www.birdresearchnw.org/Final%20Report_Steelhead%20Survival%20Covariate%20Analysis.pdf

Identifying factors that affect survival probabilities of juvenile steelhead Oncorhynchus mykiss listed under the Endangered Species Act (ESA) is paramount to develop effective plans for recovery. To evaluate which factors best explained steelhead survival in the middle Columbia River during 2008-2015, we compared and contrasted survival models that incorporated various biotic and abiotic factors experienced by smolts during outmigration. Biotic factors investigated included (1) predation by colonial waterbirds, (2) the relative abundance of steelhead in the river, (3) fish travel times, and (4) individual fish characteristics or traits (condition, size, and rear-type). Abiotic factors investigated included (1) river temperatures, (2) river flows, (3) water transit times, and (4) dam operations (percent spill, powerhouse indices). Two independent release groups of fish were included in survival models, with the suite of biotic and abiotic factors investigated differing based on the data available for each release group. Release groups included double-tagged steelhead (fish tagged with both acoustic telemetry [AT] and passive integrated transponder [PIT] tags) travelling through a 105 river kilometer [Rkm] section of the middle Columbia River (hereafter "Reach 1") and single-tagged steelhead (PIT tags only) travelling through a 259 Rkm section of the middle and lower Columbia rivers (hereafter "Reach 2"). Best fitting survival models for steelhead in Reach 1 indicated a strong relationship between avian predation and steelhead survival, with bird predation accounting for 12% to 62% of all mortality sources experienced by steelhead during outmigration. There was an inverse relationship between steelhead survival and the proportion of steelhead migrating through a powerhouse (PH index) compared with other passage routes at Wanapum Dam. The odds of survival through Reach 1 decreased, on average, by a factor of 0.95 for every 0.1 increase in the PH index. There was a direct relationship between survival and the relative abundance of steelhead (STHD index) in the middle Columbia River. On average, for every 1,000-unit increase in the STHD index the

odds of survival through Reach 1 increased by a factor of 1.11. Additional models with significant support from the data indicated a relationship between water transit times and survival, with survival increasing as water transit times decreased. A comparison of best fitting survival models for steelhead in the Wanapum and Priest Rapids reservoirs (spatial subsets within Reach 1) further confirmed the importance of avian predation, steelhead abundance, and water transit times. Additionally, reservoir-specific models provided evidence of an inverse relationship between water temperature and survival. Best fitting survival models for steelhead in Reach 2, which investigated biotic factors only, indicated that avian predation, fish size (fork length), external condition (body injuries, descaling, fin damage and/or disease), and rearing-type (hatchery, wild) were all significantly related to survival. Bird predation accounted for between 31% and 83% of all smolt mortality sources. Survival was directly related to fish size, with each 10 mm increase in fork length associated with 2% greater odds of surviving Reach 2. Compromised fish (i.e., fish with signs of external damage or disease), which were disproportionately hatchery-reared, had 62% lesser odds of surviving Reach 2 compared with uncompromised fish (i.e., fish with little to no signs of external damage or disease). Wild fish, which were generally uncompromised, had 144% greater odds of surviving Reach 2 compared with hatchery-reared fish. Collectively, results indicated that a combination of biotic and abiotic factors were associated with variation in steelhead survival in the middle Columbia River; demonstrating the complexity and interrelated nature of factors that regulate smolt survival during outmigration. Results suggest that management plans aimed at reducing avian predation, coupled with dam operations that minimize powerhouse passage, increase water transit times, and minimize passage-related injuries to juvenile steelhead are the most likely to increase steelhead survival in the middle Columbia River. Releases of uncompromised hatchery-reared steelhead during the peak outmigration period may also increase survival rates by increasing steelhead abundance, abundance that is likely associated with a predator swamping effect. Additional research to understand the association between these various biotic and abiotic factors on survival at larger spatial and temporal scales may be warranted to evaluate if survival gains in the middle Columbia River are additive throughout the entire smolt life history.

Payton, Q., Evans, A. F., Hostetter, N. J., Roby, D. D., Cramer, B., & Collis, K. (2020). Measuring the additive effects of predation on prey survival across spatial scales. *Ecological Applications*, *n/a*(n/a). https://doi.org/10.1002/eap.2193

The degree to which predation is an additive versus compensatory source of mortality is fundamental to understanding the effects of predation on prey populations and evaluating the efficacy of predator management actions. In the Columbia River basin, USA, predation by Caspian terns (Hydroprogne caspia) on U.S. Endangered Species Act (ESA)-listed juvenile salmonids (smolts; Oncorhynchus spp.) has led to predator management actions to reduce predation; however, the assumption that reduced predation translates into greater salmonid survival, either within the life stage where predation occurs or across their lifetime, has remained untested. To address this critical uncertainty, we analyzed a long-term (2008-2018) mark-recapture-recovery dataset of ESA-listed steelhead trout (O. mykiss) that were tagged (n = 78,409) and subsequently exposed to predation during smolt out-migration through multiple river reaches (spatial-scales), jointly estimating weekly probabilities of steelhead survival, mortality due to bird predation, and mortality due to other causes. This concurrent estimation across time-stratified cohorts allowed for the direct measurement of the strength, magnitude, and direction of relationships between survival and Caspian tern predation. Estimates of tern predation on steelhead were substantial in

most years, with cumulative annual estimates ranging from 0.075 (95% creditable interval = 0.058-0.099) to 0.375 (0.290–0.461). Increases in tern predation probabilities were associated with statistically significant decreases in steelhead survival probabilities in all evaluated years and salmonid life-stages (smolt out-migration and smolt-to-adult returns). Results provide novel evidence that predation by Caspian terns may have been a super additive source of mortality during the smolt life-stage and a partially additive source of mortality to the adult life-stage. Annual estimates of the difference between observed survival and baseline survival (i.e., in the absence of tern predation) ranged from 0.052 (0.017–0.103) to 0.314 (0.172–0.459) during the steelhead smolt life-stage and from 0.011 (0.001–0.029) to 0.049 (0.025–0.078) to the adult life-stage. The estimated levels of compensation have important implications for predator management actions aimed at increasing the survival of endangered salmonids, and the modelling approach developed herein provides a framework to directly quantify the impacts of source-specific mortality factors on prey populations.

Payton, Q., Hostetter, N. J., & Evans, A. F. (2019). Jointly estimating survival and mortality: Integrating recapture and recovery data from complex multiple predator systems. *Environmental and Ecological Statistics*, *26*(2), 107–125. https://doi.org/10.1007/s10651-019-00421-8

Identifying where, when, and how many animals live and die over time is principal to understanding factors that influence population dynamics. Capture–recapture–recovery (CRR) models are widely used to estimate animal survival and, in many cases, quantify specific causes of mortality (e.g., harvest, predation, starvation). However, the restrictive CRR framework can inhibit the consideration and inclusion of some types of recovery data. We developed an extension to the CRR framework to allow for the incorporation of recoveries from indeterminate temporal or spatial origin. This model jointly estimates cause-specific mortality and survival probabilities across multiple spatial and temporal scales, while accounting for differences in mortality-specific reporting and recovery rates. We fitted the model to data on a group of juvenile steelhead trout (Oncorhynchus mykiss) marked with passive integrated transponder tags in the Columbia River basin, USA. Following tagging and release, fish were detected alive at up to six downstream locations and/or recovered dead on one of nine bird colonies during seaward migration. We estimated that, in aggregate, avian predators consumed 31% of juvenile steelhead during outmigration to the ocean (95% CRI: [27, 36]). Colony-specific predation rates ranged from < 1 to 14% among river reaches, with avian predation accounting for > 95% of all steelhead mortality within some reaches. This integrated modelling approach provides a flexible framework to integrate multiple recapture and recovery data sources, providing a more holistic understanding of animal life history, including direct comparisons of cause-specific mortality factors and the cumulative impact of multiple mortality factors across time or space.

Pearcy, W. G. (1992). *Ocean Ecology of North Pacific Salmonids*. Washington Sea Grant Program.

A compendium of Northeast Pacific salmon ecology, encompassing all five salmon and two trout species of Oncorhynchus--with Oregon coho salmon, the author's specialty for the past decade, acting as centerpiece.

Peck-Richardson, A. G. (2017). *Double-crested Cormorants (Phalacrocorax auritus) and Brandt's Cormorants (P. penicillatus) Breeding at East Sand Island in the Columbia River Estuary: Foraging Ecology, Colony Connectivity, and Overwinter Dispersal* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/j9602425t

Double-crested cormorants (Phalacrocorax auritus) and Brandt's cormorants (P. penicillatus) nest sympatrically in a large mixed-species colony on East Sand Island (ESI) in the Columbia River estuary. Ecological theory predicts that such morphologically similar species will partition prey resources when faced with resource limitations. During the summer of 2014, I investigated local movements, foraging dive behavior, and foraging habitat selection by breeding adults of both cormorant species using GPS tags with integrated temperature and depth dataloggers (GPS-TDlog, Earth & Ocean Technologies). The overall foraging areas and core foraging areas (defined as the 95% and 50% kernel density estimates of dive locations, respectively) of double-crested cormorants were much larger and covered a broader range of estuarine habitats than those of Brandt's cormorants. Only 26% and 27% of the overall and core foraging areas, respectively, for double-crested cormorants overlapped with those of Brandt's cormorants. Most of the overall and core foraging areas of Brandt's cormorants (59% and 89%, respectively) overlapped with those of double-crested cormorants, however. Within areas of overlap, Brandt's cormorants tended to dive deeper (median depth = 6.48 m) than double-crested cormorants (median depth = 2.67 m), and selected dive locations where the water was deeper. After accounting for local water depth, Brandt's cormorants utilized a deeper, more benthic portion of the water column than did double-crested cormorants. Our results indicate that species-specific patterns of foraging habitat utilization likely reflect past evolutionary divergence in foraging niche and evolved differences in behavioral and physiological adaptations, resulting in some partitioning of prey resources that would mitigate interspecific competition. Nevertheless, the substantial overlap in foraging habitat between the two cormorant species, particularly for Brandt's cormorants, suggests that superabundant prey resources allow these two large and productive cormorant colonies to coexist on a single island near the mouth of the Columbia River. Annual consumption of millions of out-migrating juvenile salmonids (Oncorhynchus spp.), including smolts from populations listed under the U.S. Endangered Species Act, by double-crested cormorants nesting at ESI motivated natural resource managers to investigate potential management techniques to reduce cormorant predation by reducing the size of the breeding colony. To better understand potential dispersal of cormorants from the ESI colony due to management to reduce colony size, satellite transmitters were fitted on 83 double-crested cormorants captured on the ESI colony before egg-laying in 2013. Dispersal from ESI immediately following tagging was nearly ubiquitous, but temporary, and provided limited information on where cormorants might prospect for alternative nest sites if prevented from nesting on ESI. During this initial pre-nesting period, tagged cormorants were detected at colonies and roost sites as far from ESI as the Puget Sound region of coastal Washington; nevertheless, all but 4% of tagged cormorants returned to ESI within 2 weeks of being tagged. Following the subsequent breeding season, tagged cormorants staged at several nearby estuaries before migrating both north and south from ESI to overwinter in areas from British Columbia to northwestern Mexico; only 3% overwintered in the Columbia River estuary. Tracking data revealed substantial connectivity between the ESI colony and other colonies and regions within the range of the western North America population, suggesting the potential for widespread dispersal throughout the population's breeding range if nesting habitat on ESI was reduced or eliminated. Dispersal did not extend across the Cascade-Sierra Divide, however; greater connectivity existed with estuary locations throughout the range and particularly with more proximate estuaries that served as post-breeding staging areas. Surprisingly low regional and colony connectivity was observed with the Oregon Coast, despite numerous active and historical colonies in that region, as well as proximity to the colony at ESI. The strong philopatry to ESI that nearly all tagged cormorants exhibited, however, suggests that few alternative nesting opportunities are as attractive for prospecting double-crested cormorants as the ESI colony site.

Peck-Richardson, A. G., Lyons, D. E., Roby, D. D., Cushing, D. A., & Lerczak, J. A. (2018). Three-dimensional foraging habitat use and niche partitioning in two sympatric seabird species, Phalacrocorax auritus and P. penicillatus. *Marine Ecology Progress Series*, *586*, 251–264. https://doi.org/10.3354/meps12407

Ecological theory predicts that co-existing, morphologically similar species will partition prey resources when faced with resource limitations. We investigated local movements, foraging dive behavior, and foraging habitat selection by breeding adults of 2 closely related cormorant species, double-crested cormorants Phalacrocorax auritus and Brandt's cormorants P. penicillatus. These species nest sympatrically at East Sand Island in the Columbia River estuary at the border of Oregon and Washington states, USA. Breeding individuals of each species were tracked using GPS tags with integrated temperature and depth data-loggers. The overall foraging areas and core foraging areas (defined as the 95% and 50% kernel density estimates of dive locations, respectively) of double-crested cormorants were much larger and covered a broader range of riverine, mixed-estuarine, and nearshore marine habitats. Brandt's cormorant foraging areas were less expansive, were exclusively marine, and mostly overlapped with double-crested cormorant foraging areas. Within these areas of overlap, Brandt's cormorants tended to dive deeper (median depth = 6.48 m) than double-crested cormorants (median depth = 2.67 m), and selected dive locations where the water was deeper. Brandt's cormorants also utilized a deeper, more benthic portion of the water column than did double-crested cormorants. Nevertheless, the substantial overlap in foraging habitat between the 2 cormorant species in the Columbia River estuary, particularly for Brandt's cormorants, suggests that superabundant prey resources allow these 2 large and productive cormorant colonies to coexist on a single island near the mouth of the Columbia River.

Peck-Richardson, A. G., Lyons, D. E., Roby, D. D., & Lawes, T. J. (2019). *Pacific Flyway Caspian tern population monitoring, 2018 Final Annual Report* (p. 25).

This report summarizes the second survey of the Caspian tern (Hydroprogne caspia) breeding population in the Pacific Flyway region using a dual-frame, sampling-based methodology developed as a monitoring strategy by the U.S. Fish and Wildlife Service (USFWS 2015). Based on a sample of 38 pre-selected breeding colony sites (USFWS 2015, Peterson et al. 2017), we produced two estimates of the 2018 breeding population. The first population estimate, which utilized a sampling structure uninformed by 2018 survey data, was 8,569 breeding pairs (95% confidence limit: 6,080 – 11,058 breeding pairs). The second population estimate, based on the 38 sample colony sites reclassified into strata using mean colony size data from 2015 and 2018 (8 sample colonies changed from one stratum based on 2011 and 2015 counts to another stratum based on 2015 and 2018 counts). This second approach changed only slightly the point estimate of population size to 8,691 breeding pairs, but narrowed the estimate of uncertainty (95% confidence limit: 6,875 – 10,507 breeding pairs). Data on the size of additional breeding colonies not included in the pre-selected sample of 38 colony sites were available in 2018 because of separately funded research, communication with cooperating agencies or researchers, or both. We surveyed a total of 33 supplemental colony sites, 14 of which were active in 2018. Our minimum census estimate for the Pacific Flyway population was 10,580 breeding pairs, the total number of pairs observed at sample colonies combined with total number observed at

supplemental colonies. This minimum census estimate slightly exceeds the 95% confidence limit of the second estimate based on the monitoring strategy. The 2018 sample-based population size estimates of 8,569 and 8,691 breeding pairs were not significantly lower than the corresponding 2015 population estimates. Placing sample-based estimates of breeding population size for 2018 and 2015 into the context of census-based estimates from previous years is not straightforward because of methodological differences, however. A marked decline in the census breeding population was evident between 2009 and 2011, consistent with a temporary reduction that was expected to result from a large number of terns being displaced from the East Sand Island colony in the Columbia River estuary. The large displacement of terns from East Sand Island between 2009 and 2011 was due to the onset of nesting habitat restrictions at that colony site as part of the Caspian Tern Management Plan for the Columbia River Estuary (USFWS 2005). The cumulative number of breeding pairs at the 38 pre-selected sample sites was lower in 2018 than in any previous year when data were available for most colonies in the Pacific Flyway (2000 – 2011 & 2015). The minimum census of breeding pairs at all known monitored sites in 2018 (38 pre-selected sites plus 33 supplemental sites) was also the lowest since at least 2000. Following the substantial decline in numbers of breeding pairs between 2009 and 2011, there was no substantial change in size of the breeding population between 2011 and 2018. This suggests that the pool of Caspian terns displaced from East Sand Island by 2011 had limited success over the subsequent seven years in finding alternative breeding sites within the Flyway. The redistribution of the breeding population has taken longer than expected when Caspian tern management in the Columbia River basin was first proposed (USFWS 2005). Additional updates and refinements to the dual-frame sampling and estimation method in future years are needed to standardize results, provide estimates that are comparable among years, and maintain an up-to-date master list of active colony sites and colony size strata.

Penland, S. (1982). Distribution and Status of the Caspian Tern in Washington State. *The Murrelet*, *63*(3), 73–79. JSTOR. https://doi.org/10.2307/3534285

The Caspian Tern in Washington State originally nested only in eastern Washington, but now more than 80% breed in Grays Harbor in western Washington. The shifting of breeding sites in Grays Harbor during the last ten years is believed to be related to competition and predation from gulls and erosion of nestling islands. A major threat to breeding success in small colonies occurs during the incubation period when human disturbance allows gulls access to eggs. Large colonies are most affected by human disturbances when chicks run from their territories and enter the territories of other aggressive adults.

Petersen, J. H. (1994). Importance of Spatial Pattern in Estimating Predation on Juvenile Salmonids in the Columbia River. *Transactions of the American Fisheries Society*, *123*(6), 924–930. https://doi.org/10.1577/1548-8659(1994)123<0924:IOSPIE>2.3.CO;2

The impact of piscivores in aquatic systems is often estimated by assuming that predation rate and predator density can be characterized as means throughout large, homogeneous areas. Predation losses of juvenile Pacific salmonids Oncorhynchus spp. migrating through Columbia River reservoirs were previously estimated with the assumption that each reservoir consisted of one or two homogeneous areas. Data from the John Day Reservoir and throughout the river system showed that predation rate and predator density vary greatly between near-dam and midreservoir areas, suggesting that reservoirs in the Columbia River should be divided into at least three or four areas for estimating salmonid losses. For example, the estimated number of salmonids annually eaten by northern squawfish Ptychocheilus oregonensis in John Day Reservoir decreased from 2.9 million when all samples in the reservoir were pooled into one area, to 1.4 million when samples were partitioned among four areas. Variance about the estimates also decreased steadily with finer partitioning. Mortality of juvenile salmon from predation was substantial with any type of partitioning; however, spatial variation in predation rates and other density-dependent processes may be especially important in river models of migrating juvenile salmon that repeatedly apply predation rates in a series of reservoirs or river reaches.

Peterson, J. H., Mesa, M. G., Hall-Griswold, J., Schrader, W. C., Short, G. W., & Poe, T. P. (1990). *Magnitude and dynamics of predators on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1989-1990.* (p. 86). Bonneville Power Administration (BPA).

Three aspects of predation upon juvenile salmonids in the Columbia River are addressed in this report: 1) Indexing predator consumption. During 1989-90, two indices of northern squawfish consumption upon juvenile salmonids were developed for use throughout the Columbia River Basin. The direct Consumption Index (CI) is based upon the concept of meal turnover time and takes into account number of salmonids, temperature, total gut content weight and predator weight. Computing formulae, laboratory methods, sample size requirements and preliminary tests are presented. A Bioenergetics Index (BI) for consumption indexing was also developed to complement the direct CI. In the BI, growth, consumption, excretion/evacuation and respiration processes are modeled to predict the consumption required to produce an observed growth increment. Preliminary parameter estimates are presented and a sensitivity study of the model was done to direct further development. 2) Studies on predator-smolt dynamics. Northern squawfish consumption data were collected in the McNary Dam tailrace during nine days in July, 1988 to improve our understanding of the predator-smolt functional response. Data were summarized and fitted, along with July-August data from 1983-86, to a Type II functional response equation. Maximum consumption experiments with northern squawfish were completed and results appear in Appendix A. Finally, a workshop was held to discuss aspects of predation modeling in the Columbia River. A separate Bonneville Power Administration report that summarizes the workshop has been published. 3) Selective predation by northern squawfish. Laboratory and field protocols were developed to evaluate northern squawfish selection and prey vulnerability. We conducted preliminary selection experiments on three categories of substandard vs. standard juvenile salmonids: live vs. dead; injured vs. non-injured; and stressed vs. unstressed. Results from laboratory studies suggest that northern squawfish prefer dead over live prey and that descaled prey may be more vulnerable to predation than non-descaled prey. Stressed and unstressed prey were consumed in equal proportions when predation occurred for 6 or 24 h. Physiological and behavioral effects of stress on juvenile salmon are presented.

Peterson, W. T., & Burke, B. B. (2013). *Oceanographic and ecological indicators for salmon returns in the northern California Current* (North Pacific Anadromous Fish Commission Technical Report No. 9; pp. 71–75). https://npafc.org/wp-content/uploads/TechReport9.pdf

Peterson, W. T., Fisher, J. L., Strub, P. T., Du, X., Risien, C., Peterson, J., & Shaw, C. T. (2017). The pelagic ecosystem in the Northern California Current off Oregon during the 2014–2016 warm anomalies within the context of the past 20 years. *Journal of Geophysical Research: Oceans*, *122*(9), 7267–7290. https://doi.org/10.1002/2017JC012952

A warm anomaly in the upper ocean, colloquially named "the Blob," appeared in the Gulf of Alaska during the calm winter of 2013–2014, spread across the northern North Pacific (NP) Ocean, and shifted eastward and onto the Oregon shelf. At least 14 species of copepods occurred which had never been observed in shelf/slope waters off Oregon, some of which are known to have NP Gyre affinities, indicating that the source waters of the coastal "Blob" were likely of both offshore (from the west) and subtropical/tropical origin. The anomalously warm conditions were reduced during strong upwelling in spring 2015 but returned when upwelling weakened in July 2015 and transitioned to downwelling in fall 2015. The extended period of warm conditions resulted in prolonged effects on the ecosystem off central Oregon, lasting at least through 2016. Impacts to the lower trophic levels were unprecedented and include a novel plankton community composition resulting from increased copepod, diatom, and dinoflagellate species richness and increased abundance of dinoflagellates. Additionally, the multiyear warm anomalies were associated with reduced biomass of copepods and euphausiids, high abundance of larvaceans and doliolids (indictors of oligotrophic ocean conditions), and a toxic diatom bloom (Pseudo-nitzschia) throughout the California Current in 2015, thereby changing the composition of the food web that is relied upon by many commercially and ecologically important species.

Peterson, W. T., Morgan, C. A., Peterson, J. O., Fisher, J. L., Burke, B. J., & Fresh, K. L. (2014). *Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current* (p. 83). https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Peterson_etal_2014.pdf

As many scientists and salmon managers have noted, variations in marine survival of salmon often correspond with periods of alternating cold and warm ocean conditions. For example, cold conditions are generally good for Chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon, whereas warm conditions are not. These pages are based on our annual report of how physical and biological ocean conditions may affect the growth and survival of juvenile salmon in the northern California Current off Oregon and Washington. We present a number of physical, biological, and ecosystem indicators to specifically define the term "ocean conditions." More importantly, these metrics can be used to forecast the survival of salmon 1–2 years in advance, as shown in Table 1. This information is presented for the non–specialist; additional detail is provided via links when possible. Material presented on this website has two sources. One is the World Wide Web, from which we have drawn values for the Pacific Decadal Oscillation, Multivariate ENSO index, Upwelling Index, and sea surface temperatures. Links and references to these sources are given in the respective sections that deal with these four physical variables. All other data are from our direct observations during a) biweekly oceanographic sampling along the Newport Hydrographic Line and b) annual juvenile salmonid surveys conducted in June and September. Survey station locations are shown in Figure HP-01; sampling and survey methods are presented in "Ocean Sampling Methods." Using all of these data, we developed a suite of ocean ecosystem indicators upon which to base forecasts of salmon returns. These forecasts are presented as a practical example of how ocean ecosystem indicators can be used to inform management decisions for endangered salmon. At this time, the forecasts are qualitative in nature: we rate each in terms of its "good," "bad," or "neutral" relative impact on salmon marine survival (Table 1). We use this suite of indicators to complement existing indicators used to predict adult salmon runs, such as jack returns, smolt–to–adult return rates (Scheuerell and Williams 2005), and the Logerwell production index. The strength of this approach is that

biological indicators are directly linked to the success of salmon during their first year at sea through food–chain processes. These biological indicators, coupled with physical oceanographic data, offer new insight into the mechanisms that lead to success or failure for salmon runs. In addition to forecasting salmon returns, the indicators presented here may be of use to those trying to understand how variations in ocean conditions might affect recruitment of fish stocks, seabirds, and other marine animals. We reiterate that trends in salmon survival track regime shifts in the North Pacific Ocean, and that these shifts are transmitted up the food chain in a more–or–less linear and bottom–up fashion as follows: upwelling → nutrients → plankton → forage fish → salmon The same regime shifts that affect Pacific salmon also affect the migration of Pacific hake and the abundance of sea birds, both of which prey on migrating juvenile salmon. Therefore, climate variability can also have "top down" impacts on salmon through predation by hake and sea birds (terns and cormorants). Both "bottom up" and "top down" linkages are explored here.

Petrosky, C. E., & Schaller, H. A. (2010). Influence of river conditions during seaward migration and ocean conditions on survival rates of Snake River Chinook salmon and steelhead. *Ecology of Freshwater Fish*, *19*(4), 520–536. https://doi.org/10.1111/j.1600-0633.2010.00425.x

Petrosky CE, Schaller HA. Influence of river conditions during seaward migration and ocean conditions on survival rates of Snake River Chinook salmon and steelhead. Ecology of Freshwater Fish 2010: 19: 520–536. © 2010 John Wiley & Sons A/S Abstract – Improved understanding of the relative influence of ocean and freshwater factors on survival of at-risk anadromous fish populations is critical to success of conservation and recovery efforts. Abundance and smolt to adult survival rates of Snake River Chinook salmon and steelhead decreased dramatically coincident with construction of hydropower dams in the 1970s. However, separating the influence of ocean and freshwater conditions is difficult because of possible confounding factors. We used long time-series of smolt to adult survival rates for Chinook salmon and steelhead to estimate first year ocean survival rates. We constructed multiple regression models that explained the survival rate patterns using environmental indices for ocean conditions and in-river conditions experienced during seaward migration. Survival rates during the smolt to adult and first year ocean life stages for both species were associated with both ocean and river conditions. Best-fit, simplest models indicate that lower survival rates for Chinook salmon are associated with warmer ocean conditions, reduced upwelling in the spring, and with slower river velocity during the smolt migration or multiple passages through powerhouses at dams. Similarly, lower survival rates for steelhead are associated with warmer ocean conditions, reduced upwelling in the spring, and with slower river velocity and warmer river temperatures. Given projections for warming ocean conditions, a precautionary management approach should focus on improving in-river migration conditions by increasing water velocity, relying on increased spill, or other actions that reduce delay of smolts through the river corridor during their seaward migration.

Pierotti, R. J., & Annett, C. A. (1995). *Western Gull—Larus occidentalis—Birds of the World*. https://birdsoftheworld.org/bow/species/wesgul/cur/introduction

Pochop, P. A., Cummings, J. L., & Engeman, R. M. (2001). Field evaluation of a visual barrier to discourage gull nesting. *Pacific Conservation Biology*, *7*(2), 143. https://doi.org/10.1071/PC010143

Expanding gull populations along the Columbia River have been implicated in depredations to threatened and endangered migrating salmon smolt. We tested a visual barrier made of woven black polypropylene fabric to discourage gull nesting. The barrier was installed on Upper Nelson Island, Benton County, Washington, in parallel rows spaced 5 m apart. Gulls used 87% of the 7.9 ha island as nesting habitat and we estimated >21 000 gull nests, 80% Ringbilled Gull Larus delawarensis and 20% California Gull L. califomicus nests. The zone with fencing had 84% fewer nests than the control zone. Silt fencing showed potential as a nonlethal bird management technique.

Pollet, I. L., Shutler, D., Chardine, J. W., & Ryder, J. P. (2012). *Ring-billed Gull—Larus delawarensis—Birds of the World*. https://birdsoftheworld.org/bow/species/ribgul/cur/introduction

Purcell, M., Mackey, G., LaHood, E., Huber, H., & Park, L. (2004). Molecular methods for the genetic identification of salmonid prey from Pacific harbor seal (Phoca vitulina richardsi) scat. *Fishery Bulletin*, *102*, 213–220.

Quinn, J. S., & Sirdevan, J. (1998a). Experimental measurement of nesting substrate preference in Caspian terns, Sterna caspia, and the successful colonisation of human constructed islands. *Biological Conservation*, *85*(1), 63–68. https://doi.org/10.1016/S0006-3207(97)00142-0

Caspian terns, Sterna caspia, recently bred in Hamilton Harbour, at the western end of Lake Ontario, on private property that is likely to be developed in the next decade. To reduce this land-use conflict and to promote the current level of biodiversity of colonial nesters in the area, artificial islands were built in the winter of 1995–1996 with different areas designated for a variety of nesting waterbirds including Caspian terns. In 1994, prior to island construction, we tested three substrate types for tern nesting preferences so that an appropriate substrate could be placed on the Caspian tern designated portion of the new islands. We found a preference for sand over pea-gravel and crushed stone, and indirect evidence for a preference favouring the experimental substrates over the pre-existing substrate of hard-packed ground. Based on these results, the small area of the island designed for Caspian tern nesting was surfaced with sand and was subsequently colonised successfully. The colony established and reproduced successfully on the designated site in 1996 and grew in numbers of nesting pairs in 1997.

Quinn, J. S., & Sirdevan, J. (1998b). Experimental measurement of nesting substrate preference in Caspian terns, Sterna caspia, and the successful colonisation of human constructed islands. *Biological Conservation*, *85*(1), 63–68. https://doi.org/10.1016/S0006-3207(97)00142-0

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Quinn, T. P. (2018). *The Behavior and Ecology of Pacific Salmon and Trout* (2nd ed.). University of Washington Press; JSTOR. https://www.jstor.org/stable/j.ctvcwnvv1

The Behavior and Ecology of Pacific Salmon and Trout combines in-depth scientific information with outstanding photographs and original artwork to fully describe the fish species critical to the Pacific Rim. This completely revised and updated edition covers all aspects of the life cycle of these remarkable fish in the Pacific: homing migration from the open ocean through coastal waters and up rivers to their breeding grounds; courtship and reproduction; the lives of juvenile salmon and trout in rivers and lakes; migration to the sea; the structure of fish populations; and the importance of fish carcasses to the ecosystem. The book also includes information on salmon and trout transplanted outside their ranges.

Reynolds, D. S., & Kunz, T. H. (2001). Standard methods for destructive body composition analysis. In J. R. Speakman (Ed.), *Body Composition Analysis of Animals: A Handbook of Non-Destructive Methods* (pp. 39–55). Cambridge University Press. https://doi.org/10.1017/CBO9780511551741.004

Body composition analysis can provide insight into many aspects of an animal's physiology, ecology, and life history. Historically, this analysis has required sacrificing individuals to obtain accurate estimates of body composition. Recent advances in technology and innovative approaches towards developing non-destructive relationships have begun to advance our understanding of body composition without sacrificing individuals. However, these new approaches must still be validated for both accuracy and precision using direct measurements. The purpose of this chapter is to present standard methods for body composition analysis, point out some of the problems encountered when attempting to analyse body composition, and provide guidance for avoiding some of these problems.

Rieman, B. E., Beamesderfer, R. C., Vigg, S., & Poe, T. P. (1991). Estimated Loss of Juvenile Salmonids to Predation by Northern Squawfish, Walleyes, and Smallmouth Bass in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society*, *120*(4), 448–458. https://doi.org/10.1577/1548-8659(1991)120<0448:ELOJST>2.3.CO;2

We estimated the loss of juvenile salmonids Oncorhynchus spp. to predation by northern squawfish Ptychocheilus oregonensis, walleyes Stizostedion vitreum, and smallmouth bass Micropterus dolomieu in John Day Reservoir during 1983–1986. Our estimates were based on measures of daily prey consumption, predator numbers, and numbers of juvenile salmonids entering the reservoir during the April–August period of migration. We estimated the mean annual loss was 2.7 million juvenile salmonids (95% confidence interval, 1.9–3.3 million). Northern squawfish were responsible for 78% of the total loss; walleyes accounted for 13% and smallmouth bass for 9%. Twenty-one percent of the loss occurred in a small area immediately below McNary Dam at the head of John Day Reservoir. We estimated that the three predator species consumed 14% (95% confidence interval, 9–19%) of all juvenile salmonids that entered the reservoir. Mortality changed by month and increased late in the migration season. Monthly mortality estimates ranged from 7% in June to 61% in August. Mortality from predation was highest for chinook salmon O. tshawytscha, which migrated in July and August. Despite uncertainties in the estimates, it is clear that predation by resident fish predators can easily account for previously unexplained mortality of out-migrating juvenile salmonids. Alteration of the Columbia River by dams and a decline in the number of salmonids could have increased the fraction of mortality caused by predation over what it was in the past.

Roby, D D, Collis, K., & Lyons, D. E. (2002). Conservation and Management for Fish-Eating Birds and Endangered Salmon. *Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference*, 161–165. https://www.fs.fed.us/psw/publications/documents/psw_gtr191/psw_gtr191_0161-0165_roby.pdf

A conflict involving piscivorous birds and salmonids in the Pacific Northwest pits the conservation of protected migratory waterbirds against the restoration of Columbia Basin salmonids (Oncorhynchus spp.) that are listed under the U.S. Endangered Species Act. The Columbia River Avian Predation Project is a cooperative, collaborative research project designed to monitor populations of piscivorous colonial waterbirds on the lower Columbia River and their impact on the survival of juvenile salmonids from the Columbia River basin. The Project includes biologists from Oregon State University, Columbia River Inter-Tribal Fish Commission, U.S. Geological Survey, and RTR Consultants.

Roby, D D, Collis, K., & Lyons, D. E. (2005). Conservation and Management for Fish-eating Birds and Endangered Salmon. *Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference*, 161–165.

