EVALUATION OF PINNIPED PREDATION ON ADULT SALMONIDS AND OTHER FISH IN THE BONNEVILLE DAM TAILRACE, 2017

Kyle S. Tidwell, Bjorn K. van der Leeuw, Lindsay N. Magill, Brett A. Carrothers, and Robert H. Wertheimer

Corresponding author: Kyle.S.Tidwell@usace.army.mil

U.S. Army Corps of Engineers
Portland District, Fisheries Field Unit
Bonneville Lock and Dam
Cascade Locks, OR 97014

March 5, 2018

Past reports and more information on the Pinniped Monitoring Program at Bonneville Lock and Dam can be found at the following link:

http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Pinnipeds/

The correct citation for this report is: Tidwell, K.S., B.K. van der Leeuw, L.N. Magill, B.A. Carrothers, and R. H. Wertheimer. 2018. EVALUATION OF PINNIPED PREDATION ON ADULT SALMONIDS AND OTHER FISH IN THE BONNEVILLE DAM TAILRACE, 2017. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR. 54pp.

EXECUTIVE SUMMARY

California sea lions (CSL; *Zalophus californianus*) and Steller sea lions (SSL; *Eumetopias jubatus*) aggregate at the base of Bonneville Dam, where they feed on Pacific salmon and steelhead (*Oncorhynchus spp.*) which are protected under the Endangered Species Act. As directed by a Biological Opinion, the U.S. Army Corps of Engineers has been monitoring the seasonal presence, abundance, and predation activities of pinnipeds at the dam since 2002. Monitoring is conducted during the Focal Sampling Period (FSP; approximately January – May), and additional abundance monitoring is conducted when animals are present outside of the FSP.

The following is a summary of the 2017 FSP and the fall/winter season:

PRESENCE AND ABUNDANCE:

- Abundance monitoring began on August 15, 2016 when the first pinniped returned to the dam and terminated on June 2, 2017 when the last pinniped was documented at the dam.
- An average of 15.4 ± S.E. 1.3 SSLs per day were observed during the FSP.
- An average of 5.1 ± S.E. 0.6 CSLs per day were observed during the FSP.

PREDATION

- The FSP including predation monitoring, started January 10, 2017 and ended on June 2, 2017.
- An estimated 5,384 (CI 4,671 – 6,042) adult salmonids were consumed by pinnipeds in 2017, which equates to 4.7% of all salmonids passing the dam during the season.
- An estimated 4,951 (CI 4,276 – 5,585) spring Chinook salmon (*O. tshawytscha*) were consumed, which equates to 4.5% of the run during the FSP.
- An estimated 322 (CI 144 – 454) summer and winter steelhead (*O. mykiss*) were consumed, which equates to 9.0% of the run during the FSP.

MANAGEMENT AND DETERRENCE

- Physical barriers – excluded pinnipeds from entering fishways.
  - Continued placement of SLEDS should be maintained.
- Boat and dam-based hazers used 4,956 non-lethal deterrence devices.
  - Hazing provides circumspect benefits that merit better evaluation.
- Wildlife managers branded 18 and removed 24 CSLs, and branded 12 SSLs.
  - Branding allows unique identification(s) and should be emphasized.
  - A management plan for SSLs should be developed and implemented at Bonneville Dam.