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Roby, Daniel D., Collis, K., Lawes, T. J., Bixler, K. S., Lyons, D. E., Bailey, O., Turecek, A., & Hawbecker, M. (2020). *Monitoring and Evaluation of Efforts to Reduce Predation on ESA-listed Salmonids by Caspian Terns Nesting at East Sand Island, Columbia River Estuary, 2019* (p. 51). http://www.birdresearchnw.org/2019_BPA_Final_Annual%20Report_v2.pdf

The objective of this study in 2019 was to monitor and evaluate management implemented by resource management agencies to reduce the number of Caspian terns (Hydroprogne caspia) nesting on East Sand Island in the Columbia River estuary as an approach to reducing tern predation rates on ESA-listed juvenile salmonids (Oncorhynchus spp.). During the 2019 Caspian tern breeding season on East Sand Island, we monitored tern nesting activity, assessed tern diet composition, and monitored factors that limited tern colony size and nesting success. In addition, we monitored inter-colony movements and dispersal patterns of banded Caspian terns to East Sand Island, and conducted an aerial reconnaissance flight to search for incipient tern colonies in lower Columbia River and/or estuaries on the outer coast of Washington. In 2019, the U.S. Army Corps of Engineers (USACE) prepared 1.0 acre of habitat for tern nesting on East Sand Island

and installed passive nest dissuasion materials and hazed terns to prevent tern nesting outside of the designated 1.0-acre tern colony area both on East Sand Island and elsewhere in the Columbia River estuary (i.e. Rice Island) in 2019. The management plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary" was first implemented in 2008, and implementation continued during the 2019 nesting season. The objective of this management plan is to reduce the size of the Caspian tern breeding colony on East Sand Island to 3,125-4,375 breeding pairs by reducing the amount of suitable nesting habitat on East Sand Island to 1.0 acre, while preventing Caspian terns from colonizing other sites in the Columbia River estuary (USACE 2015a). One acre of nesting habitat represents 20% of the area of habitat prepared for Caspian terns on East Sand Island prior to the initiation of implementation of the management plan in 2008. Caspian terns have been provided with just 1.0 acre of nesting habitat on East Sand Island since the 2015 nesting season; however, the location of the 1.0-acre colony area has shifted in most years due to erosion along the southern edge of the colony area during winter storms. Prior to the 2019 nesting season, USACE personnel delineated 1.0 acre of prospective nesting habitat for Caspian terns on East Sand Island and prepared the colony surface for tern nesting by removing existing vegetation. First, at the end of March, a USACE contractor used heavy equipment to prepare the colony surface for Caspian tern nesting by removing dense surface vegetation from about half of the 1.0-acre area, as well as an above-ground tunnel used to access an observation blind during the 2018 breeding season, and fence-rows of landscape fabric used to dissuade terns from nesting along the eastern edge of the designated colony area in 2018. Then, in early April, USACE personnel used a disking harrow on the entire 1.0-acre colony area to break up any shallow surface vegetation that remained on the colony following colony site preparation by heavy equipment. Caspian terns arrived at the East Sand Island colony and initiated nesting around the same time as in recent years (i.e. early to mid-April), but high predation rates on tern eggs by gulls early in the breeding season resulted in delayed hatching of the first chick and a delayed chick-rearing period in 2019 compared to previous years. The tern colony slowly grew to peak size by mid-June, when about 3,860 breeding pairs (95% c.i. = 3,667– 4,055 breeding pairs) were estimated to be nesting in the designated 1.0-acre colony area on East Sand Island. Subsequently, the number of breeding pairs on the tern colony slowly declined until the colony area was completely vacated by nesting terns in late September. The 2019 peak colony size estimate on the 1.0-acre colony area was significantly less than the 2018 peak colony size estimate (4,959 breeding pairs), and was within the range in colony size (i.e. 3,125-4,375 breeding pairs) stipulated in the management plan. In 2019, Caspian terns were displaced for nesting territories by glaucous-winged/western gulls (Larus glaucescens X L. occidentalis) on part of the eastern half of the prepared 1.0-acre colony area; consequently, Caspian terns nested on just 0.86 acres of the 1.0 acre provided. The portion of the 1.0-acre prepared tern colony area that was occupied by nesting gulls in 2019 was also used by nesting gulls in 2018. Similar to the 2015 and 2016 breeding seasons, hundreds of pairs of Caspian terns attempted to nest on East Sand Island outside of the 1.0-acre colony area in 2019 with a sustained effort but were unsuccessful in raising any chicks to fledging. In 2015 and 2016, satellite colonies supported a total of about 810 breeding pairs and 700 breeding pairs, respectively. In 2019, Caspian terns were frequently observed in nest scrapes under passive dissuasion materials, apparently sitting on eggs. A total of about 550 breeding pairs of terns were counted in nest scrapes on several satellite colonies outside of the 1.0-acre prepared colony area at the peak of the 2019 nesting season. At peak colony size, tern nesting density on the 1.0-acre designated colony area averaged 1.11 nests/m2 (95% c.i. = 1.06–1.17 nests/m2), slightly lower than the nesting density of 1.23 nests/m2 (95% c.i. = 1.16–1.29 nests/m2) observed in 2018, but higher than the nesting density of 0.97 nests/m2 (95% c.i. = 0.87–1.06 nests/m2) observed in 2017. Tern productivity (average number of young raised/nesting pair) in 2019 was again much lower than the long-term average, but the colony did not fail to produce any young, as it did in 2017. During the last decade, two factors have emerged as causes of low productivity at the East Sand Island Caspian tern colony: (1) reduced availability of marine forage fish in the estuary associated with high Columbia River discharge and (2) frequent colony disturbances by bald eagles (Haliaeetus leucocephalus) and associated high predation rates on tern eggs and chicks by gulls. In 2019, eagle disturbances of the tern colony were frequent and northern anchovies (Engraulis mordax, a common marine forage fish in the Columbia River estuary) were a smaller proportion of the tern diet at East Sand Island compared to most previous years, despite below average Columbia River discharge that is usually associated with high abundance of anchovies in the estuary. Northern anchovy are generally a major prey type late in the breeding season for Caspian terns nesting at the East Sand Island colony, as this marine forage fish provides a high-energy food source for fledgling Caspian terns. In 2019, a large number of nearly fledged tern chicks were depredated by gulls, especially those gulls nesting in the designated 1.0-acre colony area. High gull predation rates on older Caspian tern chicks may have been a result of the relatively low availability of anchovy for Caspian terns raising young in 2019. The average proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during the 2019 season was 33.5% (percent of identified prey items), lower than the salmonid proportion in 2015, 2017, and 2018 (37.9%, 36.0%, and 40.1%, respectively); data on diet composition were not collected in 2016. During the 2019 tern nesting season, the average proportion of juvenile salmonids in the diet of terns nesting at East Sand Island was only slightly higher than the long-term average (31.7%), measured during the 2000-2015 nesting seasons. As in previous years, estuarine and marine forage fishes (e.g., anchovy [Engraulidae], surf perch [Embiotocidae], smelt [Osmeridae], and herring [Clupeidae]) were collectively most prevalent in the tern diet, together averaging 57% of all identified bill-loads in the diet of terns nesting on East Sand Island in 2019. Although the proportion of anchovy in the diet of Caspian terns nesting at East Sand Island was well below the long-term average, herring represented a much greater proportion of the tern diet in 2019, compared to the long-term average. Bioenergetics calculations to estimate total smolt consumption by Caspian terns nesting at East Sand Island in 2019 are currently in progress and will be included in a subsequent version of this annual report. Predation rates on specific populations of anadromous salmonids (ESUs/DPSs) by Caspian terns nesting on East Sand Island in 2019 were again investigated by recovering smolt PIT tags from the surface of the tern colony after the breeding season. That study was performed separately by the U.S. Army Corps of Engineers – Portland District, however, and those results are not presented as part of this report. Resightings of previously banded Caspian terns on East Sand Island during the 2019 nesting season indicated that there is strong natal and breeding philopatry to the East Sand Island colony, and some terns are immigrating to the East Sand Island colony from other colonies in the Pacific Flyway. Despite low resighting effort and small sample size, a few banded terns that were observed on East Sand Island during the 2018 breeding season were detected at the Blalock Islands in 2019, suggesting that some adult terns continue to disperse from the East Sand Island colony to other colony sites in the Columbia Plateau region. There was no effort to resight banded terns at other colony locations in the Pacific Flyway outside the Columbia River basin in 2019; as such the level of connectivity between the East Sand Island colony and other colonies throughout the region during the 2019 breeding season is unknown. We recorded almost 400 Caspian terns at locations other than East Sand Island during the aerial survey of the lower Columbia River and estuaries on the outer coast of Washington in 2019. We observed about 135 Caspian terns loafing at four different sites on the lower Columbia River, and about 245 terns loafing at five different sites in Willapa Bay and Grays Harbor. However, we did not detect Caspian tern breeding activity at any of the sites where loafing terns were detected.

Roby, Daniel D., Collis, K., Lawes, T. J., Bixler, K. S., Lyons, D. E., Suzuki, Y., Scheibe, J., Turecek, A., & Hawbecker, M. (2019). *Implementation and Evaluation of Efforts to Reduce Predation on ESA-listed Salmonids by Caspian Terns Nesting at East Sand Island, Columbia River Estuary, 2018* (p. 68). http://www.birdresearchnw.org/2018_BPA_Final%20Annual%20Report.pdf

The primary objective of this study in 2018 was to monitor and evaluate management implemented by resource management agencies to reduce the number of Caspian terns (Hydroprogne caspia) nesting on East Sand Island in the Columbia River estuary. The goal of these management actions is to reduce tern predation rates on ESA-listed juvenile salmonids (Oncorhynchus spp.) in the estuary. First, with guidance from the responsible resource management agencies, we delineated and prepared 1.0 acres of bare ground habitat for terns to nest on at East Sand Island. Then we attempted to prevent nesting by terns on East Sand Island outside that designated 1.0-acre nesting area, while monitoring for potential effects of tern management actions on other colonial waterbirds that nest and roost on the island. We also monitored tern nesting activity on East Sand Island throughout the tern nesting season and assessed tern diet composition and factors that limited tern colony size and nesting success. Lastly, we monitored inter-colony movements and dispersal patterns of Caspian terns from East Sand Island to evaluate the efficacy of management implemented to disperse nesting Caspian terns to alternative colony sites outside the Columbia River basin. The management plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary" was first implemented in 2008, and implementation continued during the 2018 nesting season. The objective of this management plan is to reduce the size of the Caspian tern breeding colony on East Sand Island to 3,125-4,375 breeding pairs by reducing habitat to 1.0 acres of suitable nesting habitat at East Sand Island, while preventing Caspian terns from colonizing other sites in the Columbia River estuary (USACE 2015a). As part of this plan, we delineated 1.0 acres of lightly vegetated habitat and, using disking and rototilling, created 1.0 acres of bare-ground nesting habitat for Caspian terns on East Sand Island prior to the 2018 nesting season; the same surface area of nesting habitat was provided for terns during the 2015-2017 nesting seasons. One acre of nesting habitat is 20% of the area of habitat prepared for terns on East Sand Island prior to the implementation of the management plan in 2008. Caspian terns arrived on the East Sand Island colony and initiated nesting late in 2018 compared to previous years. The tern colony slowly grew to a peak size (number of breeding pairs) in mid-June, when about 4,959 breeding pairs (95% c.i. = 4,682 – 5,236 breeding pairs) were estimated to be nesting at the East Sand Island colony. The number of breeding pairs on the colony then slowly declined until the colony area was vacated for the season in early September. The 2018 colony size estimate is significantly larger than the 2017 estimate of peak colony size on the 1.0-acre colony area (3,500 breeding pairs), and 13-59% greater than the management objective of 3,125-4,375 breeding pairs for the tern colony on East Sand Island. At peak colony size, tern nesting density on the 1.0-acre designated colony area averaged 1.23 nests/m2 (95% c.i. = 1.16 – 1.29 nests/m2), significantly greater than average nesting density in 2017 (0.97 nests/m2), but significantly lower than the average nesting density in 2016 (1.36 nests/m2). Although productivity (average number of fledglings raised/nesting pair) was much lower than the long-term average, some Caspian tern young were raised at the East Sand Island colony in 2018 despite high Columbia River discharge, which negatively affects forage fish availability, and frequent disturbance of the tern colony by bald eagles (Haliaeetus leucocephalus) early in the breeding season. Before and during the 2018 nesting season, we installed a total of 3.81 acres of passive tern nest dissuasion materials (posts, rope, and flagging) in a successful effort to limit tern nesting on East Sand Island to just the 1.0 acres of designated tern nesting habitat. Any Caspian terns that attempted to nest on the eastern half of East Sand Island outside the 1.0-acre designated colony site were actively hazed by members of our field crew to further discourage nesting. This was the fourth breeding season that we were tasked with Caspian tern nest dissuasion activities as part of BPA-funded monitoring and evaluation on East Sand Island, and the second year that those efforts were effective in preventing any Caspian terns from successfully nesting outside the 1.0-acre designated colony area. In 2015 and 2016, satellite tern colonies became established, at least briefly, outside the designated 1.0-acre colony area; those satellite colonies supported a total of 810 breeding pairs and 700 breeding pairs in 2015 and 2016, respectively. The average proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during the 2018 nesting season was 40% (percent of identified prey items), somewhat higher than the salmonid proportion in 2017 (36%), and more similar to the proportion in 2015 (38%; no diet composition data were collected in 2016). During all three of these years, the average proportion of juvenile salmonids in the diet of terns nesting at East Sand Island has been higher than the long-term average (31%) measured during the 2000-2014 breeding seasons. As in previous years, estuarine and marine forage fishes (e.g., anchovy [Engraulidae], surf perch [Embiotocidae], smelt [Osmeridae], and herring [Clupeidae]) were collectively most prevalent in the tern diet, together averaging 50% of all identified bill-loads in the diet of terns nesting on East Sand Island in 2018. Although the proportion of anchovy in the diet of Caspian terns nesting at East Sand Island was well below the long-term average, herring represented a much greater proportion of the tern diet in 2018 compared to the long-term average. Bioenergetics calculations to estimate total smolt consumption by Caspian terns nesting at East Sand Island in 2018 are currently in progress and will be included in a subsequent version of this annual report. Predation rates on specific populations of anadromous salmonids (ESUs/DPSs) by Caspian terns nesting on East Sand Island in 2018 were investigated by recovering smolt PIT tags from the surface of the tern colony after the breeding season. That study was funded separately by the U.S. Army Corps of Engineers – Portland District, and study results will be presented as part of a separate report to that funding agency. Resightings of previously-banded Caspian terns on East Sand Island during the 2018 nesting season indicated that there is strong natal and breeding philopatry to the East Sand Island colony, and some terns are immigrating to the East Sand Island colony from other colonies throughout the Pacific Flyway, especially the two managed colony sites in the Columbia Plateau region: Goose Island and Crescent Island. Resightings of banded terns in 2018 that were seen on East Sand Island during the 2017 breeding season indicate that some adults are dispersing from the East Sand Island colony to alternative colony sites in the Columbia Plateau region. There was no effort to resight banded terns at other colony locations in the Pacific Flyway outside the Columbia River basin in 2018, however, so the level of connectivity between the East Sand Island colony and other colonies throughout the region during the 2018 breeding season is unknown.

Roby, Daniel D., Collis, K., Loschl, P. J., Bixler, K. S., Lyons, D. E., Suzuki, Y., Lawes, T. J., Underwood, B., Turecek, A., & Hawbecker, M. (2018). *Implementation and Evaluation of Efforts to Reduce Predation on ESA-listed Salmonids by Caspian Terns Nesting at East Sand Island, Columbia River Estuary, 2017* (p. 59). http://www.birdresearchnw.org/Final_2017_BPA_Annual%20Report.pdf

The primary objective of this study in 2017 was to monitor and evaluate management implemented by resource management agencies to reduce the number of Caspian terns (Hydroprogne caspia) nesting on East Sand Island in the Columbia River estuary. The goal of these management actions is to reduce tern predation rates on ESA-listed juvenile salmonids (Oncorhynchus spp.) in the estuary. First, with guidance from the responsible resource management agencies, we delineated 1.0 acres of bare ground habitat for terns to nest on at East Sand Island. Then we attempted to prevent nesting by terns on East Sand Island outside that designated 1.0-acre nesting area, while monitoring for potential effects of tern management actions on other colonial waterbirds that nest and roost on the island. We also monitored tern nesting activity on East Sand Island throughout the tern nesting season, and assessed tern diet composition and factors that limited tern colony size and nesting success. Lastly, we evaluated inter-colony movements and dispersal patterns of Caspian terns from East Sand Island to evaluate the efficacy of management implemented to disperse nesting Caspian terns to alternative colony sites outside the Columbia River basin. The management plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary" was first implemented in 2008, and implementation continued during the 2017 nesting season. The objective of this management plan is to reduce the size of the Caspian tern breeding colony on East Sand Island to 3,125 breeding pairs or less, while preventing Caspian terns from colonizing other sites in the Columbia River estuary. As part of this plan, we delineated 1.0 acres of bare-ground nesting habitat for Caspian terns on East Sand Island prior to the 2017 nesting season; the same surface area of nesting habitat was provided for terns during the 2015 and 2016 nesting seasons. One acre of nesting habitat is 20% of the area of habitat prepared for terns on East Sand Island prior to the implementation of the management plan in 2008. Caspian terns arrived on the East Sand Island colony and initiated nesting later in 2017 than in previous years. The tern colony slowly grew to a peak size (numbers of breeding pairs) in early June, when about 3,500 breeding pairs (95% CI = 3,200 – 3,900 breeding pairs) were estimated to be nesting at the East Sand Island colony. This is a significantly smaller colony size than last year's estimate of peak colony size on the 1.0-acre colony area (5,200 breeding pairs), and approximately 12% greater than NOAA's management objective of 3,125 breeding pairs for the tern colony on East Sand Island. At peak colony size, tern nesting density on the 1.0-acre designated colony area averaged 0.97 nests/m2 (95% c.i. = 0.87 – 1.06 nests/m2), significantly less than average nesting density in either 2015 (1.32 nests/m2) or 2016 (1.36 nests/m2), and the lowest nesting density observed at the East Sand Island tern colony since 2011. By mid-June the size of the tern colony began to decline rapidly, however, and ultimately all active tern nesting attempts failed. The proximate cause of nest failure was disturbance by predators, primarily bald eagles (Haliaeetus leucocephalus), and associated secondary predation on tern eggs and young chicks by gulls (Larus spp.). By 23 June the tern colony was completely abandoned and remained devoid of terns for 10 days, an unprecedented event at this colony. A second, much smaller wave of tern nesting activity at the East Sand Island colony began in early July and persisted until early September, with up to several hundred active tern nests with eggs present on the colony at one time. All nesting attempts in this second wave ultimately failed, however, and no Caspian tern young were raised at the East Sand Island colony in 2017. Before and during the 2017 nesting season, we installed a total of 3.85 acres of passive tern nest dissuasion materials (posts, rope, and flagging) in a successful effort to limit tern nesting on East Sand Island to just the 1.0 acres of designated tern nesting habitat. Any Caspian terns that attempted to nest on the eastern half of East Sand Island outside the 1.0-acre designated colony site were actively hazed to further discourage nesting. This was the third breeding season that we were tasked with Caspian tern nest dissuasion activities as part of BPA-funded monitoring and evaluation on East Sand Island, and the first year that those efforts were successful in preventing any Caspian terns from nesting outside the 1.0-acre designated colony area. In 2015 and 2016, satellite tern colonies became established, at least briefly, outside the designated 1.0-acre colony area; those satellite colonies supported a total of 810 breeding pairs and 700 breeding pairs in 2015 and 2016, respectively. The average proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during the 2017 nesting season was 36% (percent of identified prey items), similar to the proportion (38%) in 2015 (the last year that tern diet composition was measured at East Sand Island), but higher than the average proportion of salmonids in the diet (29%) prior to the initiation of management to reduce colony size on East Sand Island (2000-2007). As in previous years, estuarine and marine forage fishes (e.g., anchovies [Engraulidae], surf perch [Embiotocidae], smelt [Osmeridae], and herring [Clupeidae]) were collectively most prevalent in the tern diet, together averaging 53% of all identified bill-loads in the diet of terns nesting on East Sand Island in 2017. Bioenergetics calculations to estimate total smolt consumption by Caspian terns nesting at East Sand Island in 2017 are currently in progress and will be included in a subsequent annual report. Predation rates on specific populations of anadromous salmonids (ESUs/DPSs) by Caspian terns nesting on East Sand Island in 2017 were investigated by recovering smolt PIT tags from the surface of the tern colony after the breeding season. That study was funded separately by the U.S. Army Corps of Engineers – Portland District, and study results will be presented as part of a separate report to the funding agency. Resightings of previously-banded Caspian terns on East Sand Island during the 2017 nesting season indicated that there is strong natal and breeding philopatry to the East Sand Island colony, but some terns are immigrating to the East Sand Island colony from other colonies throughout the Pacific Flyway, especially the two managed colony sites in the Columbia Plateau region: Goose Island and Crescent Island. Resightings of banded terns in 2017 that were seen on East Sand Island during the 2016 breeding season indicate that some adults are dispersing from the East Sand Island colony to alternative colony sites in the Columbia Plateau region and the Puget Sound region. One tern banded as a fledgling on East Sand Island and resighted at that colony in 2016 was resighted at the Corps-constructed tern islands in Don Edwards NWR in San Francisco Bay during the 2017 breeding season. Although the proximate causes of nesting failure at the Caspian tern colony on East Sand Island in 2017 were eagle disturbance and associated gull nest predation, ultimate cause(s) of tern colony failure and abandonment are less certain. Unusually high river discharge and poor ocean conditions during much of the 2017 Caspian tern nesting season appear to have played a major role. In 2011, the only other year when the tern colony at East Sand Island failed to raise any fledglings, river discharge was also exceptionally high, and marine forage fishes were scarce in the Columbia River estuary. In 2017, the diet of terns nesting at East Sand Island consisted of more salmonid smolts and fewer marine forage fishes during much of the nesting season, compared to the average in previous years. Our results suggest that the failure of the tern colony on East Sand Island to produce any young in 2017 was due to the interaction of top-down effects (eagles, gulls) and bottom-up effects (river discharge, ocean conditions) as they influence

availability of marine forage fishes. While these factors likely had a major impact on tern nesting success at East Sand Island in 2017, they also may have limited the size and nest density of the East Sand Island tern colony in 2017.

Roby, Daniel D., Collis, K., Loschl, P. J., Suzuki, Y., Lyons, D., Lawes, T. J., Bixler, K. S., Caillouet, B., Underwood, B., Evans, A., Cramer, B., Turecek, A., Payton, Q., & Hawbecker, M. (2017). *Avian Predation on Juvenile Salmonids: Evaluation of the Caspian Tern Management Plan in the Columbia River Estuary, 2016* (p. 83). http://www.birdresearchnw.org/FINAL_2016_BPA_Report.pdf

The primary objectives of this study in 2016 were to monitor, evaluate, and adaptively manage initiatives implemented to reduce the number of Caspian tern (Hydroprogne caspia) nesting on East Sand Island and, therefore, reduce tern predation rates on ESA-listed juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary. First, with guidance from resource managers, we prepared 1 acre of tern nesting habitat for terns to use on East Sand Island and attempted to prevent nesting by terns outside that designated nesting area. Second, we monitored tern nesting activity on East Sand Island and evaluated their predation rates on ESA-listed juvenile salmonids. Third, we evaluated movement rates of previously color-banded Caspian terns to and from the East Sand Island colony to assess the efficacy of management initiatives implemented to relocate nesting terns to sites outside the Columbia River basin. Lastly, we monitored the effects of Caspian tern management actions implemented on East Sand Island on the other colonial waterbirds that nest and roost on the island. The management plan entitled, Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary was first implemented in 2008, and implementation continued in 2016. The objective of this plan is to reduce the size of Caspian tern colony on East Sand Island to 3,125 - 4,375 breeding pairs, while preventing Caspian terns from colonizing other sites in the Columbia River estuary. As part of this plan, we prepared 1.0 acre of suitable nesting habitat for Caspian terns on East Sand Island prior to the 2016 nesting season, the same area of nesting habitat that was provided for terns in 2015, and an 80% reduction in what was provided for terns on East Sand Island prior to implementation of the management plan. The estimate of Caspian tern colony size on the 1.0-acre designated colony area in 2016 was 5,215 breeding pairs (95% c.i. = 5,000 – 5,430 pairs), slightly lower than the colony size in 2015 (5,430 breeding pairs; 95% c.i. = 5,200 – 5,660 pairs), and about a 50% reduction from the peak size of the tern colony on East Sand Island (ca. 10,670 pairs), which occurred in 2008. We attempted to limit tern nesting on East Sand Island to the 1.0-acre designated colony area using passive dissuasion (stakes, rope, and flagging) and active dissuasion (human hazing). A total of 5.1 acres of passive dissuasion was installed on East Sand Island prior to the 2016 nesting season, 2.4 acres of which was installed on the east end of the island near the Caspian tern colony. Intensive human hazing was implemented in areas where terns prospected for nest sites. Despite these efforts, two satellite tern colonies formed late in the 2016 nesting season, one adjacent to the main colony area on the upper beach and the other adjacent to a ring-billed gull (Larus delawarensis) colony at the northeast tip of the island. Combined, these two satellite tern colonies consisted of an additional 700 breeding pairs, when the size of the satellite colonies was at its peak. Thus, the estimated total number of Caspian terns that attempted to nest on East Sand Island in 2016 was 5,915 pairs (95% c.i. = 5,410 – 6,425 pairs), which was slightly lower than the total number of Caspian terns nesting on East Sand Island in 2015 (6,240 pairs). In 2016, the average nesting density of Caspian terns in the 1-acre designated colony area on East Sand Island was 1.36 nests/m2,

similar to the average nesting density in 2015 (1.32 nests/m2), and the highest average nesting density ever recorded for Caspian terns nesting on East Sand Island. The peak nesting density on the tern colony in 2016 was 1.50 nests/m2, the same as in 2015. These results suggest that Caspian tern nesting density on the designated colony area is approaching the maximum. Given the more than 30-year history of Caspian terns nesting in the Columbia River estuary, it is expected that some, perhaps most, terns will initially adapt to reductions in suitable nesting habitat on East Sand Island by nesting at higher densities and/or attempting to nest in other, sometimes marginal, nesting habitat on East Sand Island (e.g., upper beaches) and elsewhere in the Columbia River estuary (e.g., Rice Island). Efforts to reduce Caspian tern predation rates on juvenile salmonids in the Columbia River estuary to levels stipulated in the management plan will likely require that all Caspian terns nesting in the Columbia River estuary be restricted to just the designated colony area on East Sand Island, and that the area of designated Caspian tern nesting habitat be reduced to about two-thirds of an acre, thereby forcing terns displaced from East Sand Island to relocate to alternative colony sites outside the Columbia River estuary. As was the case in 2015, Caspian terns nesting on East Sand Island in 2016 were relatively resilient to disturbances by bald eagles (Haliaeetus leucocephalus) and associated gull (Larus spp.) depredation of tern eggs and chicks. These limiting factors caused the Caspian tern colony on East Sand Island to fail or nearly fail during 2010-2012. In 2016, the Caspian tern colony on the 1-acre designated colony site produced about 2,870 fledglings (average of about 0.55 young raised/breeding pair; 95% c.i. = 0.38 – 0.61), similar to the average productivity during 2015 (0.63 young raised/breeding pair). To assess the efficacy of management implemented to disperse Caspian terns from nest sites within the Columbia River basin to alternative colony sites outside the basin, we monitored Caspian tern movements by re-sighting terns previously banded with field-readable leg bands at colonies both inside and outside the basin. Most resighted Caspian terns exhibited site fidelity to the colony on East Sand Island in 2016, although some banded individuals dispersed to colonies in the Columbia Plateau region and in the Salish Sea region. Estimated numbers of Caspian terns that moved from the Corps-constructed alternative colony sites in interior Oregon and northeastern California to the Columbia River estuary and to the Columbia Plateau region were high in 2016, probably due to continued severe drought that has negatively affected tern nesting and foraging habitat in interior Oregon and northeastern California during 2014-2016. Predation rates on specific populations of anadromous salmonids (ESUs/DPSs) by Caspian terns nesting on East Sand Island in 2016 were some of the lowest ever recorded, particularly predation rates on steelhead (O. mykiss) populations. For example, predation rates on Snake River steelhead in 2016 were 6.1% (95% credible interval = 4.8 – 8.8), compared with an average of 22.2% (95% CI = 20.3 – 24.8) observed prior to implementation of management to reduce the size of the tern colony on East Sand Island. Reductions in tern predation rates were commensurate with reductions in tern colony size, indicating that Caspian tern management actions to reduce tern nesting habitat on East Sand Island are resulting in lower average annual predation rates on salmonid smolts. Like predation rates measured in previous years, Caspian tern predation rates in 2016 were significantly higher on populations of steelhead (6.1 – 8.8%, depending on DPS) compared with populations of salmon (0.7 – 1.4%, depending on ESU). An investigation of variation in predation rates based on fish rear-type (hatchery, wild), outmigration history (in-river, transported), run-timing, and smolt abundance (density) indicated that multiple factors influence a fish's susceptibility to tern predation; reflecting dynamic and complex predator-prey interactions in the Columbia River estuary. To further reduce predation rates by Caspian terns nesting at East Sand Island on salmonid smolts in the Columbia River estuary, more Caspian terns will need to be relocated to colonies outside the estuary. Based on the size of the East Sand Island colony in 2016 (5,915 breeding pairs) relative to the target colony size stipulated in the Management Plan (3,125 – 4,375 breeding pairs), an additional 1,500 – 2,800 breeding pairs will need to be relocated outside the estuary. This will likely require an increased effort to prevent Caspian terns from nesting outside the designated 1-acre designated colony area on East Sand Island. The potential for the formation of satellite tern colonies on East Sand Island can be reduced by (1) installing preseason passive dissuasion more strategically, (2) move the designated tern nesting habitat further from the beach, and (3) collect a limited number of tern eggs (under permit) at incipient satellite colonies. In addition, the designated colony area will need to be reduced to less than 1 acre of nesting habitat (ca. 0.67 acres) to meet the management objective for colony size stipulated in the Plan.

Roby, Daniel D., Collis, K., Lyons, D. E., Craig, D. P., Adkins, J. Y., Myers, A. M., & Suryan, R. M. (2002). Effects of Colony Relocation on Diet and Productivity of Caspian Terns. *The Journal of Wildlife Management*, *66*(3), 662. https://doi.org/10.2307/3803132

We investigated the efficacy of management to reduce the impact of Caspian tern (Sterna caspia) predation on survival of juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary. Resource managers sought to relocate approximately 9,000 pairs of terns nesting on Rice Island (river km 34) to East Sand Island (river km 8), where terns were expected to prey on fewer juvenile salmonids. Efforts to attract terns to nest on East Sand Island included creation of nesting habitat, use of social attraction techniques, and predator control, with concurrent efforts to discourage terns from nesting on Rice Island. This approach was successful in completely relocating the tern colony from Rice Island to East Sand Island by the third breeding season. Juvenile salmonids decreased and marine forage fishes (i.e., herring, sardine, anchovy, smelt, surfperch, Pacific sand lance) increased in the diet of Caspian terns nesting on East Sand Island, compared with terns nesting on Rice Island. During 1999 and 2000, the diet of terns nesting on Rice Island consisted of 77% and 90% juvenile salmonids, respectively, while during 1999, 2000, and 2001, the diet of terns nesting on East Sand Island consisted of 46%, 47%, and 33% juvenile salmonids, respectively. Nesting success of Caspian terns was consistently and substantially higher on East Sand Island than on Rice Island. These results indicate that relocating the Caspian tern colony was an effective management action for reducing predation on juvenile salmonids without harm to the population of breeding terns, at least in the short term. The success of this management approach largely was a consequence of the nesting and foraging ecology of Caspian terns: the species shifts breeding colony sites frequently in response to changing habitats, and the species is a generalist forager, preying on the most available forage fish near the colony.

Roby, Daniel D., Collis, K., Lyons, D. E., Craig, D. P., & Antolos, M. (2006). Caspian Tern (Sterna caspia). In *Birds of Oregon: A General Reference* (2nd ed., pp. 277–279). Oregon State University Press.

The largest species of tern in the world, the Caspian Tern is easily recognizable by its black cap, pale gray upperparts, scarlet bill, and gull-like size. Although scarce or declining throughout much of its range, most populations in N. America have recently grown, including the Pacific coast/Western states population. Oregon currently hosts the largest known Caspian Tern nesting colony in the world (on East Sand I. in the Columbia R. estuary), but the future of this colony is uncertain. The species has recently gained notoriety in the Pacific Northwest as a predator on young salmon and its management has become highly controversial.

Roby, Daniel D, Collis, K., Lyons, D. E., Lawes, T. J., Suzuki, Y., Loschl, P. J., Bixler, K., & Schniedermeyer, E. (2018). *An evaluation of management to reduce predation on ESA-listed salmonids in the Columbia Plateau region* (p. 29). http://www.birdresearchnw.org/project-info/publications-&-reports/unpublished-reports/

This report marks the fourth year that satellite telemetry was used as a tool to assist with evaluating the response of Caspian terns (Hydroprogne caspia) to management intended to reduce predation on out-migrating salmonid smolts on the Columbia Plateau. The project began in 2014 with the capture and tagging of Caspian terns with solar-powered satellite telemetry tags at Goose Island in Potholes Reservoir. In 2015, we supplemented the sample with additional terns captured and tagged at Crescent Island, in the McNary Reservoir of the Columbia River, and again at Potholes Reservoir. Due to the long lifespan of the satellite tags, we were able to continue our efforts to monitor tern dispersal, foraging site use, and colony connectivity during the 2016 and 2017 breeding seasons without tagging additional individuals. Our objectives during the fourth year of the study were to continue to use satellite telemetry data to evaluate dispersal patterns of Caspian terns displaced through management actions associated with the Inland Avian Predation Management Plan (IAPMP) (USACE 2014), and to identify areas where terns continued to forage on juvenile salmonids in the Columbia Plateau region.

Roby, Daniel D., Collis, K., Lyons, D. E., Suzuki, Y., Loschl, P. J., Lawes, T. J., Bixler, K. S., Piggott, A., Evans, A., Cramer, B., Turecek, A., Payton, Q., Hawbecker, M., & Kuligowski, D. (2016). *Avian Predation on Juvenile Salmonids: Evaluation of the Caspian Tern Management Plan in the Columbia River Estuary, 2015* (p. 46). http://www.birdresearchnw.org/FINAL_2015_BPA_Report.pdf

The primary objective of this study in 2015 was to monitor and evaluate management initiatives implemented to reduce predation on juvenile salmonids (Oncorhynchus spp.) by Caspian terns (Hydroprogne caspia) nesting on East Sand Island in the Columbia River estuary. Specifically, we monitored and evaluated the managed reduction of tern nesting habitat on East Sand Island, which is designed to reduce the size of the Caspian tern breeding colony and, as a consequence, reduce tern predation on ESA-listed juvenile salmonids in the Columbia River estuary. The management plan entitled, Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary was first implemented in 2008, and implementation continued in 2015. As part of this plan, the U.S. Army Corps of Engineers – Portland District (Corps) provided 1.0 acre of suitable nesting habitat for Caspian terns on East Sand Island prior to the 2015 nesting season, a reduction in the area of nesting habitat provided in 2014 (1.55 acres), and a 80% reduction in what was provided for terns on East Sand Island prior to implementation of the management plan. The estimate of Caspian tern colony size on the 1.0-acre core colony area in 2015 was 5,430 breeding pairs (95% c.i. = 5,200 – 5,660 pairs), about 13% smaller than in 2014 (6,270 breeding pairs; 95% c.i. = 5,860 – 6,680 pairs), and nearly a 50% reduction from the peak size of the tern colony on East Sand Island (ca. 10,670 pairs), which occurred in 2008. Despite efforts to limit tern nesting on East Sand Island to the 1.0-acre core colony area using passive dissuasion (stakes, rope, and flagging) and active dissuasion (human hazing), two satellite colonies formed adjacent to the core colony area and supported an additional 810 breeding pairs. As a result, the total number of Caspian terns nesting on East Sand

Island in 2015 (6,240 pairs; 95% c.i. = 6,000 – 6,460 pairs) was about the same as the colony size in 2014 (6,270 pairs), despite the reduction in amount of nesting habitat prepared for terns in 2015 relative to the previous year. Additionally, some Caspian terns attempted to nest on Rice Island in 2015, a dredged material disposal island in the upper Columbia River estuary, where Caspian terns nested prior to relocating the colony to East Sand Island in 2001. In 2015, the average nesting density of Caspian terns in the 1-acre core colony area on East Sand Island was 1.32 nests/m2, an increase from the average nesting density of terns on East Sand Island in 2014 (1.06 nests/m2), and the highest nesting density ever recorded for Caspian terns nesting on East Sand Island. Given the more than 30-year history of Caspian terns nesting in the Columbia River estuary, it is expected that some, perhaps most, terns will initially adapt to reductions in the amount of suitable nesting habitat on East Sand Island by nesting at higher densities and/or attempting to nest in other, sometimes marginal, nesting habitat on East Sand Island (e.g., upland beaches) and elsewhere in the Columbia River estuary (e.g., Rice Island). Efforts to reduce Caspian tern predation on juvenile salmonids to levels stipulated in the management plan will likely require that all Caspian terns nesting in the Columbia River estuary be restricted to just the 1-acre core colony area on East Sand Island, thereby forcing terns displaced from East Sand Island to relocate to alternative colony sites outside the Columbia River Basin. Caspian terns nesting on East Sand Island in 2015 were relatively resilient to disturbances by bald eagles (Haliaeetus leucocephalus) and associated gull (Larus spp.) depredation of tern eggs and chicks, even more so than was the case during 2013-2014. These limiting factors caused the Caspian tern colony on East Sand Island to fail or nearly fail during 2010-2012. In 2015, the East Sand Island Caspian tern colony produced about 3,700 fledglings (average of 0.59 young raised/breeding pair), an increase compared to 2014 (0.28 young raised/breeding pair), and similar to the average productivity during 2000-2014 (0.57 young raised/breeding pair). To assess the efficacy of management implemented to disperse Caspian terns from nest sites within the Columbia River Basin to alternative colony sites outside the Basin, we monitored Caspian tern movements by re-sighting terns previously banded with field-readable leg bands at colonies both inside and outside the Basin. The majority of resighted Caspian terns exhibited site fidelity to the colony on East Sand Island in 2015. There was little movement of Caspian terns banded as adults on East Sand Island to the Corps-constructed alternative colony sites in interior Oregon and northeastern California in 2015; nevertheless, Caspian terns banded as chicks at East Sand Island were observed at all four of the monitored alternative colony sites in 2015. Estimated numbers of Caspian terns that moved from the alternative colony sites to the Columbia River estuary and to the Columbia Plateau region in 2015 were greater than those that moved in the opposite directions, probably due to the severe drought that has negatively affected tern nesting and foraging habitat in interior Oregon and northeastern California during 2014-2015. The average proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during the 2015 nesting season was 38% (percent of identified prey items), higher than the average during the previous 15 years (31%), and corresponding to a somewhat lower than average proportion of northern anchovy (Engraulis mordax) in the tern diet. The estimated total smolt consumption by Caspian terns nesting at East Sand Island in 2015 was 5.2 million smolts (95% c.i. = 4.6 – 5.9 million smolts), not significantly different from the average annual smolt consumption during 2000–2014, but significantly lower than annual smolt consumption when the Caspian tern colony was located on Rice Island in the upper estuary. Consumption of sub-yearling Chinook salmon by East Sand Island Caspian terns in June and July was significantly higher in 2015 than in 2014, presumably due to reduced availability of alternative prey such as northern anchovy. To further reduce predation rates by Caspian terns nesting at East Sand Island on salmonid smolts in the Columbia River estuary, more Caspian terns will need to be relocated to colonies outside the estuary. Based on the size of the East Sand Island colony in 2015 (6,240 breeding pairs) relative to the target colony size stipulated in the Management Plan (3,125 - 4,375 breeding pairs), an additional 1,900-3,100 breeding pairs will need to be relocated outside the estuary. This will likely require an increased effort to prevent Caspian terns from nesting outside the designated 1-acre core colony area on East Sand Island. In addition, either nesting density within the 1-acre core colony area on East Sand Island will need to decline from the record density observed in 2015 or the core colony area will need to be reduced to less than 1 acre of nesting habitat, or both, in order to meet the management goal for colony size stipulated in the Plan.

Roby, Daniel D., Collis, K., Lyons, D., Lawes, T., Suzuki, Y., Loschl, P., Bixler, K., Hanwacker, E., Mulligan, J., Munes, A., Schniedermeyer, E., Evans, A., Cramer, B., Turecek, A., Payton, Q., & Hawbecker, M. (2016). *Evaluation of Foraging Behavior, Dispersal, and Predation on ESA-listed Salmonids by Caspian Terns Displaced from Managed Colonies in the Columbia Plateau Region* (p. 121). http://www.birdresearchnw.org/FINAL_2015_GPUD_Report.pdf

The primary objective of this study in 2015 was to monitor and evaluate management initiatives implemented to reduce predation on U.S. Endangered Species Act (ESA)-listed populations of salmonids (Oncorhynchus spp.) by Caspian terns (Hydroprogne caspia) nesting on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River. Specifically, this study was designed to evaluate dispersal of Caspian terns dissuaded from nesting on Goose and Crescent islands and changes in Caspian tern predation rates (number consumed/number available) on juvenile salmonids as a consequence of management. In January 2014, the U.S. Army Corps of Engineers – Walla Walla District (Corps) completed the Inland Avian Predation Management Plan (IAPMP). The goal of the IAPMP is to reduce Caspian tern predation rates on ESA-listed salmonids from the Columbia River Basin to less than 2% (per colony and per ESA-listed population) by redistributing Caspian terns from the two largest colony sites in the Columbia Plateau region (i.e. colonies on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River) to sites outside the Columbia River Basin. In 2015, the Corps and the U.S. Bureau of Reclamation (BOR) implemented Phase II of the IAPMP by installing a variety of “passive nest dissuasion” materials prior to the 2015 nesting season that were designed to prevent Caspian terns from nesting on either island. An effort was also made to prevent nesting by the two species of gulls that nest abundantly on both islands (California gulls [L. californicus] and ring-billed gulls [L. delawarensis]), on the theory that nesting gulls would attract prospecting Caspian terns and could limit the efficacy of efforts to dissuade Caspian terns from nesting on the two islands. Once Caspian terns and gulls arrived on Goose and Crescent islands to initiate nesting, active nest dissuasion (i.e. human hazing) was used in an attempt to dissuade both Caspian terns and gulls from nesting anywhere on either island. Despite the lack of suitable Caspian tern nesting habitat on Goose Island in 2015, some Caspian terns displayed persistent fidelity to the Pothole Reservoir area throughout the nesting season, likely due to the history of Caspian tern nesting on Goose Island since 2004 and the presence of a large breeding colony of gulls on the island that continued to attract prospecting Caspian terns to the site. Another factor that might explain the strong site fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. Caspian tern use of Goose Island for roosting and nesting during 2015 was largely limited to areas near the shoreline where passive nest dissuasion had not been installed. Active nest dissuasion (hazing), collection of any Caspian tern eggs that were discovered, and high rates of gull predation on newly-laid Caspian tern eggs were successful in preventing the formation of a Caspian tern colony on Goose Island in 2015. A total of 43 Caspian tern eggs were found on Goose Island and nearby islets in 2015, and these eggs were laid in 39 different nest scrapes. Seventeen Caspian tern eggs were collected under permit, 23 tern eggs were depredated by gulls soon after they were laid, and three tern eggs ultimately produced chicks. In the end, only two pairs of Caspian terns nesting in separate areas of the island succeeded in hatching eggs and raising young on Goose Island and nearby islets in 2015. Passive and active nest dissuasion techniques were successful in preventing nesting and roosting by both Caspian terns and gulls on Crescent Island in 2015. This result was somewhat unexpected because it was the first year that nest dissuasion was implemented at Crescent Island and because Caspian terns and gulls have nested consistently on Crescent Island for nearly three decades. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the use of closely-spaced fence rows of privacy fabric as passive dissuasion over much of the suitable Caspian tern nesting habitat on Crescent Island; similar fencing was not deployed at Goose Island due to shallow, rocky soils. Another factor was the successful dissuasion of all gulls from nesting on Crescent Island in 2015; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to our hazing techniques and abandoned Crescent Island to establish a new colony on Badger Island (located on the mid-Columbia River just one kilometer upstream from Crescent Island) in 2015. Similarly, Caspian terns displaced from Crescent Island were able to relocate to an alternative colony site on the mid-Columbia River, the Blalock Islands (70 river kilometers downriver from Crescent Island), where Caspian terns have nested in small numbers over the last decade. The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2015 was 769 breeding pairs at five separate colonies (i.e. the Blalock Islands on the mid-Columbia River [677 breeding pairs], Twinning Island in Banks Lake [64 breeding pairs], Harper Island in Sprague Lake [10 breeding pairs], an unnamed island in Lenore Lake [16 breeding pairs], and Goose Island in Potholes Reservoir [2 breeding pairs]). The estimated total size of the breeding population of Caspian terns in the Columbia Plateau region in 2015 was similar to the estimated population size in 2014 (755 breeding pairs), but still generally lower than the numbers observed during 2000-2013. These results suggest that although nest dissuasion actions implemented on Goose and Crescent islands in 2015 were highly effective in reducing the numbers of Caspian terns nesting at these two colonies, formerly the largest Caspian tern colonies in the region, they did not result in a significant reduction in the total number of Caspian terns breeding in the region to date. This was due to the more than 10-fold increase in the number of Caspian tern nesting in the Blalock Islands in 2015 compared to 2014. The Blalock Islands colony in 2015 was similar in size to the largest Caspian tern colony recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2000. Juvenile salmonids made up 67.3% of the diet of Caspian terns nesting on the Blalock Islands in 2015; this is consistent with results from previous years for Caspian terns nesting at Crescent Island. However, a larger proportion of the salmonids in the Blalock Islands tern diet were steelhead (34%) compared to the tern diet at Crescent Island. We estimated that Caspian terns nesting on the Blalock Islands consumed ca. 550,000 juvenile salmonids in 2015 (95% CI = 310,000 – 800,000), including ca. 240,000 steelhead (95% CI = 130,000 – 350,000). Steelhead consumption by terns nesting at the Blalock

Islands colony in 2015 was likely greater than at either Crescent Island or Goose Island in any previous year for which results are available. After two years of implementation of the IAPMP, satellite-tracking of tagged Caspian terns has indicated several broad categories of response to management: (1) stay and search or compete for nest sites in reduced habitat, (2) move to a nearby colony and attempt to nest there, returning to the colony of origin if nesting fails, (3) engage in a long distance dispersal to a more favorable colony, or (4) wander nomadically across the Columbia Plateau region or a much larger area. Terns tagged at Potholes Reservoir in 2014 or 2015 have generally stayed nearby and searched for nesting habitat, moved to nearby colonies (Banks Lake, Sprague Lake) and returned to Potholes Reservoir when those colonies failed, or wandered nomadically, often across large portions of Washington, Oregon, and northeastern California. Terns tagged at Crescent Island in 2015 primarily moved to a nearby colony (the Blalock Islands), but a few individuals exhibited long distance dispersal to the Columbia River estuary. In 2015, several tagged terns visited constructed islands in interior Oregon and northeastern California, and a few of these visits were sustained and suggested possible nesting attempts. We did not detect any movement of satellite-tagged terns to the newly constructed tern islands at Don Edwards NWR in the San Francisco Bay area during 2015. Drought across the Pacific Northwest likely limited dispersal of Caspian terns from the Columbia Plateau region to the islands constructed in interior Oregon and northeastern California. Low flows in the Columbia River led to greater availability of nesting habitat at the Blalock Islands due to exposure of low-lying islands that terns nested on there. Low winter snowpack in interior Oregon and northeastern California resulted in low water levels and limited nesting and foraging habitat, particularly at Crump Lake in the Warner Valley and Malheur Lake in the Harney Basin. Expected relaxation of regional drought conditions in 2016 may make colony locations outside of the Columbia River Basin more attractive as nesting locations to prospecting terns displaced from the Columbia Plateau region by management. Resightings of Caspian terns that were previously color-banded indicated that some terns exhibited site fidelity to the Potholes Reservoir area, while the Blalock Islands experienced a large influx of terns from the Crescent Island colony in 2015. Evaluation of inter-regional movements of Caspian terns in 2015 revealed net movements to the Columbia Plateau region from the managed colony at East Sand Island in the Columbia River estuary, as well as from the Corps-constructed alternative colony sites in interior Oregon and northeastern California; the latter two regions experienced severe drought in 2015. Recoveries of passive integrated transponder (PIT) tags on Caspian tern colonies were used to estimate predation rates (percentage of tagged fish consumed by terns) to evaluate the efficacy of tern management initiatives to increase smolt survival in the region. PIT tag data were also used to evaluate smolt consumption rates by other piscivorous colonial waterbirds (e.g., California gulls, ring-billed gulls, American white pelicans [Pelecanus erythrorhynchos], double-crested cormorants [Phalacrocorax auritus]) on juvenile salmonids. Results indicate that management efforts to reduce the size of the Goose Island and Crescent Island Caspian tern colonies were successful in nearly eliminating predation by terns from these two colonies in 2015, with predicted Caspian tern predation rates ranging from < 0.1% to 1.5% (depending on the ESA-listed salmonid population) at Goose Island and < 0.1% (for all salmonid populations) at Crescent Island. This likely was the first time since the Crescent Island colony of Caspian terns formed in 1986 when no salmonid smolts were consumed by Caspian terns nesting on Crescent Island. Predation rates on juvenile salmonids by Caspian terns nesting on Goose Island were lower in 2015 than in 2014 (< 1% to 2.9%), the first year of tern management, and significantly lower than predation rates observed during 2007-2013, prior to tern management.

For instance, predation rates by Goose Island terns on ESA-listed Upper Columbia River spring Chinook salmon and steelhead averaged 2.5% and 15.7%, respectively, during 2007-2013. Despite a dramatic reduction in predation rates on smolts by Caspian terns nesting on Goose and Crescent islands in 2015, a significant increase in predation rates was observed for Caspian terns nesting at the Blalock Islands (John Day Reservoir) and at Twinning Island (Banks Lake), colonies where terns dissuaded from Goose and Crescent islands relocated following the implementation of management actions in 2015. Predation rates were highest on steelhead, with an estimated 8.2% (95% CI = 5.9–12.4%) of Upper Columbia River steelhead consumed by Blalock Islands terns and 2.6% (95% CI = 1.8–3.9%) of Upper Columbia River steelhead consumed by Twinning Island terns in 2015. These predation rates exceeded the IAPMP target goal of < 2% per ESA-listed salmonid population for these two tern colony sites. Predation rates by Caspian terns nesting at the Blalock Islands were also substantial for Snake River steelhead, with an estimated 8.0% (95% CI = 6.0–11.8%) consumed by terns in 2015, the highest predation rate on Snake River steelhead recorded for any Caspian tern colony in the Columbia Plateau region since 2007. Predation rates on salmon populations were significantly lower than those on steelhead populations, with predation rates of < 2.0% for all ESA-listed salmon populations evaluated in 2015. Predation rates by Caspian terns nesting at all colonies in the Columbia Plateau region combined during 2015 were similar to or higher than those observed in previous years due to the large and unprecedented number of Caspian terns (677 breeding pairs) that nested at the Blalock Islands in 2015. Estimates of consumption rates of juvenile salmonids by gulls nesting at certain colonies in the Columbia Plateau region were also substantial in 2015, particularly consumption by California gulls nesting on Miller Rocks (The Dalles Reservoir), Island 20 (McNary Reservoir), and the Blalock Islands. Similar to predation on smolts by Caspian terns, consumption rates by gulls were generally highest on steelhead populations relative to salmon populations, with the highest consumption rates observed on Upper Columbia River steelhead by gulls nesting on Miller Rocks (13.2%; 95% CI = 8.3–21.1%), Island 20 (7.9%; 95% CI = 5.2–12.0%), and the Blalock Islands (6.1%; 95% CI = 3.4–10.5%). Gull consumption rates of Snake River steelhead were also substantial (9.7% by gulls nesting on Miller Rocks), but lower than rates observed for Upper Columbia River steelhead in 2015. Consumption rates of salmon populations by gulls nesting at colonies in the Columbia Plateau region were generally < 2.0%, with the exception of consumption of Upper Columbia River spring Chinook salmon (3.5%; 95% CI = 2.1–6.0%) and Snake River sockeye salmon (7.4%; 95% CI = 4.1–13.1%) by gulls nesting on Miller Rocks. Consumption rates by gulls from colonies in the Columbia Plateau region during 2015 were significantly higher than those observed at the same gull colonies in previous years, with a roughly 2- to 5-fold increase observed at some gull colonies in 2015. Further research is needed to better understand the mechanisms that influence fish susceptibility to consumption by gulls and why consumption rates were significantly higher in 2015, a year of reduced river flows and increased water temperatures, compared with previous years. Regardless of the reasons, smolt consumption rates associated with certain gull colonies were comparable to or higher than predation rates associated with Caspian tern colonies in 2015, and were some of the highest consumption rates associated with any piscivorous waterbird colony in the Columbia Plateau region since 2007. Predation by American white pelicans nesting at the Badger Island colony was, however, low (< 1.0% per ESA-listed salmonid population), indicating that pelicans nesting at this colony posed little risk to smolt survival in 2015. To better understand the spatial and temporal distribution of smolt consumption by piscivorous colonial waterbirds in the middle Columbia River (i.e. from the tailrace of Rock Island Dam to just upstream of the confluence with the Snake River), detections/recoveries of acoustic tags and PIT tags implanted in juvenile steelhead and sockeye salmon (i.e. double-tagged smolts) were used to evaluate predation rates, specifically within the Priest Rapids Project. Results were based on last known detections of live fish passing telemetry arrays, coupled with the recovery of PIT tags from these fish on nearby bird colonies. Results indicate that an estimated 2.7% (95% CI = 1.7–4.4%) and 2.3% (95% CI = 0.2–4.7%) of tagged steelhead were consumed by Caspian terns within the Wanapum and Priest Rapids developments, respectively. Predation rates in 2015 were significantly lower than those observed prior to implementation of the IAPMP (4.0–10.1% per development, depending on the year). Avian predation rates on double-tagged sockeye salmon in 2015 (the only year analyzed) were estimated at 1.2% (95% CI = 0.5–2.3%) and 0.7% (95 CI = 0.1–1.6%) in the Wanapum and Priest Rapids developments, respectively, indicating that avian predators posed little risk to tagged sockeye smolts traveling through the middle Columbia River in 2015. Reductions in the number of Caspian terns nesting within foraging distance of the Priest Rapids Project is likely a contributing factor to recent improvements in survival of juvenile salmonids, particularly survival of steelhead, in the middle Columbia River.

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The primary objective of this study in 2016 was to monitor and evaluate management initiatives implemented to reduce predation on U.S. Endangered Species Act (ESA)-listed populations of salmonids (Oncorhynchus spp.) by Caspian terns (Hydroprogne caspia) nesting on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River. Specifically, this study was designed to evaluate dispersal of Caspian terns dissuaded from nesting on Goose and Crescent islands and changes in Caspian tern predation rates (number consumed/number available) on juvenile salmonids associated with management. In January 2014, the U.S. Army Corps of Engineers – Walla Walla District (Corps) completed the Inland Avian Predation Management Plan (IAPMP). The goal of the IAPMP is to reduce Caspian tern predation rates on ESA-listed salmonids from the Columbia River basin to less than 2% (per colony and per ESA-listed salmonid population) by redistributing Caspian terns from the two largest colony sites in the Columbia Plateau region (i.e. colonies on Goose Island in Potholes Reservoir and on Crescent Island in McNary Reservoir) to sites outside the Columbia River basin. During 2014-2016, the Corps and the U.S. Bureau of Reclamation (BOR) implemented the IAPMP by installing a variety of "passive nest dissuasion" materials prior to the nesting seasons that were designed to prevent Caspian terns from nesting on either island. An effort was also made to prevent nesting by the two species of gulls that nest abundantly on both islands (California gulls [Larus californicus] and ring-billed gulls [L. delawarensis]), on the theory that nesting gulls would attract prospecting Caspian terns and could limit the efficacy of efforts to dissuade Caspian terns from nesting on the two islands. Once Caspian terns and gulls arrived on Goose and Crescent islands to initiate nesting, active nest dissuasion (i.e. human hazing) was used to dissuade both Caspian terns and gulls from nesting anywhere on either island. Despite the lack of suitable Caspian tern nesting habitat on Goose Island in 2016, some Caspian terns displayed persistent fidelity to the Potholes Reservoir area throughout the nesting season, likely due to the history of Caspian tern nesting on Goose Island since 2004 and the presence of a large breeding colony of gulls on the island that continued to attract prospecting Caspian terns to the site. Another factor that might explain the strong site fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. Caspian tern use of Goose Island for roosting and nesting during 2016 was largely limited to areas near the shoreline where passive nest dissuasion had not been installed. A total of six Caspian tern eggs were found on Goose Island in 2016; all six were either depredated by gulls or collected by researchers under permit. In comparison, 43 Caspian tern eggs were discovered on Goose Island and surrounding islets in 2015. For the second year in a row, active nest dissuasion (hazing), collection of any Caspian tern eggs that were discovered, and high rates of gull predation on newly-laid Caspian tern eggs were effective in greatly reducing (2015) or eliminating (2016) successful nesting attempts (i.e. fledged young) by Caspian terns on Goose Island. As was the case in 2015, passive and active nest dissuasion techniques were successful in preventing all nesting and roosting by both Caspian terns and gulls on Crescent Island in 2016. One factor that likely contributed to the absence of nesting Caspian terns, and the lower site fidelity by terns at Crescent Island as compared to Goose Island, was the types of passive dissuasion used on the Crescent Island (i.e. fencing, rope, flagging, and native vegetation planted prior to the 2016 breeding season), which virtually eliminated all the open habitat that terns prefer for nesting on the island. Another factor was the successful dissuasion of all gulls from nesting on Crescent Island in both 2015 and 2016; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to our hazing techniques and abandoned Crescent Island to establish a new colony on Badger Island (located on the mid-Columbia River just one kilometer upstream from Crescent Island) during 2015-2016. Similarly, Caspian terns displaced from Crescent Island could relocate to an alternative colony site on the mid-Columbia River, the Blalock Islands (70 river kilometers downriver from Crescent Island), where small numbers of Caspian terns have nested over the last decade. The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2016 was 675 breeding pairs at five separate colonies, four extant colonies (i.e. the Blalock Islands in John Day Reservoir [483 breeding pairs], Twinning Island in Banks Lake [6 pairs], Harper Island in Sprague Lake [3 pairs], an unnamed island in Lenore Lake [39 pairs]) and one incipient colony on an unnamed island in northeastern Portholes Reservoir (144 pairs). This represented a 23% decline in the total number of Caspian terns nesting in the Columbia Plateau region in 2016 compared to the pre-management average of 873 breeding pairs during 2005- 2013, and was the smallest regional population size observed since Caspian tern monitoring began in 2005. These results suggest that although nest dissuasion actions implemented on Goose and Crescent islands in 2016 were highly effective in eliminating nesting at these two colonies, formerly the two largest Caspian tern colonies in the region where a total of 733 breeding pairs nested in 2013, it did not result in a commensurate decline in the regional population of nesting Caspian terns. This was due to the recent large increase in the size of the tern colony at the Blalock Islands, as well as the incipient colony that formed in northeastern Potholes Reservoir; the growth of these colonies was mostly attributable to terns that formerly nested at Goose and Crescent islands. Juvenile salmonids made up 43.7% of the diet of Caspian terns nesting on the Blalock Islands in 2016; this is substantially lower than the comparable figure from 2015 (66.2%) and in comparison to previous years when terns nested at Crescent Island. The lower than expected proportion of salmonids in the diet of Blalock Islands Caspian terns may have been due to the unusually early outmigration timing for many salmonid populations in 2016. A large proportion of the salmonids in the diet of Caspian terns nesting at the Blalock Islands were steelhead (24%), which was lower than in 2015 (34%), but comparable to the highest values observed in the diet of terns nesting at Crescent Island in previous years. We estimated that Caspian terns nesting on the Blalock Islands consumed ca. 420,000 juvenile salmonids in 2016 (95% c.i. = 230,000 – 610,000), including ca. 140,000 steelhead (95% c.i. = 73,000 – 210,000). After three years of implementation of the IAPMP, satellite-tracking of tagged Caspian terns has continued to indicate several broad categories of response to management: (1) stay and search or compete for nest sites in much reduced nesting habitat, (2) move to a relatively nearby colony and attempt to nest there, returning to the colony of origin or nearby if nesting fails, (3) engage in long distance dispersal to a more favorable colony site, or (4) wander nomadically across the Columbia Plateau region or a much larger area. Terns tagged at Potholes Reservoir have generally stayed nearby and searched for alternative nesting habitat, moved to nearby colonies (i.e. northeastern Potholes Reservoir in 2016) and returned to Goose Island when those colonies failed, or have wandered nomadically, often across large portions of Washington, Oregon, and California. Terns tagged at Crescent Island have primarily moved to a nearby colony located at the Blalock Islands in John Day Reservoir or exhibited long distance dispersal to the Columbia River estuary. In 2016, however, we saw late season movements back to McNary Reservoir to roost overnight at Badger Island, just upstream of Crescent Island. Also in 2016, very few tagged terns visited USACE-constructed islands in southern Oregon and northeastern California, and none demonstrated sustained visits suggestive of possible nesting attempts, possibly due to a lag effect in the recovery of forage fish following long-term drought in the area. We also saw tagged terns using the San Francisco Bay area in 2016, but did not observe any sustained associations with the restored colonies at the USACE-constructed tern islands at Don Edwards National Wildlife Refuge in the San Francisco Bay area. Several measures of foraging activity within the Priest Rapids Project by satellite-tagged Caspian terns suggested that incremental reductions in predation on juvenile salmonids are resulting from management actions under the IAPMP: (1) The proportion of tagged Caspian terns that used the river reaches above Richland, WA, during the smolt outmigration was lower than during the previous two years; (2) 50% or less of active terns tagged at Potholes Reservoir and < 5% of those tagged at Crescent Island were detected in the Priest Rapids Project or the Hanford Reach in 2016; and (3) the Priest Rapids Reservoir continued to be used by a subset of the tagged terns, but only the Hanford Reach was identified as a core day use area during 2016. These results suggest that many displaced terns have continued to shift their foraging away from the Priest Rapids Project, but the non-breeding terns that remained on the Columbia Plateau region still constituted a significant presence in the Project during 2016. Satellite telemetry remained a useful tool for documenting the response of Caspian terns to management at colonies in the Columbia Plateau region in 2016, helping to identify patterns of breeding dispersal, the distribution of core foraging areas, and previously unknown locations where nesting attempts occurred in 2016, or may occur in the future. Data from satellite-tagged terns documented the continued presence, movements, and distribution of nonbreeding terns within the Columbia Plateau region. These data would not otherwise have been available as ground monitoring and aerial surveys are insufficient to detect and track displaced terns not associated with a breeding colony. Tracking satellite-tagged terns continued to facilitate the detection of loafing and roosting sites where smolt PIT tag recovery efforts could be concentrated, and for documenting that non-breeding individuals were still contributing to mortality of juvenile salmonids in the study area. Caspian terns are a long-lived species, and results from the third year of the tagging study suggest that the terns displaced from Goose Island and Crescent Island display behavioral inertia. As such, reductions to the impacts of tern predation on smolt survival in the Priest Rapids Project and throughout the Columbia Plateau region are likely to proceed in gradual, incremental steps. Vigilance will be required to prevent further formation of incipient colonies and a pool of non-breeding terns is likely to remain on the Columbia Plateau region for some time following reductions in breeding habitat through management actions. Resightings of Caspian terns that were previously color-banded indicated that some terns continued to exhibit site fidelity to the Potholes Reservoir area, while the Blalock Islands experienced a large influx of terns from the Crescent Island colony during 2015-2016. Evaluation of inter-regional movements in 2016 revealed that a high number of Caspian terns moved to the Columbia Plateau region from the Corps-constructed tern islands in southern Oregon and northeastern California (SONEC); the latter region experienced lingering effects of severe drought in 2016. Predation rates (percentage of available tagged fish that were consumed) by Caspian terns nesting at colonies in the Columbia Plateau region were used to evaluate the efficacy of tern management initiatives to increase smolt survival in the region. Recoveries of tagged smolts on bird colonies were also used to estimate consumption rates by other piscivorous colonial waterbirds (e.g., California gulls, ring-billed gulls, and American white pelicans). Like results during 2014-2015, predation rates in 2016 indicated that management efforts to reduce the size of the Goose Island and Crescent Island Caspian tern colonies were successful in eliminating or nearly eliminating predation by terns from these two colonies, with estimated Caspian tern predation rates of less than 0.2% for all ESA-listed salmonid populations evaluated, per colony, in 2016. Predation rates at these two colonies in 2016 were significantly lower than predation rates observed during 2007-2013, prior to tern management. For example, predation rates by Goose Island terns on ESA-listed Upper Columbia River steelhead averaged 15.7% (95% CI = 14.1 – 18.9%) during 2007-2013 and predation rates by Crescent Island terns on ESA-listed Snake River steelhead averaged 3.9% (95% CI = 3.5 – 4.6%) during 2007-2014. Despite the dramatic reduction in predation rates on smolts due to the virtual absence of Caspian terns nesting on Goose and Crescent islands, increases in predation rates were observed for Caspian terns nesting at some unmanaged sites, like results reported in 2015. This was particularly true for Caspian terns nesting at the Blalock Islands (John Day Reservoir) and in northeastern Potholes Reservoir. Predation rates were higher on steelhead populations compared to salmon populations, with an estimated 3.9% (95% CI = 2.9 – 5.7%) of Snake River steelhead consumed by Blalock Islands terns and 4.1% (95% CI = 2.9 – 6.3%) of Upper Columbia River steelhead consumed by terns nesting in northeastern Potholes Reservoir in 2016. Predation rates by Blalock Islands terns were also elevated on Snake River sockeye salmon, with an estimated 2.3% (95% CI = 1.2 – 4.1%) of available fish consumed in 2016. These predation rates exceeded the IAPMP target goal of < 2% per ESA-listed salmonid population, per colony. Predation rates by Caspian terns nesting at two other unmanaged colonies in the Columbia Plateau region (Twinning Island in Banks Lake and Lenore Lake) during 2016 were < 1.0% per ESA-listed salmonid population, per colony. Estimates of consumption rates of juvenile salmonids by gulls nesting at certain colonies in the Columbia Plateau region were substantial in 2016. Consumption rates for gulls nesting on Miller Rocks (The Dalles Reservoir) were the highest of any bird colony evaluated as part this study, with consumption rates of 6.4% (95% CI = 2.9 – 12.8%), 6.7% (95% CI = 4.6 – 9.9%), and 10.1% (95% CI = 7.0 – 15.2%) for Snake River sockeye salmon, Snake River steelhead, and Upper

Columbia River steelhead, respectively, in 2016. Consumption rates by gulls nesting on Anvil Island in the Blalock Islands (John Day Reservoir), Badger Island (McNary Reservoir), and Island 20 (middle Columbia River) were also highest on steelhead populations (generally > 3.0% per steelhead DPSs evaluated). Like results from Caspian terns, consumption rates of salmon populations by gulls were generally < 1.0% per salmonid population, except for Snake River sockeye. Gull consumption rates of Snake River sockeye salmon were higher than for other salmon ESUs (e.g., Snake River spring/summer Chinook salmon), and higher in 2016 when compared with predation rates observed in previous years. Further research is needed to better understand the mechanisms that influence fish susceptibility to consumption by gulls, specifically whether gulls are disproportionately consuming weak or compromised smolts, especially near dams. Regardless of the reasons, smolt consumption rates associated with certain gull colonies were comparable to or higher than those associated with Caspian tern colonies, and have continued to be some of the highest consumption rates associated with any piscivorous waterbird colony in the Columbia Plateau region since multi-predator species studies were initiated in 2007. Minimum estimates of predation by American white pelicans nesting at the Badger Island colony were low (< 1.0% per ESA-listed salmonid population), indicating that pelicans nesting at this colony posed little risk to large aggregates of PIT-tagged smolts migrating through the mainstem Columbia River. Additional research is needed, however, to quantify PIT tag deposition probabilities in white pelicans and to evaluate impacts on specific stocks or groups of fish, which may be warranted. An analysis of spatially- and temporally-explicit steelhead consumption rates by piscivorous colonial waterbirds within the Priest Rapids Project, data derived from acoustic-tagged smolts, estimated that 1.8% (95% CI = 0.9 – 3.3%) and 2.0% (95% CI = 1.0 – 3.9%) of steelhead were consumed by Caspian terns within the Wanapum and Priest Rapids developments, respectively. Predation rates in 2016 were like those is 2014 and 2015, but significantly lower than those observed prior to implementation of the IAPMP (4.0 – 10.1% per development, depending on year). Reductions in the number of Caspian terns nesting within foraging distance of the Project is likely a key contributing factor to recent improvements in steelhead survival in the middle Columbia River. Improvements in survival within the middle Columbia River, however, were offset by increased predation rates by some gull colonies and Caspian tern colonies nesting further downstream. An investigation of cumulative predation rates (predation from all bird colonies combined on smolts traveling between Rock Island and Bonneville dams) estimated that 30.1% (95% CI = 26.5 – 38.5%) of steelhead were depredated by colonial waterbirds in 2016. Results suggest that management efforts aimed at decreasing colonial waterbird predation must be implemented at a larger, system-wide scale to achieve management goals in the future.

Roby, Daniel D, Lyons, D. E., Collis, K., & Lawes, T. J. (2019). *Evaluating colony displacement as a method to reduce Caspian tern predation on juvenile salmonids in the Columbia Plateau region* (p. 38). http://www.birdresearchnw.org/project-info/publications-&-reports/unpublished-reports/

The Inland Avian Predation Management Plan (IAPMP) was developed to reduce the mortality of ESAlisted anadromous salmonid smolts, especially steelhead trout, due to predation by piscivorous colonial waterbirds nesting in the Columbia Plateau region. Implementation of the IAPMP was successful in preventing Caspian terns from nesting at the two largest breeding colonies of terns in the Columbia Plateau region: Goose Island in Potholes Reservoir and Crescent Island in McNary Reservoir on the Columbia River. Our study was designed to track the movements and habitat use of adult Caspian terns that formerly nested at these two colonies as part of a comprehensive effort to assess the efficacy of the IAPMP in reducing the numbers of Caspian terns nesting and foraging in the Columbia Plateau region. We captured adult Caspian terns prior to the 2014 and 2015 breeding season at the Goose Island and Crescent Island colonies, tagged them with Platform Transmitting Terminal (PTT) tags, and tracked their subsequent movements using the ARGOS satellite telemetry system. Terns were tagged immediately before or shortly after the initiation of management to prevent Caspian terns from nesting at the two managed colonies. In total, 76 adult terns were tagged and tracked for an average of 705 days postrelease, with tracking of some tagged terns continuing for more than four breeding season following tag deployment. Data on tagged tern locations during the steelhead smolt out-migration period (April-June) were analyzed using Kernel Density Estimation (KDE) in order to identify sites and areas where tagged terns concentrated for foraging and nesting in the Columbia Plateau region. We also used Akaike Information Criterion (AICc) model selection to identify those factors that best explained variation in tern foraging habitat use, nest site use, and dispersal of tagged individuals. The a priori explanatory variables used in model selection were: (1) colony where tern captured, (2) year when tern captured, (3) sex, (4) number of years since management initiated, (5) starting date of the steelhead smolt outmigration period, (6) duration of the steelhead smolt out-migration period, and (7) the interaction between starting date and duration of the steelhead smolt out-migration period. PTT-tagged Caspian terns exhibited stronger philopatry (foraging and nest site fidelity) to the Columbia Plateau region than anticipated for a species that is known to engage in long-distance dispersal from breeding sites. The majority of terns with actively transmitting tags were detected in the Columbia Plateau region during the peak of the steelhead smolt out-migration, even in the fourth breeding season following initiation of management that successfully prevented nesting at the Goose Island and Crescent Island colonies. During the fourth breeding season after initiation of management under IAPMP, 68.1% of detected locations of tagged terns were still in the Columbia Plateau region, and 36.3% of detected locations on the Plateau were at former or existing breeding colonies for the species. Of the 16 tagged terns that were tracked during their fourth nesting season after tagging, 14 (87.5%) spent most of the season in the Columbia Plateau region. AICc model selection indicated that there was differential use of foraging areas by tagged terns depending on whether the tern was tagged at the Goose Island or Crescent Island colony; terns tagged at Goose Island foraged mainly along the Columbia River above the confluence with the Snake River, and terns tagged at Crescent Island foraged mainly below the confluence. However, the KDE analyses indicated that, overall, tagged terns concentrated at many of the same foraging, loafing, and nesting sites in the Columbia Plateau region throughout the 5-year study (2014-2018). Nevertheless, the proportion of terns tagged at the Goose Island colony that subsequently foraged along the Columbia River above the confluence with the Snake River declined steadily and significantly following 3 implementation of the IAPMP, supporting the conclusion that successfully dissuading terns from nesting at Goose Island provided benefits to smolt survival in that stretch of the Columbia River. On the other hand, the proportion of tagged terns that foraged along the Columbia River below the confluence with the Snake River did not decline significantly during the management period (2015-2018), because many Caspian terns that formerly nested at the Crescent Island colony in McNary Reservoir (Rkm 510) shifted to the colony at the Blalock Islands in John Day Reservoir (Rkm 440) and continued to forage along that stretch of the Columbia River. Following successful elimination of the Crescent Island tern colony, there was little foraging use of the lower Snake River by tagged Caspian terns. The above-mentioned slow pace of dispersal from the Columbia Plateau region by tagged Caspian

terns that formerly nested at the two largest colonies in the region indicates that most displaced terns persisted in prospecting for alternative nest sites within the region. Although tagged terns made many apparent exploratory trips both within and outside the Columbia Plateau region, most terns that ventured away from the region during the nesting season returned to the region instead of permanently emigrating. This behavior has two implications: (1) tagged terns were unsuccessful in locating suitable alternative nesting habitat outside the Columbia Plateau region and/or (2) available alternative nesting habitat in the Columbia Plateau region, although less suitable than the former colony sites on Goose and Crescent islands, offered more favorable conditions for nesting and foraging than sites outside the region. Our results suggest that to achieve the IAPMP goal of no more than 200 breeding pairs of Caspian terns nesting throughout the Columbia Plateau region, (1) more than four years will be required for terns that formerly nested at the Crescent Island and Goose Island colonies to identify and disperse to alternative breeding colonies outside the region, (2) additional quality nesting habitat for terns may need to be provided outside the Columbia Plateau region, perhaps at or near former colony sites along the Washington coast, and (3) adaptive management will be needed to dissuade Caspian terns from nesting at colony sites in the Columbia Plateau region where more than 40 breeding pairs currently nest and predation rates on some stocks of juvenile salmonids are above the 2% threshold identified in the IAPMP, in particular at the Caspian tern colony in the Blalock Islands in John Day Reservoir.