We documented an increasingly high number of Steller sea lions during 2017. Spring Chinook were consumed at similar levels as 2016, but were primarily consumed by Steller sea lions, which is the first instance where Steller sea lions consumption was markedly greater than California sea lion consumption. The low run size and high percentage of steelhead consumed by pinnipeds in 2017 is alarming, and warrants particular attention from fish and wildlife managers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Interspecific competition for anadromous salmonids in the Columbia River by marine mammals and humans has been present for hundreds of years (SBFC 1889, Thwaites 1969), and has contributed to the disdain and attempted eradication of some marine mammal species in the Pacific Northwest (Scheffer 1928, Newby 1973, Braje and Rick 2011). Chief among these competing species, the pinnipeds (seals and sea lions) in Oregon and Washington were targeted for eradication through bounty-incentivized removal programs by State wildlife managers which contributed to reducing populations to all-time lows (Bartholomew 1967, Pearson and Verts 1970, NOAA 2016). In response to the universal decline of marine mammal stocks, the Marine Mammal Protection Act (MMPA) was initiated in 1972 and effectively buoyed most northwest pinniped stocks to all-time high levels in the following 30 years (Jefferies et al. 2003, Brown et al. 2005). Concomitant to the success of the MMPA (Magera et al. 2013), salmonid stocks declined to a point where many are now threatened or endangered, especially those of the Columbia River and its tributaries (NFSC 2015). Thus, the flux of predator and prey in the Columbia River has now transitioned to high numbers of protected pinnipeds, and low levels of endangered salmonids.

Analyses of pinniped-salmonid interactions in or near the Columbia River suggest that all life stages of salmonids are at risk of predation by pinnipeds (Brown et al. 2017, Chasco et al. 2017), and that some salmonid runs are at greater risk of depredation and potential extinction than others (Keefer et al. 2012, Falcy 2017). As such, pinniped predation on endangered salmonids in the Columbia River has garnished considerable attention and continues to be a focus of concern and research (Kinsey et al. 2007).

Historical pinniped distribution in the Columbia River system has been detailed through archeological records, whereby, seal (Family: Phocidae [true seals]) remains were documented at river kilometer 323 (mile 201) near Celilo Falls (Lyman et al. 2002), a falls now inundated by The Dalles Reservoir. Sea lions (Family: Otariidae [eared seals]) have historically frequented the lower portions of the Columbia River system, but there is no evidence of congregations of these animals upriver of what is now Bonneville Dam (BON) in the time preceding Dam construction (i.e. 1938) or the six decades following construction (Keefer et al. 2012). The dam is largely impassable to pinnipeds and is now seasonally frequented by sea lions and an occasional harbor seal (*Phoca vitulina*).

Sea lions were first documented at BON in the late 1980's when California sea lions (CSL; *Zalophus californianus*) were sporadically observed depredating spring Chinook salmon (*Oncorhynchus tshawytscha*) (Stansell 2004). Steller sea lions (SSL; *Eumetopias jubatus*) were first documented at BON in 2003 (Keefer et al. 2012). Anecdotal observation suggested the duration of residency and level of salmonid predation by both pinniped species increased in subsequent years, leading fish managers to question the potential impact such predators may be having on migrating adult salmonid fish runs (NMFS 1997).

Potential impacts of fish predators at hydroelectric dams have long been of concern to fish managers (Schilt 2007, Evans et al. 2016), and can present challenges to management agencies (Friesen and Ward 1999, McKinney et al. 2001). The Columbia River System of hydroelectric dams presents one of the most advanced hydropower systems in the world, and has been subject to in-depth study of fish predator activities and deterrence (Roscoe and Hinch 2010, Patterson et al. 2017). Historically, focus was given to the predation of juvenile, and thus more vulnerable cohorts of out-migrating fish given the extensive suite of predators that can depredate these younger age classes (e.g. warm water fish [Poe et al. 1991, Mesa et al. 1994, Sorel et al. 2016] and piscivorous birds [Collis et al. 2002]). However, attention has now been turned to up-stream migrating adult fish exposed to pinniped predators. Like natural fish-passage impediments (e.g., waterfalls, cascades, chutes), hydroelectric dams can delay up-stream fish passage and congregate fish searching for ladder entrances (Kareiva et al. 2000, Quinones et al. 2015). Such delays can make fish vulnerable to predation by pinnipeds (Stansell 2004, Naughton et al. 2011), a clade known to be efficient predators of Pacific Northwest fish (Weise and Harvey 2005).