Roby, Daniel D, Lyons, D. E., Collis, K., & Patterson, A. (2019). *Using dispersing individuals and network analyses to assess the colony network of Caspian terns in the Pacific Flyway* (p. 18). http://www.birdresearchnw.org/project-info/publications-&-reports/unpublished-reports/
Seabirds and other colonial waterbirds nest in a variety of settings, including both pelagic islands offering stable habitat conditions and few predators, and coastal islands or mainland settings where habitat can be ephemeral and predators (e.g., terrestrial mammals) may have ready access. These ecological conditions presumably dictate selection pressures that drive breeding site philopatry and capacity for dispersal. In this study, we used a robust, multi-year tracking dataset to explore the dispersal capacity and colony network structure of Caspian terns (Hydroprogne caspia) in the Pacific Flyway of North America. We found that Caspian terns have the capacity to visit a significant portion (mean = 17%) of colonies in this extensive Flyway each year, traveling > 3,500 km/year to do so across annual individual networks spanning an average of > 300,000 km2. Mapping the linkages between colonies in a variety of ways – both geographically and in various types of ‘network space’ allows assessment of network structure based on geographic proximity and other factors. At the scale of the entire Pacific Flyway (south-central Alaska to southern California), distance was related to measures of network connectivity for individual colonies. If the spatially distant colonies in Alaska are removed from the analysis of network connectivity, distance is no longer a significant effect. Thus, we conclude that dispersal between colonies in Washington, Oregon, and California is well within the capacity of Caspian terns. Through our analyses, we identified a subset of colonies that facilitate connectivity between regions. Maintaining active colonies outside the Columbia River basin that are particularly well linked to colonies in the Columbia Plateau region, such as those on the Everett, Washington waterfront, in Arcata Bay and the Salton Sea of California, would likely facilitate greater dispersal away from the Plateau region and support efforts to reduce Caspian tern predation on juvenile salmonids (Oncorhynchus spp.) there.

Roby, Daniel D, Lyons, D. E., Craig, D. P., Collis, K., & Visser, G. H. (2003). Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. *Canadian Journal of Zoology*, *81*(2), 250–265. https://doi.org/10.1139/Z02-242

We estimated the consumption of juvenile salmonids (Oncorhynchus spp.) and other forage fishes by Caspian terns (Sterna caspia) nesting on Rice Island in the Columbia River estuary in 1997 and 1998 using a bioenergetics modeling approach. The study was prompted by concern that Caspian tern predation might be a substantial source of mortality to out-migrating juvenile salmonids from throughout the Columbia River basin, many populations of which are listed as threatened or endangered under the U.S. Endangered Species Act. The bioenergetics model used estimates of the energy requirements of the tern population and the proportion of tern energy requirements met by various prey types. The resulting estimate of the number of juvenile salmonids consumed by Rice Island Caspian terns was 8.1 million (5.9–10.4 million) in 1997 and 12.4 million (9.1–15.7 million) in 1998. Tern predation rates on juvenile salmonids were substantial, representing up to 15% of the juveniles to reach the estuary from some listed populations. Nevertheless, based on simple age-structured models of salmonid populations, it appears unlikely that management of Caspian tern predation alone would reverse salmonid declines. Management to reduce tern predation could, however, contribute to a comprehensive strategy to recover imperiled salmonid populations in the Columbia River basin.

Rocke, T. E., Nol, P., Pelizza, C., & Sturm, K. K. (2004). Type C botulism in pelicans and other fish-eating birds at the Salton Sea. *Studies in Avian Biology*, *27*, 136–140.

In 1996, type C avian botulism killed over 10,000 pelicans and nearly I0,000 other fisheating birds at the Salton Sea in southern California. Although botulism had been previously documented in waterbirds at the Sea, this die-off was unusual in that it involved primarily fish-eating birds. The American White Pelican (Pelecanus erythrorynchos) was the species with the greatest mortality in 1996. Since 1996, mortality has recurred every year but losses have declined (< 2000 bird /year), with relatively more Brown Pelicans (P. occidentalis) than White Pelicans afflicted. In 2000, morbidity and mortality of Brown Pelican with type C botulism (1311) approached the number afflicted in 1996 (2034). In recent years, mortality reached a peak earlier in the summer, July and August, in contrast to 1996 when mortality reached a peak in September. An exotic fish species, tilapia (Oreochromis mossambict1s), has been implicated as the source of toxin for birds at Salton Sea, but the source of toxin for fish is unknown.

Roegner, G. C., McNatt, R., Teel, D. J., & Bottom, D. L. (2012). Distribution, Size, and Origin of Juvenile Chinook Salmon in Shallow-Water Habitats of the Lower Columbia River and Estuary, 2002–2007. *Marine and Coastal Fisheries*, *4*(1), 450–472. https://doi.org/10.1080/19425120.2012.675982

We monitored fish assemblages monthly at estuarine and tidal freshwater sites in the lower Columbia River and estuary from January 2002 through September 2007 in order to identify specific salmon stocks and migration stages that may benefit from habitat restoration initiatives. We report landscape-scale and seasonal variation in abundance, size, hatchery production (based on adipose fin clips), and genetic stock of origin of juvenile Chinook salmon Oncorhynchus tshawytscha. From fish implanted with coded wire tags (CWTs), we also determined the sites of release and inferred migration patterns. Chinook salmon were found in diverse life history stages and forms, including fry migrants, fingerlings, and (fewer) yearlings. Abundance increased in

February and decreased in August, but salmon were present in all months each year. Spatial gradients in abundance and size were strong, with fewer but larger fish in brackish than in tidal freshwater zones. Overall, 30% of the Chinook salmon measured were fry (≤60 mm) that were likely naturally produced fish. These occurred at higher mean monthly proportions in tidal freshwater than in estuarine zones. In contrast, most larger fish were probably raised in hatcheries. Genetic stock assessment revealed that the majority of the Chinook salmon analyzed were from fall-run stock groups originating in the lower Columbia River, with 15% originating from other stock groups. Of these minority contributors, about 6% were identified as upper Columbia River summer–fall-run Chinook salmon while seven other stock groups accounted for the remainder, including 3% from transplants originating in southern Oregon's Rogue River. Recaptures of tagged fish revealed maximum migration times of 143 d for subyearlings and 52 d for yearlings, and both CWT and genetic data indicated that fall Chinook salmon from coastal rivers occasionally entered the estuary. These data demonstrated a widespread temporal and spatial distribution of subyearling Chinook salmon in shallow-water habitats of the lower Columbia River and estuary.

Rosenbaum, B., & Rall, B. C. (2018). Fitting functional responses: Direct parameter estimation by simulating differential equations. *Methods in Ecology and Evolution*, *9*(10), 2076–2090. https://doi.org/10.1111/2041-210X.13039

1. The feeding functional response is one of the most widespread mathematical frameworks in ecology, marine biology, freshwater biology, microbiology, and related scientific fields describing the resource-dependent uptake of a consumer. Since the exact knowledge of its parameters is crucial to predict, for example, the efficiency of biocontrol agents, population dynamics, food web structure, and subsequently biodiversity, a trustworthy parameter estimation method is highly important for scientists using this framework. Classical approaches for estimating functional response parameters lack flexibility and often only provide approximations of the correct parameters. 2. Here, we combined ordinary differential equation (ODE) models that were numerically solved using computer simulations with an iterative maximum likelihood fitting approach. We compared our method to classical approaches of fitting functional responses using data both with and without additional resource growth and mortality. 3. We found that for classical functional response models, such as the frequently used type II and type III functional responses, the established fitting methods are reliable. However, by using more complex and flexible functional responses, our new method outperforms the traditional methods. Additionally, our method allows the incorporation of side effects such as resource growth and background mortality. 4. Our method will enable researchers from different scientific fields who are measuring functional responses to calculate more accurate parameter estimates. These estimates will enable community ecologists to parameterize their models more precisely, thus allowing a deeper understanding of complex ecological systems, and will increase the quality of ecological prediction models.

Ruggerone, G. T. (1986). Consumption of Migrating Juvenile Salmonids by Gulls Foraging below a Columbia River Dam. *Transactions of the American Fisheries Society*, *115*(5), 736–742. https://doi.org/10.1577/1548-8659(1986)115<736:COMJSB>2.0.CO;2

Consumption of migrating juvenile Pacific salmon Oncorhynchus spp. and steelhead Salmo gairdneri by gulls was estimated below the turbine area of Wanapum Dam on the Columbia River in 1982. Foraging success of the gulls, chiefly ring-billed gulls Larus delawarensis, averaged 65% during

bright light conditions and 51% during the evening. The number of salmonids consumed by gulls ranged from 50 to 562 fish/h. Multiple-regression analysis indicates that the number of salmonids consumed by gulls is significantly affected by the passage rate of fish through the turbines and spillgates, and by light intensity. The number of salmonids consumed by gulls foraging below the turbines during 25 d of peak salmonid migration was approximately 111,750 to 119,250 fish or 2% of the estimated spring migration. Although some salmonids consumed by gulls had been killed when passing through the turbines, the mortality of salmonids caused by gulls is potentially important. Inexpensive measures could be implemented to discourage foraging by gulls below the turbine area of Columbia River dams, thereby enhancing survival of emigrating salmonids.

Ryan, B. A., Ferguson, J. W., Ledgerwood, R. D., & Nunnallee, E. P. (2001). Detection of Passive Integrated Transponder Tags from Juvenile Salmonids on Piscivorous Bird Colonies in the Columbia River Basin. *North American Journal of Fisheries Management*, *21*(2), 417–421. https://doi.org/10.1577/1548-8675(2001)021<0417:DOPITT>2.0.CO;2

We modified 400-kHz passive integrated transponder (PIT) tag detection equipment, previously used in water, to detect PIT tags in piscivorous bird-nesting areas in the Columbia River basin. Two land-based recovery mechanisms were developed: a flat-plate antenna that was drawn over the surface of bird-nesting areas with a four-wheel-drive vehicle and a pole-mounted antenna that was passed by hand over smaller nesting areas. In 1998 and 1999, we detected more than 100,000 unique PIT tag codes by the use of the flat-plate antenna, and in 1999, we detected more than 10,000 unique PIT tag codes by the use of the pole-mounted antenna. Codes were detected for every release year since 1987, the first year that salmonids were marked with PIT tags in the Columbia River basin; however, the majority of tag codes came from juveniles marked for the 1999 migration year (>50,000 tag codes recovered). In 2000, researchers in the Columbia River basin changed to a 134.2-kHz PIT tag, in accordance with guidelines from the International Standards Organization (ISO). We are adapting the land-based apparatus to detect ISO tags, which will provide information on management issues critical to recovering salmonid stocks listed under the Federal Endangered Species Act.

Ryan, B. A., Smith, S. G., Butzerin, J. A. M., & Ferguson, J. W. (2003). Relative Vulnerability to Avian Predation of Juvenile Salmonids Tagged with Passive Integrated Transponders in the Columbia River Estuary, 1998–2000. *Transactions of the American Fisheries Society*, *132*(2), 275–288. https://doi.org/10.1577/1548-8659(2003)132<0275:RVTAPO>2.0.CO;2

Caspian terns Sterna caspia and double-crested cormorants Phalacrocorax auritus that colonize dredge-spoil islands in the Columbia River estuary prey upon millions of juvenile Pacific salmonids annually. We estimated the relative vulnerability of various salmonid stocks to these predators by using data from passive integrated transponder (PIT) tags detected on these colonies; 96,382 tags were detected from the 1998–2000 migration years. On tern colonies, detection rates were highest for tags from steelhead Oncorhynchus mykiss and lowest for tags from yearling chinook salmon O. tshawytscha. However, detection rates on cormorant colonies were similar for tags from steelhead and coho salmon O. kisutch but lower for tags from yearling chinook salmon. Analyses based on migration history showed tags of transported fish were frequently detected in lower proportions than those of their counterparts that migrated in-river, the pattern being most pronounced in steelhead. Analyses based on origin (hatchery versus wild) showed similar detection proportions for the tags of wild versus hatchery steelhead on both tern and cormorant colonies. In contrast, 3.1% of hatchery versus 1.1% of wild chinook salmon tags previously detected at Bonneville Dam were detected on a colony, the greater vulnerability of hatchery fish being more pronounced on tern colonies. These tags accounted for 11.5% of steelhead, 4.6% of coho salmon, and 2.6% of yearling chinook salmon detected at Bonneville Dam, the last downstream impoundment encountered by seaward migrants. These estimates of predation are minimal because detection efficiency was not 100% and tags from many salmonid prey were not deposited on a nesting colony.

Sandercock, B. K., Nilsen, E. B., Brøseth, H., & Pedersen, H. C. (2011). Is hunting mortality additive or compensatory to natural mortality? Effects of experimental harvest on the survival and cause-specific mortality of willow ptarmigan. *Journal of Animal Ecology*, *80*(1), 244–258. https://doi.org/10.1111/j.1365-2656.2010.01769.x

1. The effects of harvest on the annual and seasonal survival of willow ptarmigan Lagopus lagopus L. were tested in a large-scale harvest experiment. Management units were randomly assigned to one of three experimental treatments: 0%, 15% or 30% harvest. Seasonal quotas were based on the experimental treatment and estimates of bird density before the hunting season. Survival rates and hazard functions for radio-marked ptarmigan were then estimated under the competing risks of harvest and natural mortality. 2. The partially compensatory mortality hypothesis was supported: annual survival of ptarmigan was 0·54 ± 0·08 SE under 0% harvest, 0·47 ± 0·06 under 15% harvest, and was reduced to 0·30 ± 0·05 under 30% harvest. Harvest mortality increased linearly from 0·08 ± 0·05, 0·27 ± 0·05 and 0·42 ± 0·06 from 0% to 30% harvest, whereas natural mortality was 0·38 ± 0·08, 0·25 ± 0·05 and 0·28 ± 0·06 under the same treatments. 3. Realized risk of harvest mortality was 0·08-0·12 points higher than our set harvest treatments of 0–30% because birds were exposed to risk if they moved out of protected areas. The superadditive hypothesis was supported because birds in the 30% harvest treatment had higher natural mortality during winter after the hunting season. 4. Natural mortality was mainly because of raptor predation, with two seasonal peaks in fall and spring. Natural and harvest mortality coincided during early autumn with little potential for compensation during winter months. Peak risk of harvest mortality was 5× higher than natural mortality. Low natural mortality during winter suggests that most late season harvest would be additive mortality. 5. Environmental correlates of natural mortality of ptarmigan included seasonal changes in snow cover, onset of juvenile dispersal, and periods of territorial activity. Natural mortality of ptarmigan was highest during autumn movements and nesting by gyrfalcons Falco rusticolus L. Mortality was low when gyrfalcons had departed for coastal wintering sites, and during summer when ptarmigan were attending nests and broods. 6. Our experimental results have important implications for harvest management of upland gamebirds. Seasonal quotas based on proportional harvest were effective and should be set at ≤15% of August populations for regional management plans. Under threshold harvest of a reproductive surplus, 15% harvest would be sustainable at productivity rates ≥2·5 young per pair. Impacts of winter harvest could be minimized by closing the hunting season in early November or by reducing late season quotas.

Satterthwaite, W. H., Kitaysky, A. S., & Mangel, M. (2012). Linking climate variability, productivity and stress to demography in a long-lived seabird. *Marine Ecology Progress Series*, *454*, 221–236. JSTOR.

We examined the reproductive ecology of black-legged kittiwakes Rissa tridactyla in several breeding colonies in the North Pacific to test if inter-annual changes in the Pacific Decadal Oscillation

(PDO), Winter Ice Cover (ICI), or local sea-surface temperature (SST) predict changes in productivity (fledglings per nest) or nutritional stress (corticosterone). We explored the implications of the observed variation in productivity and stress for projected population dynamics based on a previously demonstrated corticosterone–survival relationship. Although productivity was highly variable (0 to 0.9 fledglings nest–1), the relationships between productivity and environmental indices were weak, with local SST providing slightly more explanatory power than PDO or ICI, suggesting that local factors rather than large-scale climate variability may determine variation in productivity. The relationships between stress and environmental indices were stronger than the relationship between productivity and environment. The measured response of stress to environment showed opposite signs between the southern and northern colonies, and typically implied annual mortality rates varying from 11 to 17%. The observed relationships between climate and stress indicate that anticipated warming might bring at least short-term demographic benefits for kittiwakes in the Bering shelf region, while having negative impacts on birds breeding in the Gulf of Alaska and western Aleutians. We predict decline (without immigration) for colonies with the lowest productivity and conclude that climate variability is likely to affect survival of North Pacific kittiwakes on a region-specific basis. Longevity of these birds may not always be sufficient to buffer their populations from low reproductive performance.

Schaub, M., & Pradel, R. (2004). Assessing the Relative Importance of Different Sources of Mortality from Recoveries of Marked Animals. *Ecology*, *85*(4), 930–938. https://doi.org/10.1890/03-0012

Overall mortality rates often are based upon a variety of mortality sources such as predation, disease, and accidents, and each of these sources may influence population dynamics differently. To better understand population dynamics or to derive effective conservation plans, it is thus crucial to know the frequency of specific mortality causes as well as their variation over time. However, although the mortality cause of retrieved marked animals is often known, this information cannot be used directly to estimate the frequency of a mortality cause. By calculating the ratio of the number of animals reported dead from a specific cause to the total number of retrieved animals, one does not consider the fact that the probability of finding a dead individual depends on the cause of its death. Although frequently used, such ad hoc estimates can be heavily biased. Here we present a new way of estimating the frequency of a mortality cause from ring-recovery (band-recovery) data without bias. We consider the states “alive,” “dead because of mortality cause A,” and “dead due to all other causes” and estimate within a multistate capture–recapture framework the transition probabilities as well as the state-specific resighting probabilities. Among the transition probabilities are the overall survival probability and the proportion of animals dying because of A. From these, the probability that an animal dies during a year due to the specific cause of interest (cause A kill rate) can easily be calculated. We illustrate this model using data from White Storks Ciconia ciconia ringed in Switzerland to estimate the proportion of storks that died due to power line collision. Average unbiased estimates of this proportion were 0.37 ± 0.08 (mean ± 1 se) for juveniles, about 25% lower than ad hoc estimates, and 0.35 ± 0.09 for adults. The annual survival rate of juveniles was 0.33 ± 0.05 and of adults, 0.83 ± 0.02. Power line mortality is thus important for White Storks, with about one in four juveniles and one in 17 adults dying each year because of power line collision. We discuss advantages and disadvantages of the new model and how the results could be used to explore the link between a specific mortality cause and population dynamics.

Scheerer, P. D., Gunckel, S. L., Heck, M. P., & Jacobs, S. E. (2010). Status and distribution of native fishes in the Goose Lake Basin, Oregon. *Northwestern Naturalist*, *91*(3), 271–287. JSTOR.
We describe the current distribution of native and non-native fishes in the Goose Lake basin, Oregon, with comparisons to prior unpublished surveys. We employed a generalized random tessellation stratified design to achieve a spatially-balanced sampling distribution across the drainage, including samples representative of both public and private lands. We collected all 9 native Goose Lake fishes, including 4 endemic fishes and the endangered Modoc Sucker. Two native fish species, the Modoc Sucker and the Pit Sculpin, were rarely encountered. The Modoc Sucker was limited to the upper Thomas Creek drainage; however, we documented a range expansion from that known at the time of listing in 1985. We collected the Pit Sculpin from only 2 sampling locations, indicating that the Oregon distribution of Pit Sculpins has contracted in the past 50 y. We also documented the apparent expansion of 2 non-native fishes, Fathead Minnow and Brown Bullhead, in the drainage. Within the Goose Lake fish assemblage, we describe 3 species groups that are correlated with land use and physical habitat parameters. The results of this study provide a baseline to assess trends in fish community structure over time and under different climatic conditions, measure the effects of restoration projects, and guide future restoration efforts.

Scheuerell, M. D., Moore, J. W., Schindler, D. E., & Harvey, C. J. (2007). Varying effects of anadromous sockeye salmon on the trophic ecology of two species of resident salmonids in southwest Alaska. *Freshwater Biology*, *52*(10), 1944–1956. https://doi.org/10.1111/j.1365-2427.2007.01823.x
1. Anadromous salmon transport marine-derived nutrients and carbon to freshwater and riparian ecosystems upon their return to natal spawning systems. The ecological implications of these subsidies on the trophic ecology of resident fish remain poorly understood despite broad recognition of their potential importance. 2. We studied the within-year changes in the ration size, composition and stable isotope signature of the diets of two resident salmonids (rainbow trout, Oncorhynchus mykiss; Arctic grayling, Thymallus arcticus) before and after the arrival of sockeye salmon (Oncorhynchus nerka) to their spawning grounds in the Bristol Bay region of southwest Alaska. 3. Ration size and energy intake increased by 480–620% for both species after salmon arrived. However, the cause of the increases differed between species such that rainbow trout switched to consuming salmon eggs, salmon flesh and blowflies that colonized salmon carcasses, whereas grayling primarily ate more benthic invertebrates that were presumably made available because of physical disturbances by spawning salmon. 4. We also observed an increase in the δ15N of rainbow trout diets post-salmon, but not for grayling. This presumably led to the observed increase in the δ15N of rainbow trout with increasing body mass, but not for grayling. 5. Using a bioenergetics model, we predicted that salmon-derived resources contributed a large majority of the energy necessary for growth in this resident fish community. Furthermore, the bioenergetics model also showed how seasonal changes in diet affected the stable isotope ratios of both species. These results expand upon a growing body of literature that highlights the different pathways whereby anadromous salmon influence coastal ecosystems, particularly resident fish.

Scheuerell, M. D., & Williams, J. G. (2005). Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (Oncorhynchus tshawytscha). *Fisheries Oceanography*, *14*(6), 448–457. https://doi.org/10.1111/j.1365-2419.2005.00346.x

Effective conservation and management of natural resources requires accurate predictions of ecosystem responses to future climate change, but environmental science has largely failed to produce these reliable forecasts. The future response of Pacific salmon (Oncorhynchus spp.) to a changing environment and continued anthropogenic disturbance is of particular interest to the public because of their high economic, social, and cultural value. While numerous retrospective analyses show a strong correlation between past changes in the ocean environment and salmon production within the north Pacific, these correlations rarely make good predictions. Using a Bayesian time-series model to make successive 1-yr-ahead forecasts, we predicted changes in the ocean survival of Snake River spring/summer chinook salmon (O. tshawytscha) from indices of coastal ocean upwelling with a high degree of certainty (R2 = 0.71). Furthermore, another form of the dynamic times-series model that used all of the available data indicated an even stronger coupling between smolt-to-adult survival and ocean upwelling in the spring and fall (R2 = 0.96). This suggests that management policies directed at conserving this threatened stock of salmon need to explicitly address the important role of the ocean in driving future salmon survival.

Scheuerell, M. D., Zabel, R. W., & Sandford, B. P. (2009). Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (Oncorhynchus spp.). *Journal of Applied Ecology*, *46*(5), 983–990. https://doi.org/10.1111/j.1365-2664.2009.01693.x

1. Migration timing in animals has important effects on life-history transitions. Human activities can alter migration timing of animals, and understanding the effects of such disruptions remains an important goal for applied ecology. Anadromous Pacific salmon (Oncorhynchus spp.) inhabit fresh water as juveniles before migrating to the ocean where they gain >90% of their biomass before returning to fresh water as adults to reproduce. Although construction of dams has delayed juvenile migration for many populations, we currently lack a synthesis of patterns in migration timing and how they relate to subsequent survival to adulthood for Pacific salmon, especially for at-risk populations. 2. We studied two groups of Pacific salmon from the Columbia River basin in the northwestern United States currently listed under the U.S. Endangered Species Act. We examined how the proportion of juveniles surviving to return as adults varied with year of migration, date of arrival in the estuary, water temperature and coastal ocean upwelling using data from over 40 000 individually tagged Chinook salmon Oncorhynchus tshawytscha and steelhead Oncorhynchus mykiss. 3. In general, models with year, day and day2 had much better support from the data than those with temperature and upwelling. For Chinook salmon, we also found a residual effect of temperature after controlling for day, but the effect was small for steelhead. 4. For both species, juveniles migrating from early to mid-May survived 4–50 times greater than those migrating in mid-June. As expected, however, the estimated peak in survival varied among years, presumably reflecting interannual variation in the nearshore physical environment and trophic dynamics that affect salmon during the critical juvenile life stage. 5. Synthesis and applications. Our results indicate a possible management objective would be to speed arrival to the estuary by increasing springtime river flows. These findings also provide some insight into the mechanisms underlying seasonal differences in survival patterns, but additional studies are needed to better resolve the issue. Future changes to river flow and water temperature associated with climate change and human activities may further alter migration timing, and thus this phenomenon deserves further attention.

Schniedermeyer, E. (2018). *The Response of Caspian Terns to Managed Reductions in Nesting Habitat in the Columbia Plateau Region, Washington State, USA* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/v692tc482

Declines in populations of anadromous salmonids (Oncorhynchus spp.) in the Columbia River drainage basin have resulted in extensive programs to annually release large numbers of hatchery-raised juvenile salmonids in an effort to support salmonid restoration. The Pacific Flyway population of Caspian terns (Hydroprogne caspia) has grown from around 3,500 nesting pairs in 1960 to around 13,000 nesting pairs in 2000, and the majority of breeding Caspian terns in the Pacific Flyway population were nesting in the Columbia River basin by 2000. This population growth is in part a result of the stabilization of nesting habitat due to human management of the Columbia River and nearby water bodies, plus the yearly release of over a hundred million hatchery-raised juvenile salmonids into the system. Research on the consumption of juvenile salmonids by piscivorous waterbirds resulted in the identification of Caspian tern predation as a factor limiting salmonid restoration in the basin. Caspian terns nesting in the Columbia Plateau region, which lies within the Columbia River drainage basin, were found to consume a much larger number of juvenile salmonids per capita than Caspian terns nesting elsewhere in the Columbia River basin. This finding resulted in the development of a management plan to reduce mortality of juvenile salmonids in the Columbia Plateau region by preventing nesting of Caspian terns at the two largest colonies in the region, in conjunction with the concurrent creation of alternative nesting habitat for Caspian terns elsewhere in the breeding range of the Pacific Flyway population. I investigated the response of Caspian terns to the loss of available nesting habitat in the Columbia Plateau region. The management plan, developed by an interagency working group led by the U.S. Army Corps of Engineers, met its goal of preventing Caspian terns from nesting at the sites of the two largest colonies in the Columbia Plateau region, Goose Island in Potholes Reservoir and Crescent Island in McNary Reservoir, Washington State. The goal of lowering the region-wide number of breeding Caspian terns from about 875 nesting pairs to ≤ 200 nesting pairs, however, was not met within the first three years of management implementation. The majority of terns that previously nested at Goose or Crescent islands moved to nest on several low-lying gravel bars in the Blalock Islands, an archipelago downstream from Crescent Island in John Day Reservoir on the Columbia River. A new small tern colony also became established at Lenore Lake, north of Potholes Reservoir. While regional numbers of Caspian tern nesting pairs declined significantly in 2015 and 2016, the second and third years post-management, regional nesting success of terns did not decline. Instead, regional nesting success remained within the range estimated by Suryan et al. (2004) for a stable population of Caspian terns (average of 0.32 - 0.74 young raised per breeding pair per year). Analysis of banded terns that nested at either Goose Island or Crescent Island immediately prior to the initiation of management found that the proportion of terns that returned to breed in 2015 and 2016 declined significantly, while a significantly greater proportion of terns returned as non-breeding floaters in the Columbia Plateau region compared to pre-management. Also, the proportion of terns that went unobserved, either within the Columbia Plateau region or elsewhere in the Pacific Flyway, increased significantly in 2015 and 2016 compared to pre-management. The management plan resulted in the loss of available nesting space for at least 90% of nesting Caspian terns in the Columbia Plateau region during 2004 - 2013. Despite the capacity of Caspian terns for long-distance breeding dispersal, the birds mostly took advantage of previously active and potential nesting habitat within the region instead of emigrating from the region. My results suggest that, despite the regional drop in numbers of active nesting pairs,

Caspian terns did not disperse from the Columbia Plateau region in large numbers. Instead, terns that were unable to successfully compete for nest sites within the region returned as nonbreeding floaters. This philopatric response was likely reinforced by drought conditions at alternative nesting habitat in the southern Oregon and northeastern California region, which reduced the availability of suitable nest sites. Also, concurrent management to reduce available nesting habitat for Caspian terns at the large breeding colony in the Columbia River estuary caused a major reduction in space for nesting pairs at this location. Both of these factors apparently played a role in the choice of Caspian terns to remain in the Columbia Plateau region post-management. Following the implementation of management to reduce tern nesting habitat in the Columbia Plateau region, Caspian terns exhibited considerable flexibility and adaptability in their choice of nest site, and may have integrated information on the breeding success of conspecifics at other nesting locations within the region.

Schniedermeyer, E., Roby, D. D., Lyons, D. E., Suzuki, Y., & Collis, K. (n.d.). Caspian Tern Response to Managed Reductions in Nesting Habitat. *Wildlife Society Bulletin*, *n/a*(n/a). https://doi.org/10.1002/wsb.1111

Predation on smolts by Caspian terns (Hydroprogne caspia) has been identified as a factor limiting the restoration of some populations of anadromous salmonids (Oncorhynchus spp.) from the Columbia River basin that are listed under the U.S. Endangered Species Act. Implementation of a management plan to reduce numbers of Caspian terns nesting at the 2 largest colonies in the Columbia Plateau region of Oregon and Washington, USA, began in 2014 and is ongoing. We investigated the response of Caspian terns during 2014–2016 to reductions in nesting habitat at these 2 colonies. Management prevented terns from nesting at both colonies, and the estimated numbers of nesting pairs in the region declined significantly from a mean of 877 pairs during premanagement to 769 and 675 pairs in 2015 and 2016, respectively. The management objective of reducing numbers of nesting terns in the Columbia Plateau region to ≤200 breeding pairs was not achieved during the first 2 years of full implementation of the plan. Regional nesting success did not decline significantly following the initiation of management, and remained at levels considered sufficient to sustain the regional subpopulation. Despite the species' capacity for long-distance breeding dispersal, the majority of displaced terns exhibited stronger than expected philopatry to the Columbia Plateau region. Analysis of resightings of banded terns indicated that most (>80%) terns that nested in the Columbia Plateau region premanagement returned to the region in 2015 and 2016, but the proportion that returned as breeders decreased while the proportion that returned as nonbreeding floaters increased compared with premanagement. The proportion of banded terns that were unobserved also increased during management years, suggesting that more terns became floaters in the Pacific Flyway and went unobserved because they were prospecting and foraging in locations or regions where there was little or no monitoring. The unexpectedly high regional philopatry exhibited by terns during management was likely a reflection of the low availability of suitable alternative nesting habitat outside the region. Most terns that remained in the region displayed considerable flexibility in nest site selection by nesting either at a previously smaller, intermittently successful breeding colony or at a small new colony where nesting activity had not previously been recorded. As long-lived seabirds, Caspian terns may integrate information regarding nesting success over several years before choosing to change nesting locations, longer than the 2 years of this study, especially if alternate locations are distant or intermittently available, or a history of nesting at multiple locations exists within the region. © 2020 The Wildlife Society.

Schoener, T. W. (1979). Generality of the Size-Distance Relation in Models of Optimal Feeding. *The American Naturalist*, *114*(6), 902–914. JSTOR.
If pursuit or provisioning time is unrelated to prey size, the following size-distance properties are expected for a variety of prey-handling functions. 1. The best prey size increases with distance. 2. For given values of profit (measured as energy per unit time), profit changes less with distance, the larger the prey. 3. The range of sizes taken shifts toward larger sizes, as distance increases. If pursuit or provisioning time increases with prey size, these effects can be reversed.

Schreck, C. B., Stahl, T. P., Davis, L. E., Roby, D. D., & Clemens, B. J. (2006). Mortality Estimates of Juvenile Spring–Summer Chinook Salmon in the Lower Columbia River and Estuary, 1992–1998: Evidence for Delayed Mortality? *Transactions of the American Fisheries Society*, *135*(2), 457–475. https://doi.org/10.1577/T05-184.1
Recovery of Endangered Species Act—listed salmonids in the Columbia River basin has relied upon the efficacy of the U.S. Army Corps of Engineer's juvenile salmon transportation program to move fish past Snake and Columbia River hydropower dams. The effectiveness of this program has been assessed by the indirect method of comparing smolt-to-adult returns. We present some of the first data and mortality estimates of barged and run-of-river (ROR) radio-tagged juvenile spring–summer Chinook salmon Oncorhynchus tshawytscha after release in the lower Columbia River, representing years of study. Our data suggest that smolt mortality (1) is very low for ROR and barged fish between Bonneville Dam and the estuary proper, a migratory distance of 180 river kilometers (rkm); (2) occurs in the lower estuary (rkm 0–46); (3) varies more across dates within a year than between years or between passage types (barged or ROR); (4) increases with time within a season and increasing numbers of avian predators, including Caspian terns Sterna caspia and double-crested cormorants Phalacrocorax auritus; and (5) is estimated to be 11–17% of all smolts annually. Preliminary evidence suggests that at least some smolt mortality is influenced by differential predation by avian predators on Chinook salmon infected with Renibacterium salmoninarum and possessing low smoltification levels (relatively low gill Na+,K+-ATPase activity). Fish type (barged or ROR) did not appear to influence mortality because of avian predation. This project was also the first to identify avian predators as a major source of mortality for out-migrant Columbia River basin salmonids.

Schumaker, N. H., Brookes, A., Dunk, J. R., Woodbridge, B., Heinrichs, J. A., Lawler, J. J., Carroll, C., & LaPlante, D. (2014). Mapping sources, sinks, and connectivity using a simulation model of northern spotted owls. *Landscape Ecology*, *29*(4), 579–592. https://doi.org/10.1007/s10980-014-0004-4
Source-sink dynamics are an emergent property of complex species–landscape interactions. A better understanding of how human activities affect source-sink dynamics has the potential to inform and improve the management of species of conservation concern. Here we use a study of the northern spotted owl (Strix occidentalis caurina) to introduce new methods for quantifying source-sink dynamics that simultaneously describe the population-wide consequences of changes to landscape connectivity. Our spotted owl model is mechanistic, spatially-explicit, individual-based, and incorporates competition with barred owls (Strix varia). Our observations of spotted owl source-sink dynamics could not have been inferred solely from habitat quality, and were sensitive to landscape connectivity and the spatial sampling schemes employed by the model. We conclude that a clear understanding of source-sink dynamics can best be obtained from

sampling simultaneously at multiple spatial scales. Our methodology is general, can be readily adapted to other systems, and will work with population models ranging from simple and low-parameter to complex and data-intensive.

Schwinn, M., Aarestrup, K., Baktoft, H., & Koed, A. (2017). Survival of Migrating Sea Trout (Salmo trutta) Smolts During Their Passage of an Artificial Lake in a Danish Lowland Stream. *River Research and Applications*, *33*(4), 558–566. https://doi.org/10.1002/rra.3116

Artificial lake development is often used as a management tool to reduce nutrient runoff to coastal waters. Denmark has restored more than 10 000 ha of wetlands and lakes in the last 14 years as a consequence of 'Action Plans for the Aquatic Environment', which aim to meet the demands of the European Union's Water Framework Directive. Juvenile, seaward migrating salmonids are highly affected by impounded waterbodies, as they are subjected to extraordinary high mortalities due to predation and altered habitat. From 2005 to 2015, survival and migration patterns of wild brown trout (Salmo trutta) smolts were investigated by using radio, acoustic and Passive Integrated Transponder telemetry both before and after the development of an artificial lake in a small Danish lowland stream. In 2005 and 2006, before the lake developed, survival was estimated to be 100% in the river stretch where the lake later developed. In 2007 and in the period between 2009 and 2015, mean yearly survival decreased to 26%. Mean time for passing the area increased significantly after the development of the lake from 0.42 to 5.95 days. Generalized additive models were used to model the probability of a successful passage. Water temperature and discharge were key environmental factors affecting survival of the smolts during the passage of the lake. Furthermore, smolt survival was negatively correlated with condition factor. This elevated level of smolt mortality may seriously compromise self-sustaining anadromous salmonid populations when artificial lakes are developed in connection with rivers.

Scoppettone, G. G., Fabes, M. C., Rissler, P. H., & Withers, D. (2015). *Fish Tag Recovery from Anaho Island Nesting Colony, Pyramid Lake, Nevada* (Open-File Report No. 2015–1242; Open-File Report). https://pubs.usgs.gov/of/2015/1242/ofr20151242.pdf

In 2001, tags applied to the federally endangered species cui-ui (Chasmistes cujus) to study their population dynamics were discovered strewn throughout the American White Pelican (Pelecanus erythrorhynchos) nesting colony on Anaho Island, Pyramid Lake, Nevada. Cui-ui are endemic to Pyramid Lake, and Anaho Island harbors one of North America's largest nesting colonies of American White Pelican. Cui-ui are consumed by pelicans during the fish's spring migration into the Truckee River to reproduce. The predatory success of pelican has been validated by determining the odds of finding a tag from a predated cui-ui within the Anaho Island nesting colony. It is unknown how many cui-ui tags are eliminated by birds before arrival to the colony versus how many are brought to the colony but never recovered. The focus of this study was to improve the estimate of the chances of collecting a tag from a predated adult cui-ui in the pelican nesting colony by feeding dead tagged Lahontan cutthroat trout (Oncorhynchus clarkii henshawi) and common carp (Cyprinus carpio) to pelican and subsequently searching for these tags within the colony. We also randomly deployed 1,000 dispersal tags throughout the nesting colony, searching for these after one and two breeding seasons. After adding 1,027 fed fish to 547 previously fed fish, we estimated 5.3 percent of the tagged cui-ui taken by pelican were recovered during tag searches. A study of dispersal tags randomly deployed within the pelican nesting colony showed that 51.5 percent would be expected to be recovered after at least one breeding season after being deployed. Results of our studies indicate that more than 90 percent of tags from adult cui-ui are eliminated by birds outside the pelican nesting colony. Tags recovered from other species and the site at which they were tagged are also reported. Most notable were recovered Lahontan cutthroat trout tags, which were the highest in number, but their proximity to double-crested cormorant (Phalacrocorax auritus) nests suggests this species to be the primary predator. Tags from other species of fish came from as far as the Columbia River, Washington (about 600 kilometers). This study provides an important baseline for future tag recovery from the pelican nesting colony on Anaho Island and opens new questions to American White Pelican movement patterns.

Scoppettone, G. G., Rissler, P. H., Fabes, M. C., & Withers, D. (2014). American White Pelican Predation on Cui-ui in Pyramid Lake, Nevada. *North American Journal of Fisheries Management*, *34*(1), 57–67. https://doi.org/10.1080/02755947.2013.855278
Anthropogenic changes to the Pyramid Lake–Truckee River ecosystem in Nevada are suspected to have altered the predator–prey balance between American white pelican Pelecanus erythrorhynchos and Cui-ui Chasmistes cujus. We estimated the loss of the adult Cui-ui population to pelican predation over a 13-year period by netting and tagging Cui-uis as they aggregated at the mouth of the Truckee River prior to their spawning migration into the Truckee River. Cui-ui access to the Truckee River typically required traversing a shallow delta (a foraging advantage for these American white pelicans). Dams and greater frequency of low stream flows also contributed to American white pelican foraging success. We used tag recoveries from Pyramid Lake's nesting colony of American white pelicans along with an experiment to estimate the chance of tag recovery within the colony to calculate the number of tagged fish taken by American white pelicans. We also used numbered tags to test whether there was a size preference for Cui-uis taken. Our results showed that the primary source of adult Cui-ui mortality was from American white pelican predation in the Truckee River. Within a 13-year period American white pelicans had taken 90% of the tags deployed during the first 7 years of the interval. There was no preference for the size of Cui-uis taken. A better understanding of the effects of heavy cropping by American white pelicans on Cui-ui population dynamics is still needed.

Sebring, S. H., Carper, M. C., Ledgerwood, R. D., Sandford, B. P., Matthews, G. M., & Evans, A. F. (2013). Relative Vulnerability of PIT-Tagged Subyearling Fall Chinook Salmon to Predation by Caspian Terns and Double-Crested Cormorants in the Columbia River Estuary. *Transactions of the American Fisheries Society*, *142*(5), 1321–1334. https://doi.org/10.1080/00028487.2013.806952
We quantified the percentage of PIT-tagged subyearling fall Chinook Salmon Oncorhynchus tshawytscha that were consumed by Caspian terns Hydroprogne caspia and double-crested cormorants Phalacrocorax auritus nesting on East Sand Island in the Columbia River estuary by electronically recovering PIT tags that were deposited on the bird colonies. We released 23 groups of PIT-tagged subyearling fall Chinook Salmon from hatcheries in the lower Columbia River downstream of Bonneville Dam from 2002 to 2010. Vulnerability to avian predation was compared between PIT-tagged subyearlings of two Columbia River basin stocks: tule and upriver bright (URB). Recoveries of PIT tags revealed that overall predation rates were significantly different between the tule stock (22%) and URB stock (3%); for fish that were detected as entering the lower Columbia River during the same week, predation rates also differed between stocks (tule: 21%; URB: 2%). Minimum predation rates on tule subyearlings

originating from hatcheries downstream of Bonneville Dam were among the highest documented for any salmonid species in the Columbia River basin to date, occasionally exceeding 35% of the available fish. The ratio of URB fish consumed by the two avian predators indicated that the percentages were nearly equal (cormorant [%]: tern [%] = 51:49), whereas the ratio for tule-stock fish consumed by the two avian species was not uniform (cormorant: tern = 81:19). Differences in predation rates between the tule stock and the URB stock may be attributable to migration behaviors exhibited in the estuary. We estimate that more than 8 million tule fall Chinook Salmon subyearlings released from hatcheries annually are consumed by double-crested cormorants and Caspian terns nesting on East Sand Island; ongoing management actions by multiple federal, state, and tribal governments, if successful, will decrease predation on fall Chinook Salmon stocks.

Sedinger, J. S., White, G. C., Espinosa, S., Partee, E. T., & Braun, C. E. (2010). Assessing Compensatory Versus Additive Harvest Mortality: An Example Using Greater Sage-Grouse. *The Journal of Wildlife Management*, *74*(2), 326–332. https://doi.org/10.2193/2009-071

We used band-recovery data from 2 populations of greater sage-grouse (Centrocercus urophasianus), one in Colorado, USA, and another in Nevada, USA, to examine the relationship between harvest rates and annual survival. We used a Seber parameterization to estimate parameters for both populations. We estimated the process correlation between reporting rate and annual survival using Markov chain Monte Carlo methods implemented in Program MARK. If hunting mortality is additive to other mortality factors, then the process correlation between reporting and survival rates will be negative. Annual survival estimates for adult and juvenile greater sage-grouse in Nevada were 0.42±0.07 ($\bar{x}$±SE) for both age classes, whereas estimates of reporting rate were 0.15±0.02 and 0.16±0.03 for the 2 age classes, respectively. For Colorado, average reporting rates were 0.14±0.016, 0.14±0.010, 0.19±0.014, and 0.18±0.014 for adult females, adult males, juvenile females, and juvenile males, respectively. Corresponding mean annual survival estimates were 0.59±0.01, 0.37±0.03, 0.78±0.01, and 0.64±0.03. Estimated process correlation between logit-transformed reporting and survival rates for greater sage-grouse in Colorado was ρ = 0.68±0.26, whereas that for Nevada was ρ = 0.04±0.58. We found no support for an additive effect of harvest on survival in either population, although the Nevada study likely had low power. This finding will assist mangers in establishing harvest regulations and otherwise managing greater sage-grouse populations.

Seeb, L. W., Antonovich, A., Banks, M. A., Beacham, T. D., Bellinger, M. R., Blankenship, S. M., Campbell, M. R., Decovich, N. A., Garza, J. C., III, C. M. G., Lundrigan, T. A., Moran, P., Narum, S. R., Stephenson, J. J., Supernault, K. J., Teel, D. J., Templin, W. D., Wenburg, J. K., Young, S. F., & Smith, C. T. (2007). Development of a Standardized DNA Database for Chinook Salmon. *Fisheries*, *32*(11), 540–552. https://doi.org/10.1577/1548-8446(2007)32[540:DOASDD]2.0.CO;2

An international multi-laboratory project was conducted to develop a standardized DNA database for Chinook salmon (Oncorhynchus tshawytscha). This project was in response to the needs of the Chinook Technical Committee of the Pacific Salmon Commission to identify stock composition of Chinook salmon caught in fisheries during their oceanic migrations. Nine genetics laboratories identified 13 microsatellite loci that could be reproducibly assayed in each of the laboratories. To test that the loci were reproducible among laboratories, blind tests were conducted to verify scoring consistency for the nearly 500 total alleles. Once standardized, a dataset of over 16,000

Chinook salmon representing 110 putative populations was constructed ranging throughout the area of interest of the Pacific Salmon Commission from Southeast Alaska to the Sacramento River in California. The dataset differentiates the major known genetic lineages of Chinook salmon and provides a tool for genetic stock identification of samples collected from mixed fisheries. A diverse group of scientists representing the disciplines of fishery management, genetics, fishery administration, population dynamics, and sampling theory are now developing recommendations for the integration of these genetic data into ocean salmon management.

Seto, N., Dillon, J., Shuford, W. D., & Zimmerman, T. (2003). *Review of Caspian Tern (Sterna caspia) Nesting Habitat: A Feasibility Assessment of Management Opportunities in the U.S. Fish and Wildlife Service Pacific Region* (p. 153). https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2009101813.xhtml

Shuford, W. D., & Craig, D. P. (2002). *Status assessment and conservation recommendations for the Caspian tern (Sterna caspia) in North America* (p. 95). U.S. Department of the Interior, Fish and Wildlife Service. https://www.fws.gov/pacific/migratorybirds/PDF/CATE%20Status%20Assessment.pdf
Despite recent population increases, the Caspian Tern (Sterna caspia) is of conservation concern in the Pacific Northwest because of the concentration of breeding terns at relatively few sites and fisheries conflicts at the Columbia River estuary, where currently two-thirds of the Pacific Coast and one-quarter of the North American population occurs. Although not listed at the national level, the species currently is listed as threatened or endangered in three states or provinces and is considered of special concern in ten more. The Caspian Tern still occupies most of its historic range and has expanded slightly into new areas. Historically the Caspian Tern suffered from harvest for the millinery trade, egging, human disturbance, habitat loss at interior wetlands, and, more recently, from contaminants. Historic population numbers are unknown but appear to have been substantially reduced early in the century. Relatively accurate population data for the Caspian Tern in North America were unavailable until the late 1970s, when concerns over coastal habitat modification and offshore oil development prompted national multi-species surveys of colonial nesting waterbirds. Estimates of the U.S. breeding population were roughly 9,454 pairs in the mid-1970s to early 1980s and 20,948 pairs in the late 1980s to late 1990s. Since the late 1970s, the population has increased in four of five major breeding regions in North America, and the continental population is estimated to be a minimum of 32,000 to 34,000 pairs, distributed differentially among regions: Pacific Coast/Western (interior) (45%), Central Canada (28%), Great Lakes (19%), Gulf Coast (7%), and Atlantic Coast (<1%). Continentwide population increases were fueled initially by the reduction or elimination of some historic pressures (e.g., hunting for millinery trade) but more recently by changes in breeding habitat and prey resources. Occupation of relatively stable artificial habitats (e.g., dredge spoil islands) has greatly concentrated the tern population leaving it more vulnerable to stochastic events, such as disease outbreaks, severe storms, disruption by predators or human disturbance, and oil spills. Caspian Tern population increases in the Pacific region from the mid-1980s to 2001, primarily in the Columbia River estuary, may largely reflect the crucial juxtaposition of stable human-created habitats in conjunction with a predictable food supply. Human exploitation of native fish communities leading to dominance of small fish species favored by foraging terns appears to be a significant factor in tern increases in the Great Lakes and central Canada. Conservation efforts will be most effective if focused on multiple fronts including monitoring tern populations,

resolving management conflicts with other species by addressing root causes, reducing risks to the tern population by distributing breeding colonies among a greater number of sites, filling gaps in knowledge of biology and threats on migration and the wintering grounds, and educating the public about the value of colonial waterbirds and possible effects of human actions on Caspian Terns.

Shugart, G. W., Scharf, W. C., & Cuthbert, F. J. (1979). Status and Reproductive Success of the Caspian Tern (Sterna caspia) in the U.S. Great Lakes. *Proceedings of the Colonial Waterbird Group*, *2*, 146. https://doi.org/10.2307/1520948

Sih, A., Englund, G., & Wooster, D. (1998). Emergent impacts of multiple predators on prey. *Trends in Ecology & Evolution*, *13*(9), 350–355. https://doi.org/10.1016/S0169-5347(98)01437-2
Although almost all prey live with many types of predator, most experimental studies of predation have examined the effects of only one predator at a time. Recent work has revealed new insights into the emergent impacts of multiple predators on prey and experimental studies have identified statistical methods for evaluating them. These studies suggest two main types of emergent effect—risk reduction caused by predator–predator interactions and risk enhancement caused by conflicting prey responses to multiple predators. Some theory and generalities are beginning to emerge concerning the conditions that tend to produce these two outcomes.

Simenstad, C. A., Small, L. F., David McIntire, C., Jay, D. A., & Sherwood, C. (1990). Columbia river estuary studies: An introduction to the estuary, a brief history, and prior studies. *Progress in Oceanography*, *25*(1), 1–13. https://doi.org/10.1016/0079-6611(90)90002-J

Sirdevan, J. E., & Quinn, J. S. (1997). Foraging Patterns of Caspian Terns (Sterna caspia) Determined Using Radio-Telemetry. *Colonial Waterbirds*, *20*(3), 429–435. JSTOR. https://doi.org/10.2307/1521593
Caspian Terns (Sterna caspia) were studied at 2 Lake Ontario colonies (Hamilton Harbour and Gull Island) to determine foraging patterns. Study subjects were fitted with leg-mounted radiotransmitters and tracked using a hand-held Yagi antenna. There were no significant differences between the attendance and feeding rates of control adults and adults fitted with radiotransmitters. Caspian Tern adults foraged at several different locations throughout the study period suggesting adults do not forage in predictable patterns. To our knowledge, this is the only study which has found a colonial waterbird in a freshwater system foraging in unpredictable patterns.

Skalski, G. T., & Gilliam, J. F. (2001). Functional Responses with Predator Interference: Viable Alternatives to the Holling Type Ii Model. *Ecology*, *82*(11), 3083–3092. https://doi.org/10.1890/0012-9658(2001)082[3083:FRWPIV]2.0.CO;2
A predator's per capita feeding rate on prey, or its functional response, provides a foundation for predator–prey theory. Since 1959, Holling's prey-dependent Type II functional response, a model that is a function of prey abundance only, has served as the basis for a large literature on predator–prey theory. We present statistical evidence from 19 predator–prey systems that three predator-dependent functional responses (Beddington-DeAngelis, Crowley-Martin, and Hassell-Varley), i.e., models that are functions of both prey and predator abundance because of predator interference, can provide better descriptions of predator feeding over a range of predator–prey

abundances. No single functional response best describes all of the data sets. Given these functional forms, we suggest use of the Beddington-DeAngelis or Hassell-Varley model when predator feeding rate becomes independent of predator density at high prey density and use of the Crowley-Martin model when predator feeding rate is decreased by higher predator density even when prey density is high.

Skalski, J. R., Steig, T. W., & Hemstrom, S. L. (2012). Assessing compliance with fish survival standards: A case study at Rock Island Dam, Washington. *Environmental Science & Policy*, *18*, 45–51. https://doi.org/10.1016/j.envsci.2012.01.001

Safe fish passage through hydroprojects is of paramount importance in the Pacific Northwest of the United States where anadromous runs of salmon smolts pass through as many as nine dams on the Columbia River on their way to the ocean. Minimum survival standards through the dams or hydroprojects (i.e., reservoir and dam) have been established by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion or by Habitat Conservation Plans (HCPs) in order to protect salmon stocks. These federal requirements have prompted the need to conduct scientifically and statistically rigorous and precise smolt survival studies at federally and publicly operated hydroprojects throughout the Snake-Columbia River Basin. Successful studies have been the cooperative results of regulators, hydro managers, fish biologists, engineers, and biometricians working together to conduct these high value investigations. Rock Island Dam, Washington, is used as a case study where a total of 17 release-recapture studies were conducted over a nine-year period on three salmonid species to assess compliance with HCP survival standards.

Skalski, J., Townsend, R., Seaburg, A., McMichael, G., Oldenburg, E., Harnish, R., Ham, K., Colotelo, A., Deters, K., & Deng, Z. (2013). *BiOp Performance Testing: Passage and Survival of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead at Little Goose Dam, 2012* (PNNL-22140; p. 136). https://waterpower.pnnl.gov/jsats/pdf/PNNL-22140_FINAL_LGS_BiOp_Report_2012.pdf

The purpose of this passage and survival study was to estimate fish performance metrics associated with passage through Little Goose Dam for emigrating yearling and subyearling Chinook salmon and steelhead smolts in 2012. The metrics estimated during this study included dam passage survival, forebay-to-tailrace survival, forebay residence time, tailrace egress time, and spill passage efficiency (SPE). Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival is required to be greater than or equal to 0.96 for spring migrants, and greater than or equal to 0.93 for summer migrants, and estimated with a standard error (SE) less than or equal to 0.015. The study also estimated smolt passage survival from the forebay (0.9 km upstream of the dam) to the tailrace (1.5 km below the dam), also known as “BRZ-to-BRZ survival”.1 Forebay residence time, tailrace egress time, and SPE were also estimated, as required in the Columbia Basin Fish Accords (Fish Accords). A virtual-paired-release design was used to estimate dam passage survival at Little Goose Dam. The approach included releases of acoustic-tagged smolts above Little Goose Dam that contributed to the formation of a virtual release at the face of Little Goose Dam. A survival estimate from the virtual release was adjusted by a paired release below Little Goose Dam. A total of 1,761 yearling Chinook salmon, 1,742 steelhead, and 2,684 subyearling Chinook salmon were used in the virtual releases. Sample sizes for the below-dam paired releases were 1,198 and 1,200 yearling Chinook salmon, 1,201 and 1,202 steelhead, and 2,095 and 2,096 subyearling Chinook salmon. The Juvenile Salmon Acoustic Telemetry System (JSATS) tag model number SS300 with a single 348 battery, weighing 0.346 g in air, was used in this investigation.

Skalski, J., Townsend, R., Seaburg, A., Weiland, M., Woodley, C., Hughes, J., & Carlson, T. (2012). *Compliance Monitoring of Yearling Chinook Salmon and Juvenile Steelhead Survival and Passage at John Day Dam, Spring 201* (PNNL-21176; p. 109). https://waterpower.pnnl.gov/jsats/pdf/PNNL-21176.pdf

The purpose of this compliance study was to estimate dam passage survival of yearling Chinook salmon and steelhead smolts at John Day Dam during spring 2011. Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival should be greater than or equal to 0.96 and estimated with a standard error (SE) less than or equal to 0.015. The study also estimated smolt passage survival from the forebay 2 km upstream of the dam to the tailrace 3 km below the dam,1 as well as the forebay residence time, tailrace egress, and spill passage efficiency (SPE), as required in the Columbia Basin Fish Accords (Fish Accords). A virtual/paired-release design was used to estimate dam passage survival at John Day Dam. The approach included releases of acoustic-tagged smolts above John Day Dam that contributed to the formation of a virtual release at the face of John Day Dam. A survival estimate from this release was adjusted by a paired release below John Day Dam. A total of 2441 yearling Chinook salmon and 2469 steelhead smolts were used in the virtual releases. Sample sizes for the below-dam paired releases were 1193 and 799 for yearling Chinook salmon smolts and 1196 and 797 for steelhead smolts. The Juvenile Salmon Acoustic Telemetry System (JSATS) tag model number ATS-156dB, weighing 0.438 g in air, was used in this investigation. The intent of the spring study was to estimate dam passage survival during both 30% and 40% spill conditions. The two spill conditions were to be systematically performed in alternating 2-day test intervals over the course of the spring outmigration. High flow conditions and mandatory spill during flood conditions interrupted the spill trials halfway through the study. Dam passage survival was therefore estimated separately before (i.e., early) and during (i.e., late) high flow conditions.

Skov, C., Jepsen, N., Baktoft, H., Jansen, T., Pedersen, S., & Koed, A. (2014). Cormorant predation on PIT-tagged lake fish. *Journal of Limnology*, *73*(1). https://doi.org/10.4081/jlimnol.2014.715

The present study use data from recovered PIT (Passive Integrated Transponder) tags to explore species- and size-specific annual predation rates by cormorants on three common lacustrine fishes (size range 120-367 mm) in a European lake; roach (Rutilus rutilus), common bream (Abramis brama) and perch (Perca fluviatilis). In addition, we quantify the level of age/size truncation that cormorant predation could introduce in a population of perch, an important fish for recreational angling as well as for trophic interactions and ecosystem function in European lakes. Based on three years of PIT tagging of fish in Lake Viborg and subsequent recoveries of PIT tags from nearby cormorant roosting and breeding sites, we show that cormorants are major predators of roach, bream and perch within the size groups we investigated and for all species larger individuals had higher predation rates. Perch appear to be the most vulnerable of the three species and based on a comparison with mortality estimates from lakes without significant avian predation, this study suggest that predation from cormorants can induce age/size truncation in Lake Viborg, leaving very few larger perch in the lake. This truncation reduces the likelihood of anglers catching a large perch and may also influence lower trophic levels in the lake and thus turbidity as large piscivorous perch often play an important structuring role in lake ecosystem functioning.

Smith, S. G., Muir, W. D., Hockersmith, E. E., Zabel, R. W., Graves, R. J., Ross, C. V., Connor, W. P., & Arnsberg, B. D. (2003). Influence of River Conditions on Survival and Travel Time of Snake River Subyearling Fall Chinook Salmon. *North American Journal of Fisheries Management*, *23*(3), 939–961. https://doi.org/10.1577/M02-039

From 1995 to 2000, subyearling fall chinook salmon Oncorhynchus tshawytscha reared at Lyons Ferry Hatchery were PIT-tagged at the hatchery, trucked upstream, acclimated, and released into free-flowing sections of the Snake River weekly from early June to mid-July. We estimated survival probabilities and travel time through the lower Snake River and detection probabilities at dams for each weekly release group. The average median time between release and arrival at Lower Granite Dam was 43.5 d. For each group, we split this time into two nearly equal (on average) periods: one when most fish in the group were rearing and one when most fish had apparently begun active seaward migration. The estimated survival for hatchery fish from release to the tailrace of Lower Granite Dam decreased with release date each year. The estimated survival through this reach was significantly correlated with three environmental variables: survival decreased as discharge (“flow”) decreased, as water transparency increased, and as water temperature increased. Because the environmental variables were highly correlated among themselves, we were unable to determine whether any factors were more important than the others. All three factors have plausible biological consequences for rearing and actively migrating fish, and survival is probably influenced by all of them and possibly by interactions among them as well. Summer flow augmentation will increase discharge and decrease water temperature (provided the additional water is not too warm) and probably increase the speed of seaward migration of smolts, all of which are beneficial to the recovery of threatened Snake River fall chinook salmon.

Smith, S. G., Muir, W. D., Williams, J. G., & Skalski, J. R. (2002). Factors Associated with Travel Time and Survival of Migrant Yearling Chinook Salmon and Steelhead in the Lower Snake River. *North American Journal of Fisheries Management*, *22*(2), 385–405. https://doi.org/10.1577/1548-8675(2002)022<0385:FAWTTA>2.0.CO;2

Simple and multiple linear regressions were used to evaluate factors associated with travel time and survival of yearling chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss migrating in the lower Snake River. Factors were release date and environmental variables measuring river discharge (flow), water temperature, and the percentage of total flow passed over spillways at dams. Data were collected from migrant salmonids tagged with passive integrated transponder (PIT) tags from 1995 through 1999. The greatest distance over which survival could be estimated during all 5 years was from the Lower Granite Dam tailrace to the McNary Dam tailrace (225 river km encompassing four dams and reservoirs). Release groups consisted of PIT-tagged fish leaving Lower Granite Dam daily. Data from more than 451,000 PIT-tagged yearling chinook salmon and 204,000 PIT-tagged steelhead were analyzed. For each daily group, indices of exposure to environmental factors were calculated as the average value for the factor during an index period of the group’s downstream passage. For both species, flow volume and travel time were strongly correlated within single years, and the regression equation was consistent from year to year. Survival estimates changed very little within any given migration season, despite sometimes great fluctuations in environmental factors. Correlations between river discharge and survival between Lower Granite Dam and McNary Dam and between travel time and survival were neither strong (within or between years) nor consistent

from year to year. Thus, survival benefits to the stocks from increased flow in this stretch of the river were at best minimal; any measurable benefits occurred downstream from the Snake River.

Sogard, S. M. (1997). Size-Selective Mortality in the Juvenile Stage of Teleost Fishes: A Review. *Bulletin of Marine Science*, *60*(3), 1129–1157.
Individual variability in body size provides a template for selective mortality processes during early life history stages of teleost fishes. This size variability has generated the logically intuitive hypothesis that larger or faster growing members of a cohort gain a survival advantage over smaller conspecifics via enhanced resistance to starvation, decreased vulnerability to predators, and better tolerance of environmental extremes. This review evaluates field and laboratory studies that have examined size-based differences in survival, with emphasis on the juvenile stage of teleost fishes. The results in general support the "bigger is better" hypothesis, although a number of examples indicate non-selective mortality with no obvious size advantages. The reverse pattern, with enhanced survival of smaller individuals, is rare with the notable exception of bird predation. Major size-selective processes during the juvenile stage include overwinter mortality for temperate species, associated with either starvation or intolerance of physical extremes by smaller members of the young-of-the-year cohort, and predation, with smaller fish more susceptible to successful capture by predators. Most studies examining these processes have used indirect methods to evaluate size-selective mortality, with interpretation of results dependent on several critical assumptions. For methods that track size distributions over time, unbiased samples collected from the same population are critical, and changes in size distributions associated with mortality must be distinguished from changes due to individual growth. The latter requirement can be met with the direct, "characteristics of survivors" method, but few studies have used this approach. Experimental methods isolating specific mechanisms of size-specific mortality must appropriately represent the natural context of environmental factors. Specific predator/prey combinations, for example, can elucidate size-based prey preferences but may be irrelevant compared to the natural, multi-species predator field. The composition of the predator field and its correspondence to size-spectrum theory is crucial to the probability of size-selective predation as a cohort progresses through the juvenile stage. Distinction of selection on body size vs. selection on growth rate has received little attention. However, a number of physiological constraints and ecological trade-offs can place restrictions on growth rates and apparently override the advantages of large body size. Identifying the major sources of mortality and how they operate in the juvenile stage has valuable applications in understanding population dynamics and recruitment variability.

Solomon, M. E. (1949). The Natural Control of Animal Populations. *Journal of Animal Ecology*, *18*(1), 1–35. JSTOR. https://doi.org/10.2307/1578
A. This paper attempts to clarify the subject by giving a systematic account of the processes considered to be involved in the natural control of animal populations. B. First, a brief survey is made of the chief types of theories offering an explanation of natural control. The earlier theories looked to natural enemies as the main agents of control. Somewhat later theories gave predominance to physical factors. Control has been attributed exclusively to competition, including competition between natural enemies, or, more broadly, to density-dependent mortality. Among theories of periodic fluctuations, many ascribe control to some aspect of overpopulation of the environment, while mathematical theories envisage control due primarily to natural enemies. Certain `comprehensive' theories lay emphasis on the complexity and

essential interconnectedness of the population-environment system, and hold that the particular causes of control vary with the circumstances. C. The elements of natural control are outlined as follows: C1. The numerical variation of populations is often considerable and yet is kept within certain limits. C2. A population and the items of its environment form a closely interconnected complex or ecosystem. The relationships of a population are with the whole ecosystem (which includes itself) rather than with the environment only. C3. The distinction between density-dependent and density-independent action is discussed, with examples; it by no means corresponds to the division between biotic and physical factors. Density-dependent action is defined as that which intensifies (per individual) as population density increases, and relaxes as density falls; it is the chief agent of control. Some processes are inversely related to density. Control of a population is a result of the limited capacity of the ecosystem with respect to that species or with respect to its enemies or both. The limiting influence begins to operate at densities far below the capacity limit, intensifying as this limit is approached; this is the basis of most kinds of density dependence (the other kinds are modifications of environmental capacity, the degree of modification naturally depending on density). An enemy is density-dependent in its action on a host (or prey) population if it attacks a greater proportion as the host density increases. The enemy will do this if it is capable, and if the supply of the host is a limiting factor in the enemy's environment. The presence of competitor species, and sometimes that of alternative hosts or prey for the enemies of a population, tends to intensify the action of the control factors involved. C4. Four phases of control are distinguished: limitation, which sets a variable upper limit; conservation, which tends to prevent extreme reduction; suppression, or a forced decline from high density; and release, a temporary escape from normal control after a severe reduction. Each is brought about by characteristic density relationships. Suppression and release promote fluctuations. C5. The level of abundance depends ultimately on all the major elements of the ecosystem, although the density-related, controlling factors are the immediate determinants. Only in regard to particular types of situations, or of animals, can more precise statements be made. D. Some related matters are also discussed: D1. The possibility that either physical or biotic factors may be primarily responsible for control in general is examined. Decisions can be reached only about particular types of situations. D2. Some of the ways in which the term `balance' or `equilibrium' has been applied to population relationships are checked against its physical meaning. It is generally inappropriate to any except nearly constant populations, and this applies equally to `dynamic equilibrium'. To prevent confusion, the above terms should not be used in biology without full explanation of the meaning intended. D3. Although population variation is restricted, the view that density generally fluctuates about a mean value, and the related idea that deviations from this mean set up a tendency to return to it, are over-simplifications. The idea that density tends towards a varying level raises the practical difficulty of distinguishing the two sets of variations, but may be useful. D4. The laboratory demonstration of the `classical' oscillations predicted by the mathematical theories has so far proved very difficult. Instead, `relaxation oscillations', in which the predator population kills all the prey and then dies out, have tended to appear. When `refuges' are available, as in nature, remnants of each population normally survive such crashes, and may increase again. In very regular environments, a succession of these cycles might be maintained; in more general terms, a repeated cycle of suppression and release (see C4) might occur. But this is speculative, and perhaps other causes are more important in producing periodic cycles in nature. D5. There is evidence that animal populations fluctuate less violently in very complex ecosystems, for example in tropical forests, than in woods poorer in plant and animal species, and that the most

violent fluctuations tend to occur among the animals in plantations of one species, or in barren places like the far north. Also, irregularities in the physical environment (but not in climate), by increasing the complexity of the ecosystem, probably reduce the numerical variability of populations.

Southern, L. K., & Southern, W. E. (1980). Philopatry in Ring-Billed Gulls. *Proceedings of the Colonial Waterbird Group*, *3*, 27–32. JSTOR.

Southern, L. K., & Southern, W. E. (1982). Effect of Habitat Decimation on Ring-Billed Gull Colony- and Nest-Site Tenacity. *The Auk*, *99*(2), 328–331. https://doi.org/10.1093/auk/99.2.328
Colony-site tenacity and nest-site tenacity have been documented in several larids, but the proximate factors affecting fidelity remain poorly understood. We examined the effect of severe breeding-habitat alterations (bulldozing) on site tenacity in Ring-billed Gulls (Larus delawarensis). Return rates of wing-tagged adults were similar in bulldozed and unchanged parts of the colony site. In bulldozed areas, however, most ring-bills abstained from nesting; those that did breed showed an increased tendency to move to a different nest site.

Southern, W. E. (1977). Colony Selection and Colony Site Tenacity in Ring-Billed Gulls at a Stable Colony. *The Auk*, *94*(3), 469–478. https://doi.org/10.1093/auk/94.3.469
Long-term banding, wing-marker and retrapping data from one stable Great Lakes colony were used to establish whether or not Ring-billed Gulls exhibit a preference for colony sites at the time of first breeding or during subsequent years. About 13% of the adults captured were banded previously, of which 69% had returned to the natal colony. When calculated on the basis of banding year survivorship, the return rate ranged between 19 and 33%. Immigrants came primarily from colonies within a 64-km area. Of the 436 Ring-bills captured that had been banded as adults, 90% had returned to the colony of previous nesting. In addition, 60% of the wing-marked gulls nested for at least 2 years at Rogers City. The tendency to return to the natal colony is not well defined at this colony, but colony site tenacity after first breeding is well developed. Variability exists in data for less stable colonies, as birds are forced to move by high water levels or other environmental factors.

Stankey, G. H., Clark, R. N., & Bormann, B. T. (2005). *Adaptive management of natural resources: Theory, concepts, and management institutions.* (PNW-GTR-654; p. PNW-GTR-654). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://doi.org/10.2737/PNW-GTR-654
This report reviews the extensive and growing literature on the concept and application of adaptive management. Adaptive management is a central element of the Northwest Forest Plan and there is a need for an informed understanding of the key theories, concepts, and frameworks upon which it is founded. Literature from a diverse range of fields including social learning, risk and uncertainty, and institutional analysis was reviewed, particularly as it related to application in an adaptive management context. The review identifies opportunities as well as barriers that adaptive management faces. It concludes by describing steps that must be taken to implement adaptive management.