An extreme example of deleterious pinniped-salmonid predation near a man-made impoundment was the functional extirpation of the Ballard Locks winter steelhead (*Oncorhynchus mykiss*) run in Washington State in the late 1980's (Jefferies and Scordino 1997, Fraker and Mate 1999). More recently, pinniped impacts have been documented on a number of ESA-listed salmonid species in the Columbia River and associated rivers and tributaries (Madson et al. 2016, Wright et al. 2016). For instance, pinniped predation on Upper Willamette River (UWR) winter steelhead has recently been hypothesized to be the primary cause of decline and potential extinction of the species (Falcy 2017). Similarly, winter steelhead and spring Chinook at and below BON have been documented prey of pinnipeds for over a decade (Stansell 2004) and represent a unique composition of ESA-listed Pacific salmon (NSFC 2015).

Because BON is the lowermost Columbia River dam, it passes the most and a greater diversity of anadromous migrants than any other dam on the river, and as such, has the potential to have the most impact on fish passage (Evans 2016). The ESA-listed stocks of steelhead present a unique situation insofar that Bonneville pool is the only reservoir on the Columbia River with both winter (ocean maturing) and summer (stream maturing) steelhead varieties (Withler 1966) spawning in tributaries that discharge into it (e.g. Wind River, Little White Salmon River, Big White Salmon River, Hood River, and Klickitat River [Nehlsen et al. 1991]). Thus, pinniped predation of these fish can occur over a sustained period of time while the fish stage for spawning migration and during the post-spawn kelt downstream migration. Due to disorientation of kelts that occurs during downstream dam passage (Wertheimer and Evans 2005), this important life history type (Fleming 1998, Keefer et al. 2008a) may be of particular vulnerability to pinniped predation in the dam tailrace areas.

Other threatened or endangered salmonid species exposed to pinniped predation near BON include spring Chinook, Chum Salmon (*Oncorhynchus keta*), and Coho Salmon (*Oncorhynchus kistuch*). Pinniped presence in the Columbia River is seemingly synchronized with the Spring Chinook run during the pinniped pre-breeding season, while the post-breeding season appears to be synchronized with the Coho and Chum Salmon migration period. Depredation of any of these ESA-listed stocks could damage run viability and make recovery efforts difficult.

Though not ESA protected, Pacific Lamprey, a species of concern, is also exposed to predation by pinnipeds. The chronology of Pacific Lamprey migration overlaps the later part of the pre-breeding season of pinnipeds at BON.

In response to these concerns, and to fulfill the requirements set forth in the Federal Columbia River Power System Biological Opinion (NMFS 2000, 2008) – which outlines operational criteria for dams to protect ESA-listed fish – the U.S. Army Corps of Engineers (USACE) Fisheries Field Unit (FFU) initiated a pinniped monitoring program to fulfill the Reasonable and Prudent Alternatives (RPA) outlined under the predation management strategy of the Biological Opinion. These RPA's are specific to pinnipeds at BON and state:

RPA Action 49 - Marine Mammal Control Measures

The Corps will install and improve as needed sea lion excluder gates at all main adult fish ladder entrances at BON annually. In addition, the Corps will continue to support land and water based harassment efforts by the National Oceanic and Atmospheric Administration (NOAA) Fisheries, Oregon Department of Fish &Wildlife (ODFW), Washington Department of Fish & Wildlife (WDFW), and the Tribes to keep sea lions away from the area immediately downstream of BON.

RPA Action 69 - Monitoring Related to Marine Mammal Predation

The Action Agencies will estimate overall sea lion abundance immediately below BON. Monitor the spatial and temporal distribution of sea lion predation attempts and estimate predation rates. Monitor the effectiveness of deterrent actions (e.g., exclusion gates, acoustics, harassment and other measures) and their timing of application on spring runs of anadromous fish passing BON.

Over the last 15 years, the pinniped monitoring program has evolved to fulfill the directives of the RPA and collaborated with external agencies to pioneer research techniques to better inform and guide pinniped and fish management activities. Specifically, the objectives of the FFU pinniped monitoring program are to:

1. Determine the seasonal timing and abundance of pinnipeds present at the BON tailrace, documenting individual CSL and SSL presence and predation activity when possible.