Steinmetz, J., Kohler, S. L., & Soluk, D. A. (2003). Birds Are Overlooked Top Predators in Aquatic Food Webs. *Ecology*, *84*(5), 1324–1328. https://doi.org/10.1890/0012-9658(2003)084[1324:BAOTPI]2.0.CO;2
Most freshwater food web models assume that fish occupy the top trophic level. Yet many diet studies and a few caging and artificial stream experiments suggest that birds may be top predators in many freshwater systems. We conducted a large-scale field experiment to test whether avian predators affect the size distribution and abundance of fish in two midwestern streams. We used a combination of netting and perches to manipulate predation by Great Blue Herons (Ardea herodias) and Belted Kingfishers (Ceryle alcyon), and measured the response in the fish assemblage. Bird exclusions caused significant increases in medium size classes of two common prey, striped shiners (Luxilus chrysocephalus) and central stonerollers (Campostoma anomalum). We show that these species of piscivorous birds can alter the abundance of common prey and thus need to be considered more fully when attempting to explain the structure of aquatic food webs.

Steuber, J. E., Pitzler, M. E., & Oldenburg, J. G. (1995). Protecting juvenile salmonids from gull predation using wire exclusion below hydroelectric dams. *Great Plains Wildlife Damage Control Workshop Proceedings*, 38–41. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1451&context=gpwdcwp
Predation by ring-billed gulls (Larus delawarenis) has been identified as a significant threat to migrant steelhead and salmon (Oncorhynchus spp.) smolt in the Columbia and Snake Rivers. Bird predation appears highest immediately below hydroelectric facilities. Installation of overhead wire/cable exclusion systems over the tailrace area of 12 dams has been completed to reduce gull predation. Data collected from 1 of the facilities as well as observations from other dams indicate that overhead wire/cable exclusion systems are effective in reducing predation by gulls.

Stinson, D. W. (2016). *Periodic Status Review for the American White Pelican* (p. 30). Washington Department of Fish and Wildlife. https://wdfw.wa.gov/sites/default/files/publications/01829/wdfw01829.pdf
The American White Pelican (Pelecanus erythrorhynchos) is a large colonial nesting bird that eats mostly non-game fish, such as carp, suckers, and sticklebacks, as well as amphibians and crayfish. The species was listed as a state endangered species in Washington in 1981. They are not listed under the federal Endangered Species Act, but are protected under the Migratory Bird Treaty Act. American White Pelican (or 'white pelican') numbers and range were reduced throughout the 19th and early 20th century due to habitat loss, persecution, and pesticide contaminants, especially DDT. In more recent decades, populations have recovered from pre-1970 declines; western colonies contained an estimated 42,692 breeding adults in 2014. Despite overall improved status, the white pelican remains a species of moderate conservation concern, primarily because of the concentration of birds on relatively few breeding colonies, and their vulnerability to disturbance, water level fluctuations, disease, and history of 'boom and bust' productivity. Concurrent with range-wide increases, the numbers of American White Pelicans observed in Washington have increased substantially in the last 30 years. Historically, white pelicans bred in eastern Washington on Moses Lakes, and perhaps at Sprague Lake and a few other sites. There are no published records of nesting after 1926, but several hundred pelicans were seasonally on Moses Lake into the 1940s. In 1994, after an absence of breeding for ~50 years, a breeding colony was established in the Columbia River north of the mouth of the Walla

Walla River. Since that time, the colony has grown steadily, and 3,118 white pelicans were counted in aerial photos in May 2016. In 2010, another colony formed on Miller Sands in Oregon waters of the Columbia River estuary. Aerial photographs from May 2016 contained 492 adults and 351 nests, but the colony was abandoned in June. Inland waters of eastern Washington also support significant numbers of non-breeding (1–2 year old) white pelicans, especially along the Columbia River from The Dalles to Chief Joseph Pool. During summer, up to 2,000 birds are observed in the Potholes region; smaller numbers remain in winter, but most winter in southern California. Although white pelicans eat mostly carp and suckers, they sometimes consume fish resources that are of conservation concern or have recreational value. White pelicans are large conspicuous birds that have increased in number and many observers assume they are impacting salmonid runs. However, based on smolt PIT tag detections, the pelicans nesting at Badger Island and Miller Sands, do not seem to be an important source of mortality for out-migrating juvenile salmonids in the Columbia and Snake rivers. There is some evidence that impacts on salmonids may be more significant at certain times and places in tributaries such as the Yakima River. Although white pelicans have recovered substantially, populations remain somewhat vulnerable and Washington still only hosts a single colony. White pelicans are highly sensitive if disturbed by humans or predators on breeding colonies and prone to desert or leave eggs and young exposed to predation. Other factors affecting white pelican populations include diseases, severe weather, and loss of breeding and foraging habitats due to water level changes. Given the increase in numbers and the new colony in the Columbia River estuary, the white pelican may no longer fit the definition of endangered in Washington, as defined in WAC 232-12- 297: Endangered species are, “seriously threatened with extinction throughout all or a significant portion of its range within the state.” It is recommended that the American White Pelican be down-listed to state threatened in Washington. A threatened species is, “likely to become an endangered species within the foreseeable future throughout a significant portion of its range within the state without cooperative management or removal of threats.”

Strod, T., Izhaki, I., Arad, Z., & Katzir, G. (2008). Prey detection by great cormorant (Phalacrocorax carbo sinensis) in clear and in turbid water. *Journal of Experimental Biology*, *211*(6), 866–872. https://doi.org/10.1242/jeb.014324

The scattering and absorption of light by water molecules and by suspended and dissolved matter (turbidity) degrade image transmission and, thus, underwater perception. We tested the effects on visual detection of prey size and distance (affecting apparent prey size) and of low-level water turbidity in hand-reared great cormorants (Phalacrocorax carbo sinensis) diving for natural prey (fish) in a forced-choice situation. The cormorants’ detection of underwater prey relied on vision. The minimal tested subtending visual angle of the prey at detection ranged between ~34.2′ (prey size constant; distance varied) and 9.5′ (distance constant; prey size varied). For all tested distances (0.8–3.1 m) the mean detection success was significantly higher than the chance level. The probability of a correct choice declined significantly with increased distance, with Detection success=–0.034D+1.021 (where D is distance, r2=0.5, N=70, P<0.001). The combined effect of turbidity and distance on the probability of detection success was significant, with both variables having a negative effect: Detection success=–0.286D–0.224Tu+1.691 (where Tu is turbidity, r2=0.68, N=144, P<0.001). At prey detection threshold, the relationship between distance and turbidity was: D=3.79e–4.55Tu. It is concluded that (i) the subtending angle of natural prey at detection was lower than that of resolution of square-wave, high-contrast grating and (ii)

turbidity, at levels significantly lower than commonly used in behavioural experiments, had a pronounced effect on visually mediated behaviour patterns.

Strong, C. M., Spear, L. B., Ryan, T. P., & Dakin, R. E. (2004). Forster's Tern, Caspian Tern, and California Gull Colonies in San Francisco Bay: Habitat Use, Numbers and Trends, 1982-2003. *Waterbirds*, *27*(4), 411–423. https://doi.org/10.1675/1524-4695(2004)027[0411:FTCTAC]2.0.CO;2

We analyzed data on numbers and annual trends of breeding terns and gulls based on censuses of all colonies of the Caspian Tern (Sterna caspia), Forster's Tern (S. forsteri) and California Gull (Larus californicus) in the San Francisco Bay estuary from 1982 to 2003. All species used nesting substrates that were flat, largely non-vegetated, had a wide view in all directions, and were composed of sand, gravel, or earth. The estuary supported 17, 13, and seven colonies of each species, respectively. Nesting terns were primarily on salt evaporation pond islands and tidal islands. The largest colony of California Gulls was on a deactivated salt pond. Total numbers of each species in 2003 were about 2,300, 2,450 and 21,200 breeding birds, respectively. Numbers of Forster's Terns declined significantly during the study, while California Gulls increased, and the number of Caspian Terns was stable. Numbers of each species at each colony site have shown considerable annual variation. We attribute the lack of colony site fidelity of each species, and the decline among Forster's Terns, primarily to mammalian predation, human disturbance, and possibly annual variation in food availability. Flat, minimally vegetated islands, which are few in the estuary, are critical for maintaining nesting terns and California Gulls. Yet, the planned restoration of 65% (9,050 ha) of the salt pond complex of the San Francisco Bay estuary will likely remove some of the salt pond islands and levees where 20% of the Caspian Terns (438 birds), 80% of Forster's Terns (1,958) and 96% of California Gulls (20,210) were nesting in 2003. We recommend that restoration plans should include the creation of sizeable tracts of islands specifically designed to provide nesting habitat for these larids. These replacement sites should be in place soon after the restoration has been implemented; i.e., well before scheduled completion. This is especially important because severe habitat limitation would lead to competition for nesting space among the three species, a situation expected to result in exclusion of the terns by the gull, which nests earlier, are larger, more abundant, and more aggressive.

Sundström, L. F., Petersson, E., Höjesjö, J., Johnsson, J. I., & Järvi, T. (2004). Hatchery selection promotes boldness in newly hatched brown trout (Salmo trutta): Implications for dominance. *Behavioral Ecology*, *15*(2), 192–198. https://doi.org/10.1093/beheco/arg089

By using newly hatched (approximately 2 weeks old) brown trout (Salmo trutta) from six families of wild and six families of sea-ranched origin (seventh generation), we tested the hypotheses that (1) the hatchery environment selects for increased boldness, and (2) boldness predicts dominance status. Sea-ranched trout spend their first 2 years in the hatchery before being released into the wild at the onset of seaward migration. Trout were presented with a novel object (tack) and with food (brine shrimp), and their responses were measured and scored in terms of boldness. Siblings with increasing difference in boldness were then paired in dyadic contests. Fish of sea-ranged origin were on average bolder than were fish of wild origin, and bolder individuals were more likely to become dominant regardless of origin. Boldness was not related to RNA levels, indicating that bold behavior was not a consequence of higher metabolism or growth rate. Neither was size a predictor of bold behavior or the outcome of dyadic contests. These results are consistent with studies on older life stages showing increased boldness toward predators in hatchery-selected fish, which suggests that behavioral consequences of hatchery selection are manifested very early in life. The concordance between boldness and dominance may suggest that these behaviors are linked in a risk prone-aggressive phenotype, which may be promoted by hatchery selection. However, we also found significant variation in behavioral and growth-related traits among families, suggesting that heritable variation has not been exhausted by sea-ranching procedures.

Suryan, R. M., Craig, D. P., Roby, D. D., Chelgren, N. D., Collis, K., Shuford, W. D., & Lyons, D. E. (2004). Redistribution and growth of the Caspian Tern population in the Pacific Coast region of north America, 1981-2000. *Condor*, *106*(4), 777–790. https://doi.org/10.1650/7508

We examined nesting distribution and demography of the Pacific Coast population of Caspian Terns (Sterna caspia) using breeding records and band recoveries spanning two decades since the first population assessment. Since 1980, population size has more than doubled to about 12 900 pairs, yet the proportion of the population nesting at inland (18%) versus coastal sites (82%) has remained constant. Although the breeding range of the Pacific Coast population has expanded northward into Alaska and farther south in Mexico, there was no net latitudinal shift in the distribution of breeding pairs or new colonies. The distribution of breeding birds among areas changed dramatically, however, with 69% of breeding terns now nesting in Oregon (primarily in the Columbia River estuary) versus 4% during the late 1970s. During the past 20 years, there has continued to be a greater proportion of Caspian Terns breeding at anthropogenic sites compared to natural sites. Estimated annual survival rates for hatch-year and after-third-year birds during 1981-1998 were greater than during 1955-1980, consistent with the higher rate of population increase in recent decades. Fecundity required to maintain a stable population (lambda = 1) was estimated at 0.32-0.74 fledglings/pair, depending on band recovery probabilities for sub-adults. Caspian Terns readily moved among breeding sites and rapidly colonized new areas; however, a greater concentration of breeding Caspian Terns among fewer colonies in response to anthropogenic factors is an important conservation concern for this species.

Suzuki, Y. (2012). *Piscivorous Colonial Waterbirds in the Columbia River Estuary: Demography, Dietary Contaminants, and Management* [Oregon State University]. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/47429c39b

Caspian terns (Hydroprogne caspia) and double-crested cormorants (Phalacrocorax auritus) nest in large colonies on East Sand Island in the Columbia River estuary, the largest known colonies for the two species in the world. Both species of piscivorous colonial waterbirds have been identified as predators with a significant impact on the survival of juvenile salmonids (Oncorhynchus spp.) listed under the U.S. Endangered Species Act. To better understand and address issues related to seabird-fisheries interactions in the Columbia River estuary, I conducted studies related to the ecology, conservation, and management of these two species of piscivorous waterbirds. I evaluated the demographics and inter-colony movements of Caspian terns belonging to the Pacific Coast metapopulation, with special emphasis on two breeding colonies, one on East Sand Island in the Columbia River estuary and the other on Crescent Island in the mid-Columbia River, based on re-sightings of color-banded individuals. Apparent annual adult survival at both colonies was high, and age at first reproduction was greater than previously reported for the species. Colony site philopatry of breeding adults at both colonies was high; however, some individuals prospected for breeding colonies over much of the Pacific Coast

region and moved to other colonies over distances of up to 3,000 km. Some terns from the large colony in the Columbia River estuary responded quickly to the availability of new colony sites as distant as 550 km from the estuary, and established successful breeding colonies within less than a year of the new sites becoming available. The Caspian tern colony on East Sand Island appears to be an important source colony for a number of smaller, less productive colonies distributed over an extensive area from the Salton Sea, California to the Copper River Delta, Alaska, an area with limited and ephemeral nesting opportunities. Environmental contaminants have been a conservation concern for wildlife in the Columbia River estuary, especially species that consume fish and are therefore likely to bioaccumulate persistent organic pollutants. I measured and compared levels of polychlorinated biphenyls (PCBs) in eggs and chicks of Caspian terns and double-crested cormorants, as well as their primary prey fish types, at colonies on East Sand Island and farther up-river. Based on differences in tern and cormorant diet composition at the various study colonies, higher PCB levels in eggs and chicks were associated with diets dominated by resident freshwater and estuarine fishes. PCB levels in prey fish were positively correlated with lipid content; however, PCB levels in the livers of chicks were negatively correlated with chick fat scores, suggesting that chick fat reserves are a sink for ingested PCBs. Lower PCB levels in terns and cormorants from East Sand Island compared to colonies farther up-river reflected diets with a higher proportion of marine forage fishes at East Sand Island; marine forage fishes had lower average levels of PCBs than their resident freshwater and estuarine counterparts. In order to explore non-destructive techniques for managing nesting colonies of double-crested cormorants, I evaluated habitat enhancement and social attraction, two techniques that have proven effective for relocating Caspian tern colonies to sites where impacts on fish stocks of conservation concern would be minimal. Cormorants were attracted to nest and successfully raised young at test plots on East Sand Island and on islands in the estuary with a previous history of cormorant nesting or unsuccessful nesting attempts. On an island with no history of cormorant nesting or prospecting, however, no cormorants were attracted to nest. My results suggest that attraction of nesting cormorants using these techniques is dependent on the previous history of cormorant nesting or nesting attempts, the frequency and intensity of disturbance by potential predators, and the presence of breeding cormorants nearby. While habitat enhancement and social attraction have potential as methods for redistributing nesting cormorants away from areas where fish stocks of concern are highly susceptible to predation, successful establishment of new colonies using these techniques will likely require a focus on sites with a history of cormorant nesting. Findings from this dissertation raise some concerns over the management of Caspian tern and double-crested cormorant colonies on East Sand Island in order to redistribute parts of these colonies to alternative sites and mitigate the impact of those piscivorous colonial waterbirds on ESA-listed salmonids. East Sand Island has supported source colonies of piscivorous colonial waterbirds for many smaller colonies throughout the region and is close to an abundant and relatively uncontaminated food supply. Also, alternative colony sites that can substitute for East Sand Island are not readily apparent, especially for double-crested cormorants. Therefore, management of Caspian tern and double-crested cormorant colonies on East Sand Island to benefit Columbia Basin salmonids needs to proceed cautiously and reversibly because of the implications for the region-wide populations of these piscivorous colonial waterbirds.

Suzuki, Y., Bishop, M. A., Roby, D. D., & Bixler, K. S. (2019). Colony Connectivity and the Rapid Growth of a Caspian Tern (Hydroprogne caspia) Colony on Alaska's Copper River Delta, USA. *Waterbirds*, *42*(1), 1–7. https://doi.org/10.1675/063.042.0101

North America's northernmost, sizable colony of Caspian Terns (Hydroprogne caspia) is located on the Copper River Delta of south-central Alaska, USA. The colony was monitored in June during 2008-2016 and in July during 2009-2013. This 9-year period coincided with reduction of Caspian Tern nesting habitat at East Sand Island in the Columbia River estuary, Oregon, USA, one of the world's largest Caspian Tern breeding colonies. The number of active nests on the Copper River Delta more than doubled during the early study period from 209 in 2008 to 423 in 2013. However, there was a steady decline in the number of nests during 2014 (281) to 2015 (115) and the colony failed in 2016. These declines were likely due to warm sea surface temperature anomalies across the northeastern Pacific Ocean in those years. Based on resightings of banded individuals, colony connectivity was documented between the Copper River Delta and other colonies, ranging from southeast Alaska (215 km) to central California, USA (> 3,000 km). The East Sand Island colony was the most important source of immigrants to the Copper River Delta. While the Copper River Delta now serves as important natural breeding habitat for Caspian Terns, increased flooding and severe storms associated with climate change will likely limit colony size and productivity in the long-term.

Suzuki, Y., Heinrichs, J., Lyons, D. E., Roby, D. D., & Schumaker, N. (2018). *Modeling the Pacific Flyway Population of Caspian Terns to Investigate Current Population Dynamics and Evaluate Future Management Options* (p. 107). http://www.birdresearchnw.org/CATE%20Pacific%20Flyway%20population%20model%20final%20report_ver6.4.pdf

In order to evaluate the effects of potential management options on future trends in the Pacific Flyway population of Caspian terns (Hydroprogne caspia), we developed a demographic population model in HexSim, a spatially explicit population simulator software package where individual terns are simulated to move through key life history events (e.g., recruiting into the adult breeding population, natal and breeding dispersal, producing young). Demographic parameters included in the model, such as survival rates and inter-regional movement rates, were estimated in a capture-recapture framework using data collected from 5,239 individuals marked with field-readable leg bands. This model was designed to forecast sub-population trajectories in five regions that encompass the entire breeding range of the Pacific Flyway population, which currently consists of about 12,000 breeding pairs. Empirically-based carrying capacity in each region was used to constrain the size of the breeding population. We used this population model to project the Pacific Flyway population of Caspian terns under 16 different scenarios of management and environmental conditions for breeding. First, we ran the model under a "baseline" or status quo management scenario to assess the current (as of 2017) population trajectory, under the assumption of no change in management or environmental conditions for breeding. The other 15 scenarios used for population simulation were based on various prospective or hypothetical management actions that might be implemented in the future (e.g., changes in available nesting habitat, reduced adult survival due to a cull) and environmental conditions for breeding (e.g., changes in predator disturbance rates) that the current population may have transitioned to or could experience in the future. Many other possible management scenarios or changes in environmental conditions could be assessed using this population modeling framework, either individually or in combination, if new management proposals or alternative environmental conditions emerge in the future. Using current demographic parameter estimates, model simulations assuming status quo management in the Columbia River basin (baseline) projected a larger Flyway-wide population of Caspian terns, with a 41% increase over a 30-year simulation period. The breeding portion of the population increased by about 25%, with a much more pronounced increase in the nonbreeding portion of the population (261%) during the simulation period; stability occurred in both portions of the population at about 33 years. The proportion of the adult population that was non-breeders increased from 7% to 18% over the course of the 30-year simulation period. Current rates of survival and fledgling production, and adequate carrying capacity throughout the Flyway, if sustained, appear sufficient to allow population persistence at or somewhat above the current level, even with recent managed reductions in available tern nesting habitat in the Columbia River estuary and the Columbia Plateau region. Nevertheless, the presence of at least a small colony (ca. 1,000 breeding pairs) at East Sand Island in the Columbia River estuary, with the high adult survival and peaks in fecundity associated with that site, appears to be critical to the long-term persistence of a significant Caspian tern population in the Pacific Flyway under current conditions. A hypothetical scenario to simulate complete elimination of the large Caspian tern colony at East Sand Island projects a long-term decreasing trend in the Pacific Flyway population, well beyond the 30-year simulation period. The Pacific Flyway population of Caspian terns was also simulated under eight different management scenarios to evaluate the potential effects of prospective or hypothetical tern habitat management actions, singly and in combination, on the trajectory of the Flyway-wide population. These management scenarios all reduced the available nesting habitat in one or more regions (Columbia River estuary, Columbia Plateau, and/or southern Oregon and northeastern California [SONEC]) to limit the number of breeding pairs that could nest. These three regions were selected for simulating the population-level effects of various management options because they are areas where some management has already been conducted and where additional management has been proposed. Additionally, the most complete empirical datasets allowing estimation of vital rates and movement rates were available for these regions. Habitat reductions were modeled as reductions in the estimated maximum carrying capacity of a given region. Prospective management scenarios that reduced tern nesting habitat in only a single region at a time produced increases in the overall Pacific Flyway-wide population, albeit at a lower rate than in the baseline management scenario. Potential management scenarios involving the simultaneous reduction of carrying capacity in two of the three regions revealed an additive effect of reduction in nesting habitat, and a management scenario involving the simultaneous reduction in tern nesting habitat in all three regions eliminated all projected growth in the Flyway-wide population. A potential management scenario to simulate the creation of new Caspian tern nesting habitat on the Washington coast, by increasing carrying capacity in the Salish Sea region to commensurately compensate for reduced carrying capacity in the Columbia River estuary, produced a steady increase in the total Flyway-wide population, but at a lower rate than in the baseline scenario. The population trajectory under this scenario stabilized at a level similar to that under the baseline scenario, but not until about 50 years. Scenarios where survival rates of breeding adults in the Columbia River estuary were temporarily reduced to simulate lethal control (a hypothetical 4-year cull of breeding adults) produced a decline in the Flyway-wide population during years when the cull was conducted. No long-term impact on underlying demographic rates was presumed as part of these scenarios; thus, the population increased once the culling of breeding adults ceased. Because only the direct effects of a cull on adult survival were incorporated in the model under these culling scenarios, the potential indirect effects frequently associated with culls at breeding colonies (e.g., reduced fecundity, colony abandonment) were not considered. The decline of breeding adults in the Columbia River estuary during the cull was less than the number of adults lethally removed, due to recruitment and immigration from other regions replacing culled individuals, indicating that the benefits to salmonid populations per tern culled would be less than predicted by analyses that do not incorporate recruitment and movement patterns. Environmental conditions for breeding in the Columbia River estuary were quite favorable for Caspian terns in the early 2000s. When these early, productive years were excluded from model inputs and breeding conditions (categorized based on fledging success rates) were based on just those observed during the last decade, the model still projected an increasing Pacific Flyway population, but a smaller increase (30%) than in the baseline management scenario (41%). In a scenario that simulated even poorer environmental conditions for breeding in the Columbia River estuary than the average observed over the last decade (representing a possible permanent shift in the impacts of predators such as bald eagles, or the degradation of habitat quality on the East Sand Island colony due to vegetation encroachment and island erosion), the Flyway-wide population was projected to remain stable after about a 14% increase. This level of constrained growth was similar to the prospective management scenario where reduced carrying capacity was only applied to the Columbia River estuary. We did not examine a scenario where both habitat at East Sand Island was reduced due to management and breeding conditions degraded due to predators, vegetation encroachment, or island erosion, but if management were entirely additive to degraded breeding conditions then both effects combined would result in a 13% decline in the Pacific Flyway population over the 30-year simulation period. Under a scenario that simulated better environmental conditions for breeding in the SONEC region (due to ameliorating drought conditions) than were observed during the last decade, the Flyway-wide population was projected to increase to a slightly higher level than under the baseline management scenario (45% vs. 41%). The model developed herein to examine the Pacific Flyway population of Caspian terns is among the most sophisticated population models available for colonial waterbirds. It incorporates both life history complexity (e.g., delayed maturity, age structured survival and breeding propensity) and spatial specificity (e.g., natal and breeding dispersal, region-specific demographic rates across five distinct regions of the breeding range), and is based on empirical data collected throughout the Flyway over more than a decade. Model simulations indicate resiliency of the Pacific Flyway population of Caspian terns under some prospective management scenarios. Caution should be exercised, however, because the model population trajectories under the baseline management scenario and under other prospective or hypothetical management scenarios depend on the quantity and quality of nesting habitat available for Caspian terns in the Pacific Flyway, the predominant limiting factor for this population. Also, certain combinations of management actions coupled with realistic changes in breeding conditions that follow recent trends (e.g., simultaneous reductions in nesting habitat in the Columbia River estuary and the Columbia Plateau region due to management, coupled with recent environmental conditions for breeding in the Columbia River estuary persisting into the future) would likely result in long-term declines in the Pacific Flyway population, even when assumptions are made for the continued availability of nesting habitat outside of the Columbia River basin at the maximum levels observed to date. In particular, circumstances that substantially reduce the unique capacity for fledgling production at the East Sand Island colony in the Columbia River estuary, if not compensated for by a similar high capacity for fledgling production elsewhere in the Pacific Flyway, are likely to result in a population of substantially

reduced size, or potentially even a long-term downward trend that could put the Pacific Flyway population of Caspian terns at risk of greatly reduced resiliency.

Suzuki, Y., Roby, D. D., Lyons, D. E., Courtot, K. N., & Collis, K. (2015). Developing nondestructive techniques for managing conflicts between fisheries and double-crested cormorant colonies: Nondestructive Cormorant Management Techniques. *Wildlife Society Bulletin*, *39*(4), 764–771. https://doi.org/10.1002/wsb.595

Double-crested cormorants (Phalacrocorax auritus) have been identified as the source of significant mortality to juvenile salmonids (Oncorhynchus spp.) in the Columbia River Basin. Management plans for reducing the size of a large colony on East Sand Island (OR, USA) in the Columbia River estuary are currently being developed. We evaluated habitat enhancement and social attraction as nondestructive techniques for managing cormorant nesting colonies during 2004–2007. We tested these techniques on unoccupied plots adjacent to the East Sand Island cormorant colony. Cormorants quickly colonized these plots and successfully raised young. Cormorants also were attracted to nest and raised young on similar plots at 2 islands approximately 25 km from East Sand Island; 1 island had a history of successful cormorant nesting whereas the other was a site where cormorants had previously nested unsuccessfully. On a third island with no history of cormorant nesting or nesting attempts, these techniques were unsuccessful at attracting cormorants to nest. Our results suggest that some important factors influencing attraction of nesting cormorants using these techniques include history of cormorant nesting, disturbance, and presence of breeding cormorants nearby. These techniques may be effective in redistributing nesting cormorants away from areas where fish stocks of conservation concern are susceptible to predation, especially if sites with a recent history of cormorant nesting are available within their foraging or dispersal range.

Takekawa, J. Y., Lu, C. T., & Pratt, R. T. (2001). Avian communities in baylands and artificial salt evaporation ponds of the San Francisco Bay estuary. In J. M. Melack, R. Jellison, & D. B. Herbst (Eds.), *Saline Lakes: Publications from the 7th International Conference on Salt Lakes, held in Death Valley National Park, California, U.S.A., September 1999* (pp. 317–328). Springer Netherlands. https://doi.org/10.1007/978-94-017-2934-5_29

San Francisco Bay wetlands, seasonal and tidal marshes between the historic low and high tide lines, are now highly fragmented because of development during the past 150 years. Artificial salt pond systems in the Bay are hypersaline and typically support simple assemblages of algae and invertebrates. In order to establish the value of salt ponds for migratory waterbirds, we used datasets to conduct a meta-analysis of avian communities in the baylands and salt ponds of San Pablo Bay. Fifty-three species of waterbirds in the salt ponds represented six foraging guilds: surface feeders, shallow probers, deep probers, dabblers, diving benthivores and piscivores. The total number of species and the Shannon-Weiner diversity index was higher in baylands than in salt ponds during all four seasons. However, overall bird density (number/ha) was higher in salt ponds compared with baylands in the winter and spring, primarily because of large concentrations of benthivores. Cessation of salt production in 1993 and subsequent reduction in water depth resulted in a decline of some diving duck populations that used the salt ponds.

Tarjan, M. (2018). *Citizen Science-Based Colonial Waterbird Monitoring 2018 Nesting Summary* (p. 23). https://www.sfbbo.org/uploads/1/1/6/7/116792187/cwb_annual_report_2018.pdf

The San Francisco Bay Bird Observatory (SFBBO) is a nonprofit organization dedicated to the conservation of birds and their habitats through science and outreach. The Colonial Waterbird Program (CWB) is one of SFBBO's long-standing citizen science programs, initiated in 1982 to monitor waterbird nesting colonies in the San Francisco Bay. The program has engaged hundreds of citizen scientists in waterbird nest-monitoring activities and introduced thousands of local community members to the presence of these birds and their needs for protection and management. Trained citizen scientists independently collect observational data on nesting status, timing of breeding, waterbird behavior, and evidence of disturbance at selected colonies each year. Citizen scientists also assist SFBBO staff in conducting annual walkthrough counts of all known California Gull colonies in the South San Francisco Bay (South Bay), which enables comparison of colony sizes and locations over time. This information is shared with landowners, resource agencies, and other conservation organizations and contributes to the conservation and management of these species. In addition to monitoring colonies, many citizen scientists in the program help SFBBO develop relationships with landowners and communities living near the colonies they study and lead presentations and bird viewings to share these birds with the public.

Taylor, B., & Fraser, G. S. (2012). Effects of egg oiling on ground-nesting double-crested cormorants at a colony in Lake Ontario: An examination of nest-attendance behaviour. *Wildlife Research*, *39*(4), 329–335. https://doi.org/10.1071/WR11035

Context. We assessed the effects of egg oiling on ground-nesting double-crested cormorants (Phalacrocorax auritus) in the context of an emerging management strategy for the largest known cormorant colony on the lower Great Lakes. We designed the present study to answer specific questions in response to concerns raised by stakeholders and members of the public regarding this management technique. Aims. The aim of the present study was to examine the behavioural response of adult cormorants to egg oiling. Prior work on this issue has focussed on population-response questions rather than the behavioural level. Consequently, detailed observations on how cormorants respond to egg oiling are lacking. Methods. Using instantaneous and focal observations to measure behaviours, we compared Treatment nests (n = 24, 23) to Control (n = 24) and Sham (handled, but not treated; n = 24) nests. We observed nest attendance, incubation and mate-presence behaviour, and divided observations into pre-chick and entire-season categories for analysis. Key results. Our study determined that egg oiling does not cause immediate nest desertion by adult birds; Treatment birds incubated their nests as long as did Sham and Control birds. We found no difference among the three groups in the proportion of time a mate was present during incubation for Control and Sham nests in the pre-chick period. We found that the total seasonal duration of nest attendance by Treatment birds was shorter than that for the birds in the other groups. Conclusions. Both incubation and mate-presence data suggest that egg oiling did not measurably affect the behaviour of adult cormorants in the pre-chick period. Our study also suggests that Treatment birds attended their nest long enough to preclude re-nesting within the breeding season, although this may not apply for regions with longer nesting seasons. Implications. Our study indicates that egg oiling, administered judiciously, may be an appropriate management technique for ground-nesting cormorants, although management targets must be clearly articulated.

Teuscher, D. M., Green, M. T., Schill, D. J., Brimmer, A. F., & Hillyard, R. W. (2015). Predation by American White Pelicans on Yellowstone Cutthroat Trout in the Blackfoot River Drainage,

Idaho. *North American Journal of Fisheries Management*, *35*(3), 454–463. https://doi.org/10.1080/02755947.2015.1017118

Expansion of the American white pelican Pelicanus erythrorhynchos colony on Blackfoot Reservoir, Idaho, and the associated declines in adfluvial Yellowstone Cutthroat Trout Oncorhynchus clarkii bouvieri in the upper Blackfoot River drainage has generated concern about the impact of pelican predation on this native trout stock. During a 4-year study, 4,653 wild Yellowstone Cutthroat Trout were tagged using a combination of radiotelemetry and PIT tags. Annual predation rate estimates were made by recovering Yellowstone Cutthroat Trout tags from the nesting islands of American white pelicans. On-island tag recovery rates were corrected for ingested tags that went undetected during island searches and for tags that were deposited away from the nesting islands. American white pelicans consumed tagged Yellowstone Cutthroat Trout ranging from 150 mm to 580 mm TL and showed no size selection within that range for their prey. Predation rates on adult and juvenile Yellowstone Cutthroat Trout generally exceeded 20%, and the highest values were above 60%. Our independent methods (telemetry and PIT tagging) for estimating pelican predation on adult Yellowstone Cutthroat Trout produced similar results. Annual river flow conditions varied markedly and may have contributed to some of the observed range in predation rate estimates. Predation by the pelican colony appears to be a likely contributor to the recent collapse of Yellowstone Cutthroat Trout in the upper Blackfoot River drainage. In the past, overexploitation by anglers severely reduced the trout population and was remedied by implementing catch-and-release regulations. The current predation impact poses a greater management challenge, namely, finding a balanced approach for conserving both the native trout stock and the pelican colony.

Thompson, S. P., & Littlefield, C. D. (1980). Historical Review and Status of Colonial Nesting Birds on Malheur National Wildlife Refuge, Oregon. *Proceedings of the Colonial Waterbird Group*, *3*, 156–164. JSTOR.

Tucker, S., Hipfner, J. M., & Trudel, M. (2016). Size- and condition-dependent predation: A seabird disproportionately targets substandard individual juvenile salmon. *Ecology*, *97*(2), 461–471. https://doi.org/10.1890/15-0564.1

Selection of prey that are small and in poor body condition is a widespread phenomenon in terrestrial predator-prey systems and may benefit prey populations by removing substandard individuals. Similar selection is widely assumed to operate in aquatic systems. Indeed, size-selective predation is a longstanding and central tenet of aquatic food web theory. However, it is not known if aquatic predators select prey based on their condition or state, compared to their size. Surprisingly, no comparable information is available for marine systems because it is exceedingly difficult to make direct observations in this realm. Thus the role of body condition in regulating susceptibility to predation remains a black box in the marine environment. Here we have exploited an ideal model system to evaluate selective predation on pelagic marine fish: comparing characteristics (fork length, mass corrected for fork length) of fresh, whole, intact juvenile Pacific salmon delivered by a seabird to its single nestling with salmon collected concurrently in coastal trawl surveys. Three species of juvenile salmon (Oncorhynchus spp.) are consumed by provisioning Rhinoceros Auklets (Cerorhinca nionocerata); an abundant, colonial, pursuit-diving seabird. Samples were collected from multiple colonies and fisheries surveys in coastal British Columbia in two years. As predicted, Auklets preyed on small individuals in poor condition and consistently selected them at levels higher than their relative availability. This is

the first study to provide direct evidence for both size- and condition-selective predation on marine fish in the wild. We anticipate that our results will be a starting point in evaluating how selective predation may structure or influence marine fish populations and bridges a fundamental incongruity between ecological theory and application; although "bigger is better" is considered a fundamental tenet of marine food webs, marine predators are often assumed to consume indiscriminately.

Turecek, A., Tennyson, J., Collis, K., & Cramer, B. (2018). *Double-crested Cormorant Monitoring on East Sand Island, 2017* (p. 23). http://www.birdresearchnw.org/2017%20ESI%20DCCO%20Monitoring%20%20Annual%20Report%20Final.pdf

To reduce avian predation on juvenile salmonids in the Columbia River estuary, the U.S. Army Corps of Engineers (Corps) is continuing to implement the Double-crested Cormorant Management Plan to Reduce Predation on Juvenile Salmonids in the Columbia River Estuary, which consists of measures designed to reduce the size of the double-crested cormorant (DCCO; Phalacrocorax auritus) colony at East Sand Island (ESI). The purpose of this project was to provide the Corps with information needed to implement, monitor, evaluate, and adaptively manage the Double-crested Cormorant Management Plan during the 2017 breeding season. The objectives of this study were to (1) repair and modify existing infrastructure on the DCCO colony on ESI used for monitoring and implementation of the management plan, including removal of materials that may serve as a hazard to nesting birds and (2) conduct surveys to enumerate and monitor DCCO and Brandt's cormorants (BRAC; P. penicillatus) on ESI without disrupting nesting or roosting birds. The cormorant colony was visited weekly to determine colony status, and enumerate DCCO and BRAC nests and individuals. Colony visits consisted of on-island surveys and boat-based surveys. Autonomous cameras deployed on the colony were monitored daily to broadly assess colony status (i.e., presence or absence of cormorants) and inform decisions regarding other monitoring needs throughout the season. High-resolution aerial photography was collected concurrently with on-colony monitoring by researchers when cormorants occupied the colony site for breeding. The high-resolution aerial photography was orthorectified and analyzed to enumerate cormorant individuals and active nests. Image-derived counts were classified by species based on field observations made during ground-based monitoring. Pre-breeding season colony preparations on the DCCO colony was completed on 11 April, prior to DCCO arrival. Monitoring occurred from 16 April–13 October, with 13 aerial survey flights and 23 colony monitoring surveys conducted. DCCO began loafing in large numbers on the north beaches of ESI on 17 April. DCCO began sporadic attempts at occupying the colony area during early to mid-May, and finally established a continuous presence on the colony for seven days from 13–19 May. A second week-long period of continuous presence on the colony was observed on 30 May, before cormorants dispersed from ESI on 5 June. Successful DCCO and BRAC nesting did eventually occur on ESI on the far west jetty and the adjacent upland east of the jetty beginning in mid-July, and cormorants remained on colony until the end of monitoring (13 October). Peak DCCO nesting occurred on 26 July, with 544 breeding pairs (95% CI = 512 – 576 breeding pairs), approximately 94% fewer than the peak colony count from 2016. The DCCO colony area was 0.26 acres. Nest density was 0.5 nests/m^2, approximately 50% lower than nest density prior to management. By 13 October no cormorants were observed incubating eggs, and chicks of both species had been mobile for several weeks. DCCO and BRAC breeding success was likely low. Based on our experience monitoring the DCCO colony in 2017, combined with our past ESI DCCO monitoring projects (1997-2014), we offer the following recommendations for monitoring during future DCCO breeding seasons: o Contract award at least 6 weeks prior to DCCO arrival at ESI (typically late March or early April) is essential to ensure adequate time for project planning and infrastructure maintenance o Deploy several additional autonomous camera systems on the colony to provide remote monitoring of the entire colony (including views of the west jetty, beaches, and tidal flats) o Conduct aerial mapping flights with a combination of traditional manned, fixed-wing mapping systems and small unmanned aerial systems o Include DCCO monitoring throughout the Columbia River Estuary to achieve comprehensive estuary-wide monitoring as part of a single project o Include a regional monitoring component to assess DCCO use of historical colonies (i.e. the coast of Washington and Puget Sound) to help assess where cormorants displaced from ESI and the Columbia River Estuary might be going

Turecek, A., Tennyson, J., von Weller, P., Collis, K., & Cramer, B. (2018). *Double-crested Cormorant Monitoring on East Sand Island and in the Columbia River Estuary, 2018* (p. 29). http://www.birdresearchnw.org/2018%20ESI%20DCCO%20Monitoring%20%20Annual%20Report%20Final%20Final.pdf

To reduce avian predation on juvenile salmonids in the Columbia River estuary, the U.S. Army Corps of Engineers (Corps) is continuing to implement the management plan entitled, “Double-crested Cormorant Management Plan to Reduce Predation on Juvenile Salmonids in the Columbia River Estuary”. In 2018, the Corps reduced the habitat available to double-crested cormorants (DCCO; Phalacrocorax auritus) for breeding to approximately 1.7 acres, which would accommodate approximately 7,322 nests at the historical nest density of 1.1 nest/m^2. The purpose of this project was to monitor the East Sand Island (ESI) DCCO colony during the 2018 breeding season to provide the Corps with in-season information on the colony that would inform the adaptive management of the plan. The primary objectives of this study were to (1) conduct surveys to monitor and enumerate DCCO and Brandt’s cormorants (BRAC; P. penicillatus) on ESI without disrupting nesting birds within the designated colony area and (2) conduct surveys of DCCO, BRAC, and pelagic cormorants (PECO; P. pelagicus) on the Astoria-Megler Bridge and DCCOs on the Longview Bridge located in the lower Columbia River and estuary. The ESI cormorant colony was visited at least weekly to determine colony status and enumerate DCCO and BRAC nests and individuals. Colony visits consisted of on-island surveys and boat-based surveys. Autonomous cameras deployed on the colony were monitored daily to broadly assess colony status (i.e., presence or absence of cormorants) and inform decisions regarding other monitoring needs throughout the season. High-resolution aerial photography was collected concurrently with on-colony monitoring by researchers. Aerial photography was orthorectified and analyzed to enumerate cormorant individuals and active nests. Image-derived counts were classified by species (i.e., DCCO or BRAC) based on field observations made during ground-based monitoring, and interpretation of oblique imagery collected during aerial photo surveys. Pre-breeding season colony preparations on the ESI cormorant colony was completed on 9 April. Monitoring occurred from 25 April – 26 September, with 20 aerial survey flights and 31 colony monitoring surveys conducted. DCCO began loafing on the north beaches of ESI in large numbers on 15 April. They initiated sporadic attempts at occupying the colony area during early to mid-May, and eventually began roosting on the colony overnight and consistently attending the colony during the day on 15 May. The first aerial survey of the colony was conducted on 22 May. Frequent predator pressure from bald eagles (Haliaeetus leucocephalus)

limited cormorant colony formation throughout May and June. By 4 July the bald eagle presence on ESI subsided and the DCCO colony subsequently stabilized and grew to its peak colony size of 3,672 active nests (95% CI = 3,662 – 3,682), or breeding pairs, on 25 July. The DCCO colony area was approximately 0.8 acres and occupied 65% of the available breeding habitat within the designated colony area. Efforts by United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) personnel to dissuade DCCOs from nesting outside the designated colony area on ESI in 2018 were successful. In 2018, nest density of ESI DCCO was 1.2 active nests per m^2, slightly higher than the pre-management average for nesting density (1.1 active nests per m^2). Nesting success for the DCCO on ESI was estimated to be 1.8 young raised per active nest (95% CI = 0.98 – 2.66) in 2018, identical to the average nesting success for DCCO on ESI prior to management. The DCCO colony on the Astoria-Megler Bridge peaked at 1,737 breeding pairs on 7 June, with nesting success estimated to be 2.7 young raised per active nest (95% CI = 2.55 – 2.93). The size of the DCCO colony on the Astoria-Megler Bridge has been increasing in every year since monitoring began in 2004 (which the exception of 2010), with the largest numerical increase in colony size occurring in 2018, when the colony more than doubled as compared to the size of the colony in 2017 (834 nests). Peak DCCO colony size at the Longview Bridge was observed on 4 May, with 201 active nests. This represents a ca. 25% increase in colony size on the Longview Bridge as compared to 2017 (147 active nests).

USACE. (2014). *Inland Avian Predation Management Plan Environmental Assessment* (p. 560). https://www.nww.usace.army.mil/Portals/28/docs/programsandprojects/IAPMP/Final_IAPMP_EA_Fullpackage%20vs1.pdf

This Inland Avian Predation Management Plan (IAPMP) Environmental Assessment (EA) addresses a set of proposed actions to reduce avian predation on federal Endangered Species Act (ESA)-listed salmonids in the inland Columbia River Basin above Bonneville Dam. This EA identifies a purpose and need, develops and evaluates a set of alternatives to meet the purpose and need, considers the trade-offs of the alternatives and selects a preferred alternative. The IAPMP (Appendix A) was developed as a guide for the implementation of the preferred alternative in this EA and includes detailed recommendations for implementation, monitoring, and adaptive management. The development of an IAPMP is a requirement of the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) 2008 Federal Columbia River Power System (FCRPS) Biological Opinion as updated in the 2010 Supplemental FCRPS Biological Opinion (referred to collectively as the BiOp unless the date is specified). The EA identifies actions to reduce predation on salmonids in the inland Columbia River Basin and focuses on the management of Caspian terns (CATEs) at Goose and Crescent Islands, habitat enhancement to attract CATEs to areas outside the Columbia River Basin, and adaptive management actions to limit the formation of incipient colonies within the basin. The IAPMP and Adaptive Management Plan (AMP) are included as an appendix to this document (Appendix A) which can be referenced for additional details on implementation.

USACE. (2015). *Double-crested cormorant management plan to reduce predation of juvenile salmonids in the Columbia River Estuary: Final environmental impact statement* (p. 1099). https://usace.contentdm.oclc.org/digital/collection/p16021coll7/id/2203/

In this Final Environmental Impact Statement, the U.S. Army Corps of Engineers (Corps) has evaluated several alternatives to reduce predation-related losses of juvenile salmon (Oncorhynchus spp.) and steelhead (O. mykiss) from double-crested cormorants (Phalacrocorax

auritus) nesting on East Sand Island in the Columbia River Estuary. Many of these juvenile salmon and steelhead (referred to collectively hereafter as salmonids; Figure ES-1) are listed as threatened or endangered under the Endangered Species Act. Development and implementation of a management plan to reduce avian predation is a requirement from the Corps' consultation under the Endangered Species Act with the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration (NOAA Fisheries) for the operation of the hydropower dams that make up the Federal Columbia River Power System. The proposed management plan in this Final Environmental Impact Statement was developed to comply with reasonable and prudent alternative action 46 in the 2008 and associated 2010 and 2014 Supplements to the Federal Columbia River Power System Biological Opinion issued by NOAA Fisheries. Management of double-crested cormorants is necessary to increase survival of juvenile salmonids by reducing predation-related losses. Over the past 15 years, double-crested cormorants on East Sand Island consumed approximately 11 million juvenile salmonids per year, although total consumption varies each year and by salmonid population. When compared to other known mortality factors, this level of predation is considered a substantial source of mortality. Predation-related losses of juvenile steelhead are of particular concern for resource managers, as data to date indicate they are most impacted by double-crested cormorant predation (NOAA Fisheries 2014). Average annual double-crested cormorant predation rates of juvenile steelhead originating upstream of the Bonneville Dam have ranged from 2 to 17 percent over the past 15 years (depending on the run, or distinct population segment, and year). Double-crested cormorants are native to the Columbia River Estuary. Approximately 98 percent of double-crested cormorants breeding in the Columbia River Estuary nest on East Sand Island. The colony on East Sand Island near the mouth of the Columbia River has increased from 100 breeding pairs in 1989 to approximately 15,000 breeding pairs in 2013, likely due to changes regarding habitat, nesting, and foraging conditions near the mouth of the Columbia River that are favorable for the species. The colony accounts for approximately 40 percent of the western population of double-crested cormorants, which includes the breeding colonies from British Columbia to California and east to the Continental Divide. Based on the western population abundance estimates ca. 1990 and ca. 2009, the entire western population of double-crested cormorants has increased approximately 2 percent per year. This growth has been primarily associated with the growth of the East Sand Island colony. The estimated annual sums of breeding individuals across other western colonies, not including East Sand Island, are similar or higher when comparing population data from ca. 1990 to current, even when accounting for losses in portions of the range. Thus, a re-distribution has taken place; some locations have declined while others have increased. The number of active colonies has also increased. In about 1990, Carter et al. (1995) noted 99 active colonies in British Columbia, Washington, Oregon, and California. That number increased to 160 active colonies (2008-2012) for the same states and province (Pacific Flyway Council 2013). With a typical foraging range of approximately 15 miles (25 kilometers; Figure ES-2), the diet of double-crested cormorants on East Sand Island is made up mostly of marine forage fish. However, as juvenile salmonids migrate through the Lower Columbia River Estuary and past East Sand Island on their out-migration to the ocean, they are susceptible to and consumed by double-crested cormorants; consumption is highest in early May, which coincides with the peak nesting season.

USFWS. (2005). *Caspian tern management to reduce predation of juvenile salmonids in the Columbia River estuary: Final Environmental Impact Statement, January 2005* (p. 98). https://www.fws.gov/pacific/migratorybirds/pdf/Caspian_Tern_Final_EIS.pdf

Utah Division of Wildlife Resources. (2020). *The paths of pelicans*. https://wildlife.utah.gov/news/wildlife-blog/428-the-paths-of-pelicans.html

Van Doornik, D. M., Teel, D. J., Kuligowski, D. R., Morgan, C. A., & Casillas, E. (2007). Genetic Analyses Provide Insight into the Early Ocean Stock Distribution and Survival of Juvenile Coho Salmon off the Coasts of Washington and Oregon. *North American Journal of Fisheries Management*, *27*(1), 220–237. https://doi.org/10.1577/M06-130.1

Estimating the stock proportions of mixed-stock fishery samples by means of genetic stock identification has played an important role in the management of salmon fisheries. In addition, stock identification of individual fish has applications for population studies, forensic cases, and management issues. We examined 11 microsatellite DNA loci in 84 populations of coho salmon Oncorhynchus kisutch sampled at 78 locations from southern British Columbia to northern California to construct a database of microsatellite allele frequencies. We then evaluated the applicability of the database for estimating stock proportions in a mixed fishery and assigning individuals to their regions of origin. The loci were highly polymorphic: observed heterozygosity ranged from 0.754 to 0.943. Using genetic distance calculations, we identified six major geographic regions and 15 smaller subregions into which the populations grouped. Computer simulations and a sample of 143 coho salmon with known origins showed that the database was sufficient to make accurate stock proportion estimates to the 15 subregions. For the sample of fish with known origins, individual assignments to region of origin were 82.5% accurate for all samples and 97.8% accurate for those where P was greater than 0.95. We used the database to estimate stock proportions and densities of 2,344 coho salmon sampled over eight summers in a juvenile marine ecology study conducted off the coasts of Washington and Oregon. Columbia River juveniles were caught at higher densities than coastal fish throughout the summer. Fish from Columbia River and coastal sources were captured both north and south of their points of sea entry in early summer and at higher densities than in late summer. September catch of Columbia River juveniles was correlated with adult abundance in the following year, indicating that year-class strength for this stock is largely set during the first summer in the ocean.

Vermeer, K. (1970). *Breeding biology of California and ring-billed gulls: A study of eeologieal adaptation to tbe inland babitat* (No. 12; p. 53). Canadian Wildlife Service. http://parkscanadahistory.com/wildlife/report-12.pdf

The breeding chronology, reproductive success, nesting habitat, food, and growth rates of California gulls (Larus californiens) and ring-billed gulls (Larus delaivarensis) were studied at Miquelon Lake, Alberta, in 1964 and 1965 to learn whether these species exhibit special adaptations to breeding in an inland environment. Few basic differences between gull species breeding inland and those breeding on the seacoast were found. Both species at Miquelon Lake are ground nesters like many coastal species. Growth and reproductive rates of the California and ring-billed gulls are similar to those of glaucous-winged gulls (Larus glaucescens) breeding on the coast of British Columbia. Apparent adaptations of the two species to breeding inland are the ability to exploit a seasonally abundant supply of rodents and a shortened breeding season. The results of an experiment to test the relationship of growth and survival to the time of hatching of California gull chicks did not show that the food supply governs the short breeding season.

Vermeer, K. (1982). Comparison of the Diet of the Glaucous-Winged Gull on the East and West Coasts of Vancouver Island. *The Murrelet*, *63*(3), 80–85. JSTOR. https://doi.org/10.2307/3534286

The diet of Glaucous-winged Gull (Larus glaucescens) adults and chicks was studied in 5 breeding colonies in the Strait of Georgia and in 3 colonies on the west coast of Vancouver Island in 1980. Adult gulls ate mostly human refuse in the Strait of Georgia and gooseneck barnacles (Pollicipes polymerus) on the west coast, while chicks were fed mostly herring (Clupea harengus) in the Strait, and Pacific sand lance (Ammodytes hexapterus), herring, and Pacific sauries (Cololabis saira) on the west coast. Of the intertidal foods of adult gulls, blue mussels (Mytilus edulis) predominated in the Strait, and California or sea mussels (Mytilus californianus) and gooseneck barnacles on the west coast. Glaucous-winged Gull foods reflect abundance and accessibility of prey items in the two regions.

Wallace, E. E., & Wallace, G. E. (1998). *Brandt's Cormorant—Phalacrocorax penicillatus—Birds of the World*. https://birdsoftheworld.org/bow/species/bracor/cur/introduction

Ward, D. L., Petersen, J. H., & Loch, J. J. (1995). Index of Predation on Juvenile Salmonids by Northern Squawfish in the Lower and Middle Columbia River and in the Lower Snake River. *Transactions of the American Fisheries Society*, *124*(3), 321–334. https://doi.org/10.1577/1548-8659(1995)124<0321:IOPOJS>2.3.CO;2

We developed a predation index to describe the relative magnitude of predation on juvenile salmonids by northern squawfish Ptychocheilus oregonensis throughout the lower and middle Columbia River and lower Snake River. The predation index was the product of an abundance index and a consumption index. We evaluated various catch indices and found that catch per unit effort best reflected differences among northern squawfish abundances. Northern squawfish abundance was higher in the lower Columbia River than in the middle Columbia or lower Snake rivers and was highest in Bonneville Reservoir and the Columbia River downstream from Bonneville Dam. The consumption index was based on the concept of meal turnover time for a sample of northern squawfish. Variables needed to calculate the consumption index (CI) were water temperature (T), mean weight of the northern squawfish (W), mean number of salmonids in each gut (S), and mean weight of the gut contents (GW): CI = 0.0209·T1.60·W0.27·(S·GW−0.61). Generally, northern squawfish consumption of juvenile salmonids was highest in tailraces downstream from dams and higher in the Columbia River than in the Snake River. Predation on juvenile salmonids was much higher in the lower Columbia River than in the middle Columbia or lower Snake rivers and was usually higher in summer than in spring. Predation was highest in the Columbia River downstream from Bonneville Dam and in John Day Reservoir. The predation index identified areas where predator control efforts can be most effective. Angling for northern squawfish at dams should be concentrated in tailraces. Removal efforts concentrated in the lower Columbia River would have the greatest effect on predation.

Weathers, W. W. (1992). Scaling nestling energy requirements. *Ibis*, *134*(2), 142–153. https://doi.org/10.1111/j.1474-919X.1992.tb08391.x

The total energy metabolized (TME) by nestling birds, from hatching to fledging, scales as M1.06, with body-mass at fledging (M) explaining 97% of the variation in TME. After statistically removing the effects of body-mass, multiple-regression analysis reveals that 69% of the variation in TME is explained by nestling developmental rate, expressed as the time to fledging (tfl, days). Together tfl and M explain 99% of the variation in TME for the 30 species considered (M range 9.7 to 3700 g). Peak daily metabolized energy (DME, kJ/day), the maximum rate at which parents must provision their nestlings, scales with fledging mass as M0.78. Body-mass explains 96% of the variation in nestling peak DME, with 37% of the residual variation being attributable to the time taken to fledge (tfl). Together, tfl and M explain 97% of the variation in peak DME. An examinination of residuals indicates that adaptive modifications in nestling energetics are attained principally through changes in growth rate, which affect TME and peak DME oppositely. Doubling nestling growth rate increases peak DME by 61%, but decreases total nestling energy demand (TME) by 77%. This opposing effect complicates evolutionary interpretations of avian reproductive patterns.

Weitkamp, L. A., Bentley, P. J., & Litz, M. N. C. (2012). Seasonal and interannual variation in juvenile salmonids and associated fish assemblage in open waters of the lower Columbia River estuary. *Fishery Bulletin*, *110*(4), 426–450.

The transition between freshwater and marine environments is associated with high mortality for juvenile anadromous salmonids, yet little is known about this critical period in many large rivers. To address this deficiency, we investigated the estuarine ecology of juvenile salmonids and their associated fish assemblage in open-water habitats of the lower Columbia River estuary during spring of 2007–10. For coho (Oncorhynchus kisutch), sockeye (O. nerka), chum (O. keta), and yearling (age 1.0) Chinook (O. tshawytscha) salmon, and steelhead (O. mykiss), we observed a consistent seasonal pattern characterized by extremely low abundances in mid-April, maximum abundances in May, and near absence by late June. Subyearling (age 0.0) Chinook salmon were most abundant in late June. Although we observed interannual variation in the presence, abundance, and size of juvenile salmonids, no single year was exceptional across all species-and-age classes. We estimated that >90% of juvenile Chinook and coho salmon and steelhead were of hatchery origin, a rate higher than previously reported. In contrast to juvenile salmonids, the abundance and composition of the greater estuarine fish assemblage, of which juvenile salmon were minor members, were extremely variable and likely responding to dynamic physical conditions in the estuary. Comparisons with studies conducted 3 decades earlier suggest striking changes in the estuarine fish assemblage—changes that have unknown but potentially important consequences for juvenile salmon in the Columbia River estuary.

Weitkamp, L. A., Good, T. P., Lyons, D. E., & Roby, D. D. (2016). The Influence of Environmental Variation on the Columbia River Estuarine Fish Community: Implications for Predation on Juvenile Salmonids. *Pacific Salmon and Steelhead Production in a Changing Climate: Past, Present, and Future*, *6*, 33–44. https://doi.org/10.23849/NPAFCB6/33.44

Predation is often assumed to be the ultimate cause of mortality for juvenile salmonids in marine waters, but the specific biological or physical factors that influence predation are poorly understood. The Columbia River estuary is a useful model ecosystem to understand the relationship between avian predators, alternative prey, environmental variation, and predation on juvenile Pacific salmonids (Oncorhynchus spp.). Here, we explore the influence of a suite of local and ocean basin-scale environmental variables on the composition and abundance of the estuarine fish assemblage, an important determinant of avian predation on juvenile salmon in the Columbia River estuary. Multivariate analyses indicated that variables representing both freshwater (river flow) and marine (ocean temperature, upwelling, plume volume) conditions explained up to half of the variation in the fish assemblage. Many of the same environmental variables were related to the abundances of individual fish species. Our results also suggest that the estuarine fish assemblage in the future will be quite different from the current one, with likely repercussions for predator-prey interactions. Our results from estuarine habitats provide a useful model for understanding the dynamics of predation in marine habitats, which are much more logistically difficult to study.

Weitkamp, L. A., Goulette, G., Hawkes, J., O'Malley, M., & Lipsky, C. (2014). Juvenile salmon in estuaries: Comparisons between North American Atlantic and Pacific salmon populations. *Reviews in Fish Biology and Fisheries*, *24*(3), 713–736. https://doi.org/10.1007/s11160-014-9345-y

All anadromous fishes, including juvenile salmon, encounter estuarine habitats as they transition from riverine to marine environments. We compare the estuarine use between juvenile Atlantic salmon (Salmo salar) in the Penobscot River estuary and Pacific salmon (Oncorhynchus spp.) in the Columbia River estuary. Both estuaries have been degraded by anthropogenic activities. Atlantic and Pacific salmon populations in both basins rely heavily on hatchery inputs for persistence. Pacific salmon, as a group, represent a continuum of estuarine use, from species that move through rapidly to those that make extensive use of estuarine habitats. While Atlantic salmon estuarine use is predominantly similar to rapidly moving Pacific salmon, they can exhibit nearly the entire range of Pacific salmon estuarine use. Both slow and rapidly migrating Atlantic and Pacific salmon actively feed in estuarine environments, consuming insect and invertebrate prey. Interactions between juvenile salmon and estuarine fish communities are poorly understood in both estuaries, although they experience similar avian and marine mammal predators. Estuaries are clearly important for Atlantic and Pacific salmon, yet our understanding of this use is currently insufficient to make informed judgments about habitat quality or overall estuary health. This review of salmonid migration through and residency within estuaries identifies actions that could hasten restoration of both Atlantic and Pacific salmon populations.

Welch, D. W., Rechisky, E. L., Melnychuk, M. C., Porter, A. D., Walters, C. J., Clements, S., Clemens, B. J., McKinley, R. S., & Schreck, C. (2008). Survival of Migrating Salmon Smolts in Large Rivers With and Without Dams. *PLOS Biology*, *6*(10), e265. https://doi.org/10.1371/journal.pbio.0060265

The mortality of salmon smolts during their migration out of freshwater and into the ocean has been difficult to measure. In the Columbia River, which has an extensive network of hydroelectric dams, the decline in abundance of adult salmon returning from the ocean since the late 1970s has been ascribed in large measure to the presence of the dams, although the completion of the hydropower system occurred at the same time as large-scale shifts in ocean climate, as measured by climate indices such as the Pacific Decadal Oscillation. We measured the survival of salmon smolts during their migration to sea using elements of the large-scale acoustic telemetry system, the Pacific Ocean Shelf Tracking (POST) array. Survival measurements using acoustic tags were comparable to those obtained independently using the Passive Integrated Transponder (PIT) tag system, which is operational at Columbia and Snake River dams. Because the technology underlying the POST array works in both freshwater and the ocean, it is therefore possible to extend the measurement of survival to large rivers lacking dams, such as the Fraser, and to also extend the measurement of survival to the lower Columbia River and estuary, where there are no dams. Of particular note, survival during the downstream migration of at least some endangered Columbia and Snake River Chinook and steelhead stocks appears to be as high or higher than that of the same species migrating out of the Fraser River in Canada, which lacks dams. Equally surprising, smolt survival during migration through the hydrosystem, when scaled by either the time or distance migrated, is higher than in the lower Columbia River and estuary where dams are absent. Our results raise important questions regarding the factors that are preventing the recovery of salmon stocks in the Columbia and the future health of stocks in the Fraser River.

Wetmore, A. (1919). Bird Records from the Sacramento Valley, California. *The Condor*, *21*(2), 73–74. https://doi.org/10.2307/1362876

White, A. F., Heath, J. P., & Gisborne, B. (2006). Seasonal Timing of Bald Eagle Attendance and Influence on Activity Budgets of Glaucous-winged Gulls in Barkley Sound, British Columbia. *Waterbirds*, *29*(4), 497–500. https://doi.org/10.1675/1524-4695(2006)29[497:STOBEA]2.0.CO;2

As raptor populations recover following the banning of organochlorine pesticide use, there may be consequences for prey populations. While Bald Eagles (Haliaeetus leucocephalus) actively prey on Glaucous-winged Gulls and their offspring (Larus glaucescens), their presence at colonies and roost sites may also influence reproductive success of gulls by impacting activity budgets. Here we investigate changes in Bald Eagle abundance in relation to gull breeding phenology over 6 years at Seabird Rocks (Vancouver Island, Canada) and compare activity budgets of gulls in relation to Bald Eagle abundance. Bald Eagle abundance varied seasonally, peaking during late incubation and hatching of gull eggs. As Bald Eagle presence increased, gulls showed a strong increase in time allocated to vigilance (54%) and frequency of flushing (up to 6 times/hr). These results indicate that Bald Eagle attendance patterns at gull colonies coincide with hatching of gull chicks and can influence time-activity budgets of gulls. Predator-induced changes in gull behavior during the breeding season may influence reproductive success by impacting time and energy budgets and facilitating egg and chick predation. These findings could be important for understanding failure at gull colonies in Barkley Sound and evaluating impacts of increasing Bald Eagle populations in the region.

White, G. C., & Burnham, K. P. (1999). Program MARK: Survival estimation from populations of marked animals. *Bird Study*, *46*(sup1), S120–S139. https://doi.org/10.1080/00063659909477239

MARK provides parameter estimates from marked animals when they are re-encountered at a later time as dead recoveries, or live recaptures or re-sightings. The time intervals between re-encounters do not have to be equal. More than one attribute group of animals can be modelled. The basic input to MARK is the encounter history for each animal. MARK can also estimate the size of closed populations. Parameters can be constrained to be the same across re-encounter occasions, or by age, or group, using the parameter index matrix. A set of common models for initial screening of data are provided. Time effects, group effects, time x group effects and a null model of none of the above, are provided for each parameter. Besides the logit function to link the design matrix to the parameters of the model, other link functions include the log—log, complimentary log—log, sine, log, and identity. The estimates of model parameters are computed via numerical maximum likelihood techniques. The number of parameters that are estimable in the model are determined numerically and used to compute the quasi-likelihood AIC value for the model. Both the input data, and outputs for various models that the user has built, are stored in the Results database which contains a complete description of the model building process. It is viewed and manipulated in a Results Browser window. Summaries available from this window include viewing and printing model output, deviance residuals from the model, likelihood ratio and analysis of deviance between models, and adjustments for over dispersion. Models can also be retrieved and modified to create additional models. These capabilities are implemented in a Microsoft Windows 95 interface. The online help system has been developed to provide all necessary program documentation.

Wiese, F. K., Parrish, J. K., Thompson, C. W., & Maranto, C. (2008). Ecosystem-Based Management of Predator–Prey Relationships: Piscivorous Birds and Salmonids. *Ecological Applications*, *18*(3), 681–700. https://doi.org/10.1890/06-1825.1

Predator–prey relationships are often altered as a result of human activities. Where prey are legally protected, conservation action may include lethal predator control. In the Columbia River basin (Pacific Northwest, USA and Canada), piscivorous predators have been implicated in contributing to a lack of recovery of several endangered anadromous salmonids (Oncorhynchus spp.), and lethal and nonlethal control programs have been instituted against both piscine and avian species. To determine the consequences of avian predation, we used a bioenergetics approach to estimate the consumption of salmonid smolts by waterbirds (Common Merganser, California and Ring-billed Gull, Caspian Tern, Double-crested Cormorant) found in the mid-Columbia River from April through August, 2002–2004. We used our model to explore several predator–prey scenarios, including the impact of historical bird abundance, and the effect of preserving vs. removing birds, on smolt abundance. Each year, <1% of the estimated available salmonid smolts (interannual range: 44 830–109 209; 95% CI = 38 000–137 000) were consumed, 85–98% away from dams. Current diet data combined with historical gull abundance at dams suggests that past smolt consumption may have been 1.5–3 times current numbers, depending on the assumed distribution of gulls along the reaches. After the majority (80%) of salmonid smolts have left the study area, birds switch their diet to predominantly juvenile northern pikeminnow (Ptychocheilus oregonensis), which as adults are significant native salmonid predators in the Columbia River. Our models suggest that one consequence of removing birds from the system may be increased pikeminnow abundance, which—even assuming 80% compensatory mortality in juvenile pikeminnow survival—would theoretically result in an annual average savings of just over 180 000 smolts, calculated over a decade. Practically, this suggests that smolt survival could be maximized by deterring birds from the river when smolts are present, allowing bird presence after the diet switch to act as a tool for salmonid-predator control, and conducting adult-pikeminnow control throughout. Our analysis demonstrates that identifying the strength of ecosystem interactions represents a top priority when attempting to manage the abundance of a particular ecosystem constituent, and that the consequences of a single-species view may be counterintuitive, and potentially counterproductive.

Willett, G. (1919). Bird Notes from Southeastern Oregon and Northeastern California. *The Condor*, *21*(5), 194–207. https://doi.org/10.2307/1362382

Williams, A. P., Cook, E. R., Smerdon, J. E., Cook, B. I., Abatzoglou, J. T., Bolles, K., Baek, S. H., Badger, A. M., & Livneh, B. (2020). Large contribution from anthropogenic warming to an emerging North American megadrought. *Science*, *368*(6488), 314–318. https://doi.org/10.1126/science.aaz9600

Severe and persistent 21st-century drought in southwestern North America (SWNA) motivates comparisons to medieval megadroughts and questions about the role of anthropogenic climate change. We use hydrological modeling and new 1200-year tree-ring reconstructions of summer soil moisture to demonstrate that the 2000–2018 SWNA drought was the second driest 19-year period since 800 CE, exceeded only by a late-1500s megadrought. The megadrought-like trajectory of 2000–2018 soil moisture was driven by natural variability superimposed on drying due to anthropogenic warming. Anthropogenic trends in temperature, relative humidity, and precipitation estimated from 31 climate models account for 47% (model interquartiles of 35 to 105%) of the 2000–2018 drought severity, pushing an otherwise moderate drought onto a trajectory comparable to the worst SWNA megadroughts since 800 CE.

Winkler, D. W. (1996). *California Gull—Larus californicus—Birds of the World*. https://birdsoftheworld.org/bow/species/calgul/cur/introduction

Wires, L. R., & Cuthbert, F. J. (2000). Trends in Caspian Tern Numbers and Distribution in North America: A Review. *Waterbirds: The International Journal of Waterbird Biology*, *23*(3), 388. https://doi.org/10.2307/1522176

The breeding range of the Caspian Tern (Sterna caspia) covers large parts of six geographic regions in North America. We obtained data from individuals who monitor colonial waterbirds to determine current status and distribution of the Caspian Tern in the U.S., Canada and Mexico and to report regional population trends. We estimate 32,000-34,000 pairs nested in North America from the late 1980s to 1998. The species' breeding range is expanding along the Pacific coast and in central Canada. Over the last three decades numbers of breeding pairs have significantly increased in the Great Lakes, central Canada, and along the Gulf and Pacific coasts; the Atlantic coast is the only region where significant decline has occurred. On the Pacific and Gulf coasts, large numbers of Caspians utilize artificial habitat (e.g.,dredge spoil islands, salt dikes and levees, landfills, artificial lakes). Changes in food supply may be at least partly responsible for population increases in the Great Lakes, on the Pacific coast, and in central Canada in Manitoba. Other factors that may contribute to increases include creation of artificial habitat that Caspian Terns find attractive for nesting, and legislation that protects Caspian Terns and their habitat.

Wires, L. R., & Cuthbert, F. J. (2006). Historic Populations of the Double-crested Cormorant (Phalacrocorax auritus): Implications for Conservation and Management in the 21st Century. *Waterbirds*, *29*(1), 9–37. https://doi.org/10.1675/1524-4695(2006)29[9:HPOTDC]2.0.CO;2

In North America, the Double-crested Cormorant (Phalacrocorax auritus) is currently abundant, widely distributed across five broad geographic regions, and often perceived as overabundant. In many U.S. states and Canadian provinces, policy makers are pressured to significantly reduce cormorant numbers, primarily to minimize conflicts between cormorants and fish resources. Concurrently, large-scale conservation plans recently developed for birds in the Americas depart from the traditional narrow focus on threatened and endangered species to encompass broader and more representative goals (e.g., Partners in Flight's objective to "keep common birds common"). In recent waterbird conservation initiatives, historic distribution and abundance provide the basis for conservation focus; these initiatives advocate conservation of birds in natural numbers and natural habitats. To provide a context in which current populations of Double-crested Cormorants can be understood, we reviewed historic and current breeding and wintering records to determine historic distribution (pre-1900), current distribution (1970-1999), and extent of range expansion across North America. Early records suggest Double-crested Cormorants were present in large numbers throughout much of their current range; colonies and flocks much larger than any known in the 1990s are well documented. However, numbers sharply declined through the late 1800s as cormorants were greatly reduced and/or extirpated in many areas. The population partially recovered through at least the mid-1900s, but experienced a second major decline during the 1950s-1970s. In the late 1970s, a second rebound began across much of the continent; the largest breeding populations (Canadian/U.S. interior, Atlantic Coast >80% of total) increased from approximately 32,000 pairs in the early 1970s to >226,000 pairs in the late 1990s. Comparison of historic and current records challenges the opinion that cormorants are currently overabundant, and suggests that perception of overabundance rests on socio-political rather than biological or ecological factors. For this species, and others that are seen as competitors with humans, limits of human tolerance (i.e. "social carrying capacity") are far narrower than those of biological carrying capacity. Because large numbers have been typical for cormorants historically, population targets based on fishery or other objectives derived from human values will likely be readily surpassed, require intensive management, and significantly depart from the concept of conserving birds in natural numbers and natural habitats. Although managing fish-eating birds to benefit fishery yields may increase some fish populations, this approach does not resolve or address the underlying problems causing current fish population declines across the continent, and is in direct conflict with current broad scale conservation initiatives. To ensure inclusion of cormorants and other fish-eating birds in these conservation plans, the avian conservation community must continue to press for programs based on ecosystem health and process that recognize humans, fish and cormorants as three components of a complex system driven by many species and dynamic interactions.