2. Monitor the spatial and temporal distribution of pinniped predation attempts and estimate the number of adult salmonids (*Oncorhynchus sp*.), White Sturgeon (*Acipenser transmontanus*), Pacific Lamprey (*Entosphenus tridentatus*), and other fishes consumed by pinnipeds in the BON tailrace and estimate the proportion of the adult salmonid run consumed.

3. Monitor the effectiveness of deterrent actions (e.g., exclusion gates, acoustics, harassment and other measures) and their timing of implementation on runs of anadromous fish passing BON.

Consistent with RPA Action 69, NOAA Fisheries directed the USACE on July 7, 2017 to monitor the fall and winter pinniped abundance and provide consumption estimates in the BON tailrace.

The USACE pinniped monitoring program provides monitoring data, access to the dam facilities, and collaborates with state, tribal, and federal agencies charged with managing fish and pinniped species. As such, it is pertinent to highlight the collaborative roles of the involved agencies: The states of Oregon, Washington, and Idaho (the States) received permission from NOAA Fisheries to extend the Letter Of Authorization (LOA) granted on March 15, 2012 under Section 120 of the Marine Mammal Protection Act (MMPA) to permanently remove CSLs at BON that were having significant negative impacts on the recovery of ESA-listed Chinook salmon and steelhead stocks (NOAA 2015). An extension was approved on July 7, 2016 for an additional five years (U.S. Office of the Federal Register

2016). To date, 183 CSLs have been removed under the section 120 LOA. The Columbia River Inter-tribal Fish Commission (CRITFC) supports the program with personnel and boat based hazing efforts, and the U.S. Department of Agriculture (USDA) provides dam based hazing (i.e. deterrence) efforts under contract to the USACE.

This report is a summary of abundance and predation monitoring and deterrence efforts implemented in 2017 by, or coordinated with, the aforementioned agencies. We begin with a background of the BON system, species, and study design, then present current data partitioned by pinniped species and contrast it to previous estimates to elucidate the trends of pinniped presence and predation on adult migratory fish at BON.

METHODS

STUDY AREA

Bonneville Lock and Dam is located on the Columbia River at river mile 146 (river kilometer 235) from the confluence of the Pacific Ocean. The dam spans the Columbia River between the states of Oregon and Washington and is comprised of three concrete structures separated by islands. Pinniped activities historically occur in the tailraces of the dam between the islands. Using the *a priori* knowledge of pinniped behavioral patterns at the dam, we observed pinniped abundance and predation from each of the three tailrace sub-areas downstream of Powerhouse One (PH1), Powerhouse Two (PH2), and the Spillway (SPW) (Figure 1). Elevated observation platforms at these tailraces were used to observe pinniped activity. To facilitate comparison of predation events by tailrace area, and provide continuity to previous reports (Madson et al. 2017), we divided each tailrace sub-area into seven zones (Figure 1). Pinniped abundance counts and brand re-sightings were conducted in the three tailrace sub-areas and at Tower Island, a site consistently used as a resting area for pinnipeds (Figure 1). Abundance estimates and brand re-sightings were also collected at Tanner Creek, the nearest downstream fresh water input source approximately one mile from the dam. The States anchored three floating sea lion traps in the vicinity of Tower Island and one in the PH1 forebay during the months that CSLs were present, which served as areas for pinnipeds to rest on, facilitating abundance counts and brand re-sighting.