Wires, L. R., Cuthbert, F. J., Trexel, D. R., & Joshi, A. R. (2001). *Status of the Double-crested Cormorant (Phalacrocorax auritus)* (p. 377). U.S. Fish and Wildlife Service. https://www.fws.gov/migratorybirds/pdf/management/doublecrestedcormorantstatus.pdf

Introduction: Since the late-1970s, numbers of Double-crested Cormorants (Phalacrocorax auritus) (DCCO) have increased significantly in many regions of North America. A variety of problems, both real and perceived, have been associated with these increases, including impacts to aquaculture, sport and commercial fisheries, natural habitats, and other avian species. Concern is especially strong over impacts to sport and commercial fishes and aquaculture. Because of increasing public pressure on U.S. government agencies to reduce DCCO conflicts, the USFWS is preparing an Environmental Impact Statement (EIS), and in conjunction with the U.S. Department of Agriculture/Wildlife Services (USDA/WS) and state resource management agencies, will develop a national management plan for the DCCO. This assessment will be used to prepare the EIS and management plan. Populations and trends: The DCCO breeding range in North America is divided into five geographic areas. Since at least 1980, numbers have clearly increased in three of the breeding areas: Canadian and U.S. interior, Northeast Atlantic Coast and Southern U.S. In these populations, much of the growth occurred between the late 1970s – early 1990s; from the early 1990s – 2000 growth rates have slowed or appeared to stabilize in many

states and provinces. For the Pacific Coast and Alaskan breeding populations it was not possible to summarize trends overall because recent data for birds breeding in significant portions of these regions (e.g., Alaska, Mexico) are not available, or have not been collected in a coordinated and timely fashion for the populations as a whole. Along some parts of the Pacific Coast, breeding numbers declined in the 1990s (e.g., British Columbia, species is listed as Vulnerable and is being considered for Threatened status). In other areas significant increases occurred. Concurrently, numbers also increased on the wintering grounds, particularly in the Mississippi River Delta region, an area of high human-cormorant conflict over catfish resources. Many historical records from across the continent indicate that the species was or may have been more abundant and widespread than is currently presumed. While most of these early accounts are largely qualitative, many report huge numbers of cormorants, suggesting that recent population increases may represent recovery towards historical (presettlement) levels in certain regions. In some areas where the DCCO has been documented as a recent breeder, the species is actually re-colonizing after an absence of 50 – 300 years. Reasons for population increases: There appear to be five major factors that led to dramatic increases in DCCOs in North America since about 1970. These include: 1. Ban on DDT (1972) and other pesticide reduction regulation. Prior to this time (but post WWII) widespread use of DDT occurred. Cormorants accumulated high levels of DDT through their food supply, which interfered with reproduction. Depressed populations began to increase after DDT was banned. 2. In 1972 the DCCO was added to the Migratory Bird Treaty Act protected bird list. Before 1972, federal legislation did not prevent killing or harassment of cormorants during their annual cycle. Some states also provided special protection for DCCOs around this time. 3. Human induced changes (e.g. accidental and intentional introduction of exotics; over fishing; changes in water quality) in aquatic communities in the breeding range. 4. Development of aquaculture (e.g. catfish farms) in the south (especially Mississippi Delta region) that provided a new food source. 5. Creation of additional breeding and foraging habitat (e.g. reservoirs; dredge spoil islands). Diet and native fish populations: DCCO diet is characterized by great temporal and spatial variation. The DCCO is known to feed on > 250 species of fresh and saltwater fishes. Cormorants are generalists and eat abundant fish in the size range 3 – 40 cm; < 15 cm is preferred. Review of diet studies (> 40) indicates most sport and commercially valuable fish species do not contribute substantially to DCCO diet. Though there are exceptions, most studies conclude that sport and commercially valuable fish species are not negatively impacted by DCCOs, and that DCCOs have minor effects on fish populations relative to human harvest and other mortality factors. The most common claim against DCCOs is that they reduce sport or commercial catches, but the actual relationship between cormorant predation, fish population size and human harvest is poorly understood. This lack of information contributes to the complexity of cormorant-fish-fishery interactions. Rigorous quantification of cormorant predation on fish populations or on subsequent sport or commercial catches requires more precise estimates of several key parameters, including: prey fish population sizes; prey fish mortality sources and rates; age class distribution of fish consumed. Additionally, a better understanding of compensatory processes within prey fish populations is essential (e.g., predation may reduce competition so that remaining fish survive longer or younger fish grow faster). However, no study conducted so far has obtained robust estimates for all of these parameters. Therefore, while DCCOs may cause fish populations to decline, none of the studies reviewed provided data rigorous enough to demonstrate that they do so. The effect of cormorant predation can be either compensatory (if the cormorants do not eat them, the same proportion may be removed by other factors) or additive (mortality due to cormorant predation is not replaced by another factor). However, investigators have rarely examined cormorant predation in the context of other mortality or limiting factors. Because of great spatial variation in DCCO diet and unique complexities of individual aquatic ecosystems, DCCO predation impacts need to be assessed locally. To do this biologists need a more comprehensive understanding of local fish population dynamics and standardized methods for assessing cormorant diet. Diet and aquaculture facilities: Studies show DCCOs may eat large numbers of catfish locally and temporally. However, no study has quantified the economic impact on net harvest. Only one study has examined the issue of additive and compensatory mortality and concluded that mortality due to DCCO predation impacts were additive under certain circumstances, but insignificant in others. Impacts on vegetation: Most colonial waterbirds destroy vegetation at breeding and / or roosting sites to some extent, and cormorants cause some of the most dramatic change. Cormorants impact vegetation through deposition of guano (excrement) that kills underlying vegetation and eventually trees, and through nest building behavior when they strip leaves and small branches. In the short term these changes are of greatest concern if they affect rare plant communities or private property. From a long-term perspective these changes may be insignificant on an ecosystem scale. Few studies have been conducted to characterize and quantify vegetation change due to cormorant nesting and roosting habits. Impacts on other bird species: DCCOs are hypothesized to have two potential effects on other colonial waterbird species: competition for nest sites and habitat degradation. Direct interspecific competition for nests and nest sites may occur but has not been documented through careful study. Most impacts appear to occur indirectly through habitat degradation (e.g. defoliation, tree die-off). While there is some evidence that DCCOs may displace other species, no studies have clearly established DCCO impact on other birds at even a colony level scale. Management options: Humans have attempted to manage cormorant numbers in the western hemisphere for at least 400 years. Currently in the U.S. all lethal take requires permits from the USFWS, except at aquaculture facilities in those states under the 1998 Federal Depredation Order. Depredation permits can be obtained to prevent economic impacts or impacts to endangered, threatened or species of conservation concern. Non-lethal harassment of birds depredating or about to depredate does not require permits. To reduce cormorant impacts primarily to fisheries, aquaculture, vegetation and other colonial waterbirds, a large number of techniques has been developed or proposed. These techniques utilize lethal and non-lethal measures and may be used at local, regional or population levels. The effectiveness of these measures is difficult to assess because in many cases impacts have been poorly quantified. Most techniques used at the local level are non-lethal. Lethal control may help reinforce local non-lethal control techniques. However, because cormorants are highly mobile, lethal control at the local level may be ineffective at decreasing local populations. Although economic effectiveness cannot be assessed for individual control techniques, some appear more effective than others; future research should focus on reducing the costs of the most promising techniques. Many techniques have been poorly investigated; therefore conclusions about their economic and numerical effectiveness may be premature. Because aquaculture ponds are high quality foraging sites (high fish densities; lack of escape cover), control of cormorants on the breeding grounds is unlikely to eliminate the need to practice local control. To make aquaculture ponds less desirable foraging sites, some form of control at the local level (e.g. exclosures, harassment) will likely still be needed. Previous efforts indicate that population control in general must be large scale and will require sizable human and capital inputs to be effective. Additionally, potential density dependent effects that compensate for control related mortality are poorly understood.

Addressing these and numerous other uncertainties will enhance the development of a scientifically based, large-scale population control effort. Finally, no control is a management option that is economically justified if the costs of control are greater than the losses associated with cormorant impacts. Population Models: Models have identified data gaps critical for understanding population dynamics and predicting control effectiveness; modeling is potentially a very strong tool for gaining insights into cormorant management. Prediction of future DCCO population trends and analysis of control methods is hampered by lack of age-specific data for this species. More effort needs to be put into obtaining data needed to strengthen model predictions, and increased effort should focus on predicting management outcomes and follow progress. Until better data are available, however, such modeling efforts should include rigorous sensitivity analyses to investigate uncertainties in parameters used and assumptions made in the model. Current research and monitoring efforts: Of 33 U.S. states and nine Canadian provinces to which surveys were sent, nine reported research in progress and 19 have monitoring programs. Research addresses: cormorant diet, bioenergetics, impacts to aquaculture, sport and commercial fisheries, foraging range and foraging behavior. Additional studies are attempting to determine effectiveness of harassment at day and night roosts, effectiveness of barriers at aquaculture ponds, and nutrient enrichment in aquatic and terrestrial habitats. A satellite telemetry study will determine migration patterns, breeding locations and winter movements of cormorants at catfish farms. All monitoring efforts are used to determine population distribution and trends. Future research priorities: The assessment identified many research needs. Highest priority studies on DCCOs fall within the following broad topics: (1) demography, (2) impacts on fisheries and aquaculture, (3) management techniques, (4) impacts on flora and fauna and (5) distribution.

Wright, S. K. (2004). *Disturbance and Roosting Ecology of California Brown Pelicans (Pelecanus occidentalis californicus) on East Sand Island in the Columbia River Estuary*. Oregon State University.

We examined factors that potentially influence the numbers and distribution of California brown pelicans (Pelecanus occidentalis californicus) roosting on East Sand Island, Oregon in the Columbia River estuary during 2001 and 2002. Numbers of pelicans roosting on East Sand Island have increased sharply in recent years, from less than 100 during 1979-1986 to a high count of 10,852 in 2002. The East Sand Island roost is currently the largest known non-breeding aggregation of this endangered subspecies throughout its range. Total numbers of pelicans roosting on East Sand Island increased seasonally from April to September or October, and then declined sharply with the onset of winter storms. Pelican numbers on the island were positively associated with tide height in both years. Wind direction and speed influenced where pelicans roosted on the island; roosting pelicans favored the lee side of the island during windy conditions. Natural disturbances and anthropogenic disturbances not related to research on colonial waterbirds had no detectable effect on the total number of pelicans on the island. Recreational boaters affected the distribution of pelicans on the island, causing pelicans to move away from an area of high boater traffic to sections of the island's shoreline less frequented by boaters. In 2001 pelican numbers were negatively associated with the magnitude of daytime research-related disturbance on the island. Numbers of pelicans roosting on East Sand Island were apparently not affected by research-related disturbance in 2002, when new restrictions on research activities reduced the magnitude of disturbance to roosting pelicans. Our primary objective was to determine how potential disturbance factors influence the behavior of endangered California brown pelicans (Pelecanus occidentalis californicus) at the largest known

post-breeding aggregation site for the subspecies. We studied time-activity budgets of pelicans roosting at a representative study plot on East Sand Island in the Columbia River estuary during June – August in 2001 and 2002. We investigated the effects of several extrinsic explanatory variables on timeactivity budgets of roosting pelicans, including year, date, time of day, weather, tide stage, natural and anthropogenic disturbances, and the number of pelicans on the plot. During daylight, pelicans spent the vast majority of time either resting (44%) or preening (41%). Time of day, number of pelicans, wind speed, precipitation, and disturbance accounted for 34% of the variation in the incidence of resting among pelicans; year, date, time of day, number of pelicans, and disturbance accounted for 27% of the variation in the incidence of attentive behavior. All three categories of disturbance (natural, research-related, non-research anthropogenic) were associated with significant decreases in the proportion of pelicans attentive and increases in the proportion of pelicans resting. Research-related disturbance had a larger positive association with the proportion of pelicans attentive than did natural disturbance, and it took longer for pelicans to recover to baseline behavior following a research disturbance than for non-research anthropogenic disturbance or natural disturbance. Permitted land-based human activities need to be restricted to minimize disturbance to pelicans roosting on East Sand Island, and the public needs to be notified that East Sand Island is closed. The potential exists for humans to have a major negative impact on this major roost site of endangered California brown pelicans; therefore, human activities need to be regulated on East Sand Island to provide the habitat and conditions necessary for the continued recovery of this subspecies.

Wright, S. K., Roby, D. D., & Anthony, R. G. (2007). Responses of California Brown Pelicans to Disturbances at a Large Oregon Roost. *Waterbirds*, *30*(4), 479–487. https://doi.org/10.1675/1524-4695(2007)030[0479:ROCBPT]2.0.CO;2

Numbers of California Brown Pelicans (Pelecanus occidentalis californicus) along the coast of Oregon and Washington have increased sharply in recent years. We identified East Sand Island in the Columbia River estuary as the site of the largest pelican roost within this region. Numbers of pelicans roosting on East Sand Island have increased from less than 100 during 1979-1986 to a high count of 10,852 in 2002. The East Sand Island roost is currently the site of a major non-breeding aggregation of this endangered subspecies. Total numbers of pelicans roosting on East Sand Island increased seasonally from April to September or October, and then declined sharply with the onset of winter storms. Pelicans appeared to forage more during low tides, and return to the roost during high tides; therefore, pelican numbers on the island were positively associated with tide height. Land-based human disturbance was negatively associated with total pelican numbers, whereas water-based human disturbance had no significant effect on total pelican numbers on the island. Natural disturbances, although more frequent than human disturbances, apparently did not influence the total number of pelicans on the island.

Wright, S. K., Roby, D. D., & Anthony, R. G. (2012). Factors Affecting the Behavior of Brown Pelicans at a Post-breeding Roost. *Western Birds*, *43*(1), 21–36.

We sought to determine how disturbance may influence the behavior of California Brown Pelicans (Pelecanus occidentalis californicus) at a major post-breeding roost. In addition to assessing the effects of natural and anthropogenic disturbance on Brown Pelican behavior, we investigated the effects of other potential explanatory variables, including year, date, time of day, weather, tide stage, and density of pelicans on time-activity budgets of pelicans roosting on East Sand Island in the Columbia River estuary from June to August, 2001 and 2002. We found that during the

day, pelicans spent the great majority of time either resting (44%) or preening (41%). Time of day, density of pelicans, wind speed, precipitation, and disturbance accounted for 34% of the variation in resting behavior among pelicans; year, date, time of day, number of pelicans, and disturbance accounted for 27% of the variation in vigilant behavior. All three categories of disturbance (natural, research-related human, other human) were associated with significant increases in the proportion of vigilant behavior and reductions in the proportion of resting behavior. It took longer for pelicans to recover to baseline behavior following a research-related disturbance than after other types of disturbance. This is likely because research-related disturbances involved human activity on the island (i.e., land-based), whereas most other human disturbances were water- or air-based. The potential exists for human disturbance to significantly alter pelican behavior at roost sites. Therefore, restriction of human access to the pelican's major roost sites and regulation of human activities at roosts should be considered to ensure that available sites support the continued recovery of this subspecies.

York, D. L., Cummings, J. L., Steuber, J. E., Pochop, P. A., & Yoder, C. A. (2000). Importance of Migrating Salmon Smolt in Ring-Billed (Larus delawarensis) and California Gull (L. Californicus) Diets Near Priest Rapids Dam, Washington. *Western North American Naturalist*, *60*(2), 216–220.

Ring-billed (Larus delawarensis) and California Gulls (L. californicus) have been implicated in depredations on migrating salmon smolt in the Columbia fiver. As part of a gull management program conducted in 1995 and 1996,we collected L. delawarensis (n = 120)and L. californicus (n = 45) near Priest Rapids Dam, Washington, and analyzed stomach contents to determine food habits and thus the importance of fish in gull diets. Percent volume measurements and index of relative importance rankings suggested a greater reliance on fish by L. californicus than by L. delawarensis. Peak percent consumption of fish by both species occurred in May, coinciding with peak salmon outmigration through Priest Rapids Dam; and for both species number of fish consumed by gulls was higher below Priest Rapids Dam. Gulls collected prior to, and after, peak smolt migration indicated low importance rankings for fish in both L. delawarensis and L, californicus diets. However, the importance ranking of fish in gull diets changed over time and was higher for both species as the smolt migration peaked in May.

Yoshiyama, R. M., Fisher, F. W., & Moyle, P. B. (1998). Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California. *North American Journal of Fisheries Management*, *18*(3), 487–521. https://doi.org/10.1577/1548-8675(1998)018<0487:HAADOC>2.0.CO;2

The Central Valley drainage of California formerly produced immense numbers of chinook salmon Oncorhynchus tshawytscha. Four seasonal runs occur in this system—fall, late-fall, winter, and spring runs. Differences in life history timing and spatial distribution enabled the four runs to use the drainage to the fullest possible extent and once made it one of the richest regions in the world for chinook salmon production. Native American fishers within the Central Valley drainage harvested chinook salmon at estimated levels that reached 8.5 million pounds or more annually. Native harvests, therefore, were roughly comparable to the peak commercial harvests taken later by Euro-American fishers, but whether or not native fishing depressed the productive capacities of the salmon populations to any substantial degree is not known. The commercial chinook salmon fishery in California started about 1850 in the San Francisco Bay and Sacramento–San Joaquin Delta region, where it formed the nucleus of the first major fishery conducted by Euro-

American immigrants in the state. This fishery was one of the important early industries that supported the Euro-American settlement of the Central Valley region. The salmon fishery remained centered there until the early 1900s, when ocean salmon fishing began to expand and eventually came to dominate the fishery. Annual catches by the early Sacramento–San Joaquin in-river fishery commonly reached 4–10 million pounds and generally were higher than the total statewide catches made during the most recent several decades. The historical abundances of Central Valley chinook salmon before large-scale commercial exploitation and depletion of the runs cannot be determined with certainty. However, on the basis of early commercial catch records, the maximal production levels of the Central Valley chinook salmon stocks in aggregate may be conservatively estimated to have reached approximately 1–2 million spawners annually. Although substantial investment has been made by the state of California in managing the chinook salmon resource since the early years of the commercial fishery, chinook salmon have declined over the decades to small fractions of their previous numbers. The decline of the Central Valley chinook salmon resource was caused by several factors: overfishing, blockage and degradation of streams by mining activities, and reduction of salmon habitat and streamflows by dams and water diversions. Differences between the four chinook salmon runs in life history timing and habitat requirements partly account for their different population histories; the winter run is now threatened with extinction, the spring run recently has approached a similarly imperiled state, and the late-fall run has been at moderately low population levels for the past two decades. Only the fall run, in aggregate, can be regarded as secure, but it too has undergone substantial reductions in abundance. Fall-run spawner numbers were especially low in the San Joaquin River basin in recent years, and in Sacramento River basin streams their numbers have been heavily influenced by production of hatchery fish.

Yurk, H., & Trites, A. W. (2000). Experimental Attempts to Reduce Predation by Harbor Seals on Out-Migrating Juvenile Salmonids. *Transactions of the American Fisheries Society*, *129*(6), 1360–1366. https://doi.org/10.1577/1548-8659(2000)129<1360:EATRPB>2.0.CO;2

During spring, harbor seals Phoca vitulina feed at night under two bridges spanning the Puntledge River in Courtenay, British Columbia, Canada. Positioned parallel to one another, ventral side up, the seals form a feeding line across the river to intercept thousands of out-migrating salmonid smolts. During a 4-week observation period in the spring of 1996, we attempted to disrupt the seals' feeding patterns by (a) deploying a mechanical feeding barrier (cork line), (b) altering the lighting conditions (lights on a bridge were turned off), and (c) installing an acoustic harassment device. We found acoustic harassment to be the most effective feeding deterrent. Of the other two deterrents, turning off the bridge lights was more effective than deploying a cork line, which had little effect. Acoustic harassment devices appear to be the most effective, nonlethal means for protecting juvenile salmonids from harbor seal predation in portions of the Puntledge River.

Zabel, R. W. (2002). Using "Travel Time" Data to Characterize the Behavior of Migrating Animals. *The American Naturalist*, *159*(4), 372–387. https://doi.org/10.1086/338993

For migratory species, duration of migration, or "travel time," is often a critical variable in determining the cost of migration. Observed travel times are the result of both environmental factors such as air or water currents and the behavior of individuals. In an effort to distinguish among these components, I developed a migration model based on an advection-diffusion equation that characterizes population movements in terms of two biologically meaningful parameters: migration rate and rate of population spread. I applied the model to travel time data

from juvenile chinook salmon (Onchorhynchus tshawytscha), which were tagged during their seaward migration. The tagged fish originated from three separate evolutionarily significant units (ESUs) as classified by the U. S. National Marine Fisheries Service. The model was expanded by allowing migration and diffusion rates to vary with fish length and river flow. Variability in travel times explained by these factors was strikingly similar from year to year within ESUs, and the migratory behavior revealed by the analysis was consistent with the life-history patterns that distinguish the ESUs. The approach presented here is easily adaptable to a wide range of migratory species and may be particularly useful for predicting how at-risk populations respond to variable conditions in regulated or otherwise disturbed migration habitats.

Zabel, R. W., & Achord, S. (2004). Relating Size of Juveniles to Survival Within and Among Populations of Chinook Salmon. *Ecology*, *85*(3), 795–806. https://doi.org/10.1890/02-0719
Understanding relationships between the size of individuals and their subsequent survival can not only provide insights into mechanisms of mortality, but can also identify traits to measure for monitoring at-risk populations. We analyzed a data set of more than 54 000 juvenile chinook salmon (Oncorhynchus tshawytscha) from 15 populations over five years. The juveniles were tagged during the summer in their freshwater rearing habitats and then recaptured at downstream sites the following spring after an extended rearing and overwintering period. We measured the length and weight of fish at tagging and computed a "condition index" that determined how fat or thin a fish was relative to others. Among populations, mean length and mean condition index were poor predictors of survival, but we did detect year and site effects. Within populations, survival was strongly related to the relative length of individuals but not to relative condition index. Our results are consistent with length-related mechanisms of mortality mediated by hierarchical behavior, and thus merely measuring changes in mean values of morphological traits in populations of juveniles may provide little insight into expected changes in population viability. Expanding upon these results, we predicted a nearly 60% increase in selection for juvenile fish length when we extended our observation period through adulthood. Thus, monitoring populations through only a portion of their life history may present an incomplete picture of their survival variability.

Zabel, R. W., Scheuerell, M. D., McCLURE, M. M., & Williams, J. G. (2006). The Interplay between Climate Variability and Density Dependence in the Population Viability of Chinook Salmon. *Conservation Biology*, *20*(1), 190–200. https://doi.org/10.1111/j.1523-1739.2005.00300.x
The viability of populations is influenced by driving forces such as density dependence and climate variability, but most population viability analyses (PVAs) ignore these factors because of data limitations. Additionally, simplified PVAs produce limited measures of population viability such as annual population growth rate (λ) or extinction risk. Here we developed a "mechanistic" PVA of threatened Chinook salmon (Oncorhynchus tshawytscha) in which, based on 40 years of detailed data, we related freshwater recruitment of juveniles to density of spawners, and third-year survival in the ocean to monthly indices of broad-scale ocean and climate conditions. Including climate variability in the model produced important effects: estimated population viability was very sensitive to assumptions of future climate conditions and the autocorrelation contained in the climate signal increased mean population abundance while increasing probability of quasi extinction. Because of the presence of density dependence in the model, however, we could not distinguish among alternative climate scenarios through mean λ values, emphasizing the importance of considering multiple measures to elucidate population viability.

Our sensitivity analyses demonstrated that the importance of particular parameters varied across models and depended on which viability measure was the response variable. The density-dependent parameter associated with freshwater recruitment was consistently the most important, regardless of viability measure, suggesting that increasing juvenile carrying capacity is important for recovery.

Zabel, R. W., Wagner, T., Congleton, J. L., Smith, S. G., & Williams, J. G. (2005). Survival and Selection of Migrating Salmon from Capture–Recapture Models with Individual Traits. *Ecological Applications*, *15*(4), 1427–1439. https://doi.org/10.1890/04-0940

Capture–recapture studies are powerful tools for studying animal population dynamics, providing information on population abundance, survival rates, population growth rates, and selection for phenotypic traits. In these studies, the probability of observing a tagged individual reflects both the probability of the individual surviving to the time of recapture and the probability of recapturing an animal, given that it is alive. If both of these probabilities are related to the same phenotypic trait, it can be difficult to distinguish effects on survival probabilities from effects on recapture probabilities. However, when animals are individually tagged and have multiple opportunities for recapture, we can properly partition observed trait-related variability into survival and recapture components. We present an overview of capture–recapture models that incorporate individual variability and develop methods to incorporate results from these models into estimates of population survival and selection for phenotypic traits. We conducted a series of simulations to understand the performance of these estimators and to assess the consequences of ignoring individual variability when it exists. In addition, we analyzed a large data set of >153 000 juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) of known length that were PIT-tagged during their seaward migration. Both our simulations and the case study indicated that the ability to precisely estimate selection for phenotypic traits was greatly compromised when differential recapture probabilities were ignored. Estimates of population survival, however, were far more robust. In the chinook salmon and steelhead study, we consistently found that smaller fish had a greater probability of recapture. We also uncovered length-related survival relationships in over half of the release group/river segment combinations that we observed, but we found both positive and negative relationships between length and survival probability. These results have important implications for the management of salmonid populations.

Zamon, J. E., Cross, T. A., Sandford, B. P., Evans, A., & Cramer, B. (2013). *Measuring estuary avian predation impacts on juvenile salmon by electronic recovery of passive integrated transponder (PIT) tags from bird colonies on East Sand Island, 2012* (p. 61). https://www.nwfsc.noaa.gov/assets/26/4687_05222017_132933_CRE-Avian-predation-2012.pdf

Avian predation on juvenile salmon and steelhead is one factor limiting the recovery of threatened and endangered populations of Pacific salmon Oncorhynchus spp. in the Columbia River Basin. To measure, monitor, and manage the effects of avian predation, estimated predation rates are needed for individual Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) of Pacific salmon. One method to estimate predation rates compares codes from passive integrated transponder (PIT) tags deposited on avian nesting colonies after fish are consumed by birds to all codes detected on presumed live fish in the geographic area of interest. This report presents results from our project to recover PIT-tag codes from seabird colonies on East Sand Island in the Columbia River Estuary. Tag-code recoveries were used in collaboration with Bird

Research Northwest to derive estimates of estuary predation on juvenile salmon by Caspian terns Hydroprogne caspia, double-crested cormorants Phalacrocorax auritus, and Brandt's cormorants P. penicillatus. Here we present results from three primary study components: 1. PIT-tagging three groups of subyearling fall Chinook salmon O. tshawytscha from the Lower Columbia River ESU. 2. Recovery of PIT-tag codes from nesting colonies on East Sand Island 3. Estimation of estuary predation rates, including i. Adjustments for tag-code detection efficiency and off-colony deposition rates where available ii. Estuary predation rate estimates for ESU/DPS groups originating entirely above Bonneville Dam (Columbia River) or above Sullivan Dam (Willamette River) iii. Estuary predation rate estimates for PIT-tagged Lower Columbia River Chinook salmon iv. Estuary predation rate estimates for barge-transported vs. in-river migrant Snake River fall Chinook salmon originating above Lower Granite Dam In May and June 2012, we PIT-tagged 8,885 Lower Columbia River fall Chinook salmon and released them directly into the estuary below Bonneville Dam. A subset of tags from these fish was subsequently detected on avian colonies. From these detections, we estimated that of the fish we released, 2.6% were consumed by Caspian terns, 14.9% by double-crested cormorants, and 0.8% by mixed species, including Brandt's cormorants. On the East Sand Island Caspian tern colony, we recovered 15,298 unique tag codes from juvenile fish that migrated downstream in 2012. Tag codes recovered included those of fish from 13 Pacific salmon ESU/DPS groups listed as threatened or endangered under the U.S. Endangered Species Act. On the double-crested cormorant colony, we recovered 13,829 unique tag codes, also representing all 13 listed ESU/DPS groups. Detection efficiencies varied through the season, and ranged from 42 to 90% on the Caspian tern colony and 56 to 81% on the double-crested cormorant colony. These efficiencies were comparable to those measured in prior years. Biologists from Bird Research Northwest used our tag-code recoveries for experiments designed to measure off-colony tag deposition of tags by double-crested cormorants. They estimated that 44% of tags consumed by double-crested cormorants were deposited on the colony, implying up to 56% of the tags consumed by these birds were deposited elsewhere. Data from this study were used to adjust estimated predation rates to account for off-colony deposition in groups originating above Bonneville Dam and Sullivan Dam. We estimated estuary predation rates for groups of fish with geographical origins entirely above Bonneville Dam (Columbia River) or Sullivan Dam (Willamette River). These estimates showed Caspian terns having the greatest impact on steelhead (7.4-10.0%), with a lesser impact on other groups (0.7-2.2%). Double-crested cormorants had the greatest impact on steelhead from the upper Columbia River ESU (7.2%), with a range of impacts on other fish groups (0.6-5.4%). In general, Upper Willamette spring Chinook salmon experienced the least avian predation impact (<1%), and Brandt's cormorants appeared to have minimal impacts on all population groups we examined (<1%). Fifty-two different sources contributed to PIT-tagged fish from the Lower Columbia River Chinook salmon ESU during migration year 2012; however, only three hatcheries above Bonneville Dam accounted for 66.3% of these fish. Estimated overall predation on tagged Lower Columbia River Chinook salmon was 0.91% for Caspian terns, 2.9% for double-crested cormorants, and 0.15% for mixed species including Brandt's cormorants. Fish included in the Lower Columbia River Chinook salmon ESU exhibit complex life history types, and there is no comprehensive, representative tagging program for the ESU as a whole. Therefore, inferences from these predation rates should not be made to the entire Lower Columbia River ESU, and generalizations to specific populations within the ESU should be made with caution. All fall Chinook salmon that originate in the Snake River are included in the Snake River fall Chinook salmon ESU. For fish from this ESU, we compared

predation impacts between barge-transported fish vs. in-river migrants in three ways. First, we v calculated annual predation estimates using all available data from 2012. Second, we compared estimated weekly predation rates with weekly barge releases and detections at Bonneville Dam, where releases or detections exceeded 100 fish per week. Third, we compared estimates of daily predation for calendar days on which at least 100 fish from both barge-transported and naturally-migrating life histories occurred. Caspian terns and double-crested cormorants both had higher annual impacts on barge-transported fish (0.7 and 3.3%, respectively) than on in-river migrants (0.5 and 1.3%, respectively). Mixed species, including Brandt's cormorants, had similar impacts on in-river migrants (0.1%) and barged fish (<0.1%). Paired comparisons of weekly estimated predation rates did not show any statistically significant differences between barged vs. in-river migrant fish for terns, cormorants, or mixed species/Brandt's cormorants. However, paired comparisons of daily predation rates showed tern and double-crested cormorant predation were higher on transported fish (0.5 and 2.7%, respectively) than on in-river migrants (0.3 and 1.0%, respectively), although the difference was statistically significant only for cormorants. For mixed species including Brandt's cormorants, predation rates were identical for transported vs. in-river migrant fish (0.2%). The implication is that barging in 2012 did not necessarily decrease estuary avian predation on Snake River fall Chinook salmon. However, on East Sand Island, a significant number of PIT-tag codes from in-river migrants were recovered (n = 1,891) that had not been detected at Bonneville Dam. Thus, there may be more predation on in-river migrants than we could measure in this study. To improve understanding of estuary avian predation on Columbia River salmon, we recommend that future work include support to determine the mechanisms driving variation in seasonal and annual predation rates. We also recommend that 1) A comprehensive tagging program be developed for Lower Columbia River Chinook salmon to more accurately characterize overall estuary predation for this ESU 2) An effort be made to improve detection numbers at Bonneville Dam for estuary entry timing of in-river migrant Snake River fall Chinook salmon.

Zorich, N. A., Jonas, M. R., & Madson, P. L. (2010). *Avian Predation at John Day Dam 2009: Estimating Fish Consumption Using Direct Observations and Diet Analysis* (p. 55). U.S. Army Corps of Engineers. http://pweb.crohms.org/tmt/documents/FPOM/2010/NWP%20Research/FFU%20reports/Avian%20Predation%20at%20John%20Day%20and%20The%20Dalles%20Dams%202010%20(2011-10-31%20Final).pdf

Avian predators are one highly visible cause of smolt mortality at hydropower dams. In the Columbia basin, if severe enough this predation may prevent a dam from meeting its survival goals required by the Biological opinion for Endangered Species Act listed salmonid passage. In 2010, the second year of this study, our task was to determine the impact of avian predators on fish passing John Day and The Dalles Dams. Our objectives were: 1) Determine species composition, number, and distribution of piscivorous birds 2) Estimate smolt consumption by gulls 3) Compare smolt consumption by gulls (Larus spp.) between years and between dams. To quantify avian consumption, observers used binoculars to count gulls, the rate of attacks (dives), and determine if an attack was successful (fish in bill) during the smolt outmigration period from 8 April to 28 July 2010. We then estimated salmonid consumption using those variables and diet information from weekly gull stomach collections. Additionally, counts were collected for other fish eating birds present at the dams. California gulls (Larus californicus) were the dominant piscivore at both dams followed by western grebes (Aechmorphorus occidentalis), American

white pelicans (Pelecanus erythrorhychos), double crested cormorants (Phalacrocorax auritus), and others. The daily abundance of gulls at John Day Dam ranged from zero on 8 April to a brief high of 118 on 14 June, declining rapidly to two on 17 June, yielding a seasonal mean of 17. At The Dalles Dam gull daily abundance ranged from zero on 12 April to a high of 133 on 19 May, slowly decreasing to four on 27 July, yielding a seasonal mean of 34. Overall, 349 California gull stomachs were collected for diet analysis. Stomachs from John Day Dam contained 101 salmonids, 12 Pacific lamprey macropthalmia (Entosphenus tridentatus), three other fish, eight unidentified fish, and insects. We also recovered 18 PIT tags, 12 of which were un-readable tags. Gull stomachs from The Dalles Dam contained 75 salmonids, 113 Pacific lamprey macropthalmia, and three unidentified fish as well as five readable and four un-readable PIT tags and landfill scraps (e.g. old french fries). Fewer macropthalmia were collected at John Day likely because high winds made it unsafe to operate our collection boat during the week of peak lamprey outmigration. At The Dalles Dam our estimate of smolt consumption, was 98,000 (58,000 - 145,000 95% CI). At John Day Dam our estimate of smolt consumption, was 18,000 (11,000 - 26,000 95% CI). Consumption estimates include both additive and compensatory sources of mortality. This is a reduction of 62,000 (76%) from 2009 when 80,000 smolt were consumed at John Day and is attributed to intensive boat hazing and a large avian deterrent line array.

Zorich, N. A., Jonas, M. R., & Madson, P. L. (2011). *Avian predation at John Day and The Dalles dams 2010: Estimating fish consumption using direct observations and diet analysis.* (p. 55). U.S. Army Corps of Engineers. http://pweb.crohms.org/tmt/documents/FPOM/2010/NWP%20Research/FFU%20reports/Avian%20Predation%20at%20John%20Day%20and%20The%20Dalles%20Dams%202010%20(2011-10-31%20Final).pdf

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