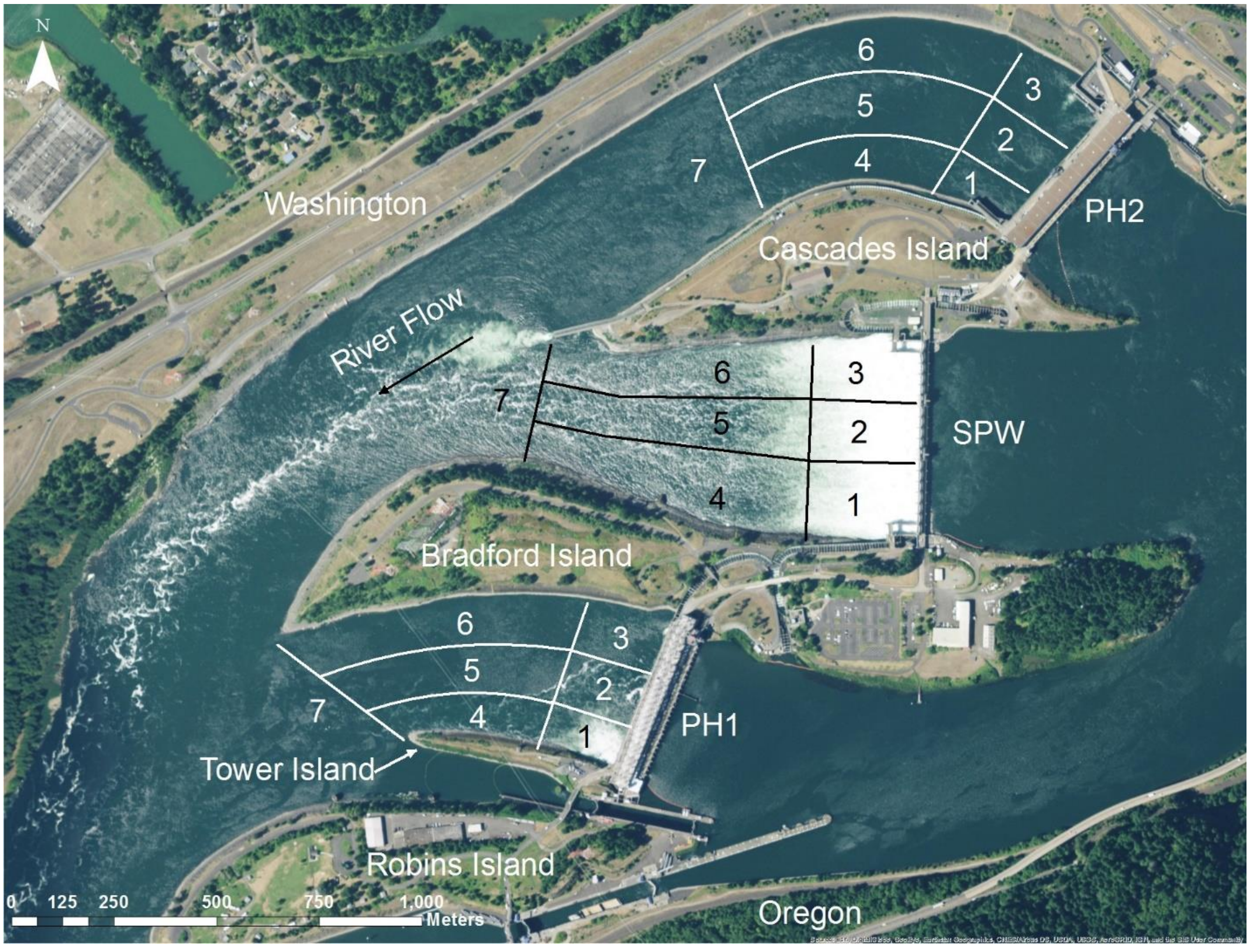


Figure 1. Bonneville Dam study area with Powerhouse One (PH1), Spillway (SPW), and Powerhouse Two (PH2) tailrace sub-areas separated into zones for assigning the location of predation events.

FOCAL SPECIES

Pinnipeds

The Order Pinnipedia evolved ≥ 20 million years ago and has likely overlapped in distribution with anadromous Pacific salmonids for the bulk of this time (Naughton et al. 2011). The co-occurrence and predation of salmonid fish by pinnipeds undoubtedly led to long-standing anthropogenic disdain for the species in the Pacific Northwest, so much so that State wildlife agencies authorized bounty programs to kill as many pinnipeds as possible (Beddington et al. 1985). Since the Marine Mammal Protection Act of 1972, the stocks of CSLs and the Eastern stock of the SSLs have rebounded (NOAA 2014, 2016b), and are now frequently observed along the Pacific Coast.

The rookeries (i.e. breeding and rearing grounds) for the sea lions entering the Columbia River system are primarily the Channel Islands off the coast of southern California for the CSLs, and the Rogue Reef outcroppings off the coast of southern Oregon for the Eastern stock of SSLs (B. Wright personal comm.). Males of both species disperse from rookeries after breeding to forage in waters different from that of the females and sub-adults to regain the weight lost during the prolonged terrestrial breeding periods. Thus, all CSLs and SSLs entering the Columbia River system are males that have left their respective breeding grounds in search of forage opportunities. Sea lions have been documented at the mouth of the Columbia for several hundred years (Lyman et al. 2002), but have only recently (i.e. < 20 years) been documented consistently traveling to BON to forage. Brand re-sighting and telemetry data suggest that approximately 7% of the CSLs occurring near the mouth of the Columbia River travel to BON to forage (NOAA 2017). These animals represent a mixture of several cohorts including juvenile (2-4 years), sub-adult (5 – 8 years) and adults (> 8 years) (Laake et al. 2016).

Natural History of Pinnipeds at Bonneville Lock and Dam

Pinnipeds that travel to, and forage at, BON consistently forage in the tailraces of the dam during the day and utilize rock outcroppings and riprap infrastructure to rest on, a process called "hauling out" during the night. Hunting forays from the rocks to the tailraces occur by almost all animals just prior to sunrise after which they can be observed transiting between the tailraces and haul-out locations during daylight hours. They return to the haul-out locations just after sundown where they remain through the evening. One feature of CSL behavior that occurs during peak abundance periods and periods of increased temperature is rafting – multiple animals floating in the water not touching the substrate but touching each other – a behavior less often observed in SSLs.

Pinnipeds can be observed periodically surfacing to breathe when foraging then submerging to pursue prey below the surface. The maximum time submerged under normal conditions for CSLs is 9.9 minutes (Feldkamp et al. 1989), however, at BON foraging dives are generally less than five minutes for both species of pinniped (KST personal obs.) Once captured, larger prey items are brought to the surface and broken through a series of violent head shakes reducing the prey to multiple pieces of manageable size (Jones et al. 2013). Of particular note for monitoring purposes is the prey handling time and capacities of each species; adult SSLs can swallow sizeable spring Chinook almost whole in a matter of seconds, whereas adult CSLs typically stay at the surface and break the fish into smaller pieces. Thus, handling time differs for each species of sea lion, a difference which likely influences the ability and confidence of observers to document predation and therein may influence inter- and intra-species differences enumerated in this report – SSL predation may be biased low as a result.

Fish

Pacific salmon (*Oncorhynchus spp*.) of the Columbia River system are composed of several species, many of which have distinct evolutionarily significant units (ESU) that have been listed under the ESA. The primary species passing during the focal sampling period of pinniped presence at BON are the Columbia River spring Chinook salmon and distinct population segments of winter and summer steelhead. These runs are historically classified by the periods of time at which they cross the dam: spring Chinook: March 14 – May 31, ocean-maturing winter steelhead: November 16 – March 31, and stream-maturing summer steelhead: April 1 – November 15 (Busby et al. 1996, NMFS 2013). However, to align with previous reports and managements' recognition of fish runs, spring Chinook are reported as March 14 – June 15.

Due to the temporal overlap of pinnipeds and migrating salmonids, data suggests that early migrating salmonid stocks may be disproportionately impacted by pinniped predation (Keefer et al. 2012), specifically ESU stocks of spring Chinook from the Icicle, Salmon, Deschutes, Clearwater, and Umatilla rivers which have the greatest temporal overlap with pinnipeds. Of these, the Icicle and Salmon River populations are listed as threatened under the ESA (Good et al. 2005) and therein provide impetus for the Biological Opinion directing the monitoring of predation of these at-risk stocks.

Different salmonid species and various runs of steelhead and Chinook salmon are encountered by pinnipeds due to the temporal overlap and misalignment of run chronology as a result of environmental conditions and migration patterns, however the bulk (i.e. > 95%) of salmonids consumed during the sampling season are of the spring Chinook and winter steelhead runs (Stansell 2004, Madson et al. 2016). Analyses of stock specific impacts are beyond the scope of this report, but are warranted. Other fish species observed as prey of pinnipeds at BON include: White Sturgeon (*Acipenser transmontanus*), Pacific Lamprey (*Entosphenus tridentatus*), American Shad (*Alosa sapidissima*), and various warm water and introduced fishes (e.g. *Micropterus spp.*, *Cyprinus spp.*). Here we enumerate the number of salmonids, Pacific Lamprey, and White Sturgeon consumed.

SAMPLING METHODS

The pinniped monitoring program has evolved since the initiation in 2002 to better capture the information required by the Biological Opinion and to facilitate research efforts by the States and collaborative agencies. Data informed modifications to sampling schemes and observer effort have produced a robust and yet cost-effective system to estimate salmonid consumption and pinniped abundance. Although the structure of the sampling has varied through the years, the methods of data collection have remained constant. In short, biological observers trained in fish and pinniped identification use field glasses (8 X 42 magnification) to document pinniped activity at predetermined locations above the tailraces of the dam (Figure 1) at a scheduled interval to develop estimates of predation and abundance.

For clarity, there are two time periods studied during the 2016 – 2017 season; the first is the fall and winter period, a period not monitored in all previous years but monitored this year for pinniped abundance only. The second period we term the “focal sampling period (FSP)” which follows the historical study period of approximately January 1 – May 31 and involves both predation and abundance monitoring. The early portion of this sampling frame captures winter steelhead and White Sturgeon consumption, while the later portion captures consumption of the spring Chinook run.

This season, we elected to conduct focal sampling until the last pinniped left the dam so as to fully enumerate pinniped presence and predation. As such, this season we sampled until June 2. Comparisons to previous data need be made with the understanding that sampling prior to the 2017 season finished on May 31. All tables listing historical data represent sampling through May 31, while this season’s data were collected through June 2. Data from the fall-winter and focal sampling periods were recorded this season based on the following design.

Monitoring: Abundance, Residency, and Recurrence

We quantified the number of pinnipeds present at the BON project each day by conducting point counts of animals from a distance using field glasses. Sampling began when the first pinniped was observed in the fall, and terminated when the last pinniped left in the spring. To increase efficiency and account for the daily flux of animals to and from the dam, we utilized historical data and our knowledge of pinniped behavior to inform the optimal times to perform point counts. Analysis of the previous 15 years of point count data revealed a strong diel pattern, whereby the greatest number of pinnipeds were consistently hauled out during the crepuscular hours. Interestingly, this pattern is inconsistent with sea lion foraging cycles in tidal systems (Boehme et al. 2016) and apparently unique to individual sea lions foraging at BON. With this knowledge, we elected to conduct point counts at known haul-out and rafting locations and each of the three observation points above the tailraces at sunrise, mid-day, and sunset.

Fall and winter pinniped abundance (August – December) is presented separately from the FSP (January – May) to facilitate comparison to the previous 15 years of abundance data. Fall and winter abundance counts were initiated when the first pinniped arrived to the dam. Abundance counts for this period were conducted at least once per day and often two to three times.

The abundance data provided herein represent a conservative estimate of pinnipeds at the dam on any one day. All pinnipeds in the three tailraces and on Tower Island were counted, however, submerged animals, animals in transit between locations but out of sight, and the ingress and egress of animals to BON occurs and may potentially influence our results. To avoid double counting animals transiting between count locations, we sampled all locations with a team of observers in one ten-minute period, a sufficiently short period of time to individually count animals before they could move between sites and long enough to ensure submerged animals will have surfaced and can be counted.

Abundance – The daily pinniped abundance for each species is presented as the highest point count taken for each species each day irrespective of time of day. For periods when FFU staff were not present to collect point count data (i.e. weekends, holidays), linear interpolation between the most recent days surrounding the missing period was used to estimate abundance. In doing so, we present the estimated maximum number of pinnipeds that could have been near the dam each day.

Yearly maximums of individually identifiable animals are presented to document how many pinnipeds of each species were observed throughout the season. Since not all CSLs are branded and very few SSLs are branded, we present the yearly maximum count as either: 1) the greatest number of animals in any one point count (sum of all three sub-tailraces, Tower Island, and Tanner Creek), or 2) the cumulative number of uniquely identifiable animals observed during the season, whichever is higher. This approach combines two metrics but provides the estimated yearly maximum because either, all the animals were individually identified at some point or were observed in one point count and thus were mutually exclusive counts of individuals. However, the latter method does have the potential to be biased low, as a non-identifiable individual could have been to BON during the season but was not present during the highest daily point count of the season. Thus, the yearly maximum abundance is a conservative measure of the most animals documented throughout the year.

Residency – To provide insight to the duration of time spent at BON for any individual pinniped we report the number of days each animals spent at BON. Pinnipeds were trapped and branded by the States, and tracked with alpha-numeric brands placed on their dorsal surface. Other markers used to identify individuals include: scars, skeletal and tissue deformities, and unique color patterns. The brands and unique markers were recorded during predation monitoring, abundance point counts, and photo-archival via camera traps at haul-out locations. Based on the seasonal variation of unique (non-brand) markers, chronology of pinniped arrival and branding efforts, ingress and egress of animals, and the reduced monitoring effort during the predation sampling season (described below) – the data provided for individual pinniped residency and abundance should be considered estimates.

Individual pinniped residency estimates are reported as the number of days each animal was documented at BON (as historically reported) and the potential number of days the animal could have been on project (i.e. the difference in days between first and last observation within the current season).

Recurrence – For previously documented individuals (i.e. observed in prior years) we present the number of days spent at BON, the percentage of these animals that have been to BON previously, and the number of years they have been documented. Given the small number of branded SSLs, the reduced numbers of sampling personnel, and the emphasis placed by the States on CSL identification, individual identification of each SSL was not targeted as a priority. As such, we relied on brands (both previously applied and those applied this year) and distinctive markings on previously documented individuals to calculate recurrence for SSLs. Recurrence of CSL was recorded only for previously branded animals.

The removal efforts of the States confounds residency and recurrence calculations with CSLs that were removed in the same year as they were branded. Thus, we present the data as three classes: All individually identifiable CSLs, individuals branded and removed in the same year, and individuals branded > 1 year before removal.

Estimating Fish Predation

Surface observations of pinniped-prey interactions were utilized to measure the number and species of fish consumed by each species of pinniped. This method is useful and has been employed elsewhere (see Roffe and Mate 1984, Wright 2014). All attempted (i.e. loss) and successful (i.e. catch) predation events were recorded, as well as the time and location of the predation event, species of fish, species of pinniped, unique pinniped identification (if possible), length of sturgeon (if applicable), and interactions with other pinnipeds during the predation event.

Sub-surface predation and consumption has been documented previously, particularly with the larger SSL and smaller fish, and may artificially truncate the estimated number of fish consumed (Stansell 2004). However, as noted, this is almost exclusively a SSL issue and likely only influences the counts of the smallest spring Chinook (i.e. jacks) and smaller steelhead. Some CSL sub-surface predation may occur, Due to the nature of observing wild animals *in situ* with field glasses, not all predation events were easily recognizable. In instances when fish were too mangled, actively being swallowed, or too far from the observer to be recognized, the predation event was recorded with all pertinent data and the fish species was listed as “unidentifiable.”

The process of accounting for the unidentifiable fish in the predation estimate has evolved over the years. Historically, the program monitored pinniped activity extensively (i.e. all daylight hours and some nighttime observations) and therein justified using the raw data of observed predation events with a correction factor applied based on *a priori* knowledge of observer skill level, program structure, and pinniped behavior (Stansell 2004). Here we use the "adjusted consumption estimate" developed by Tackley et al. (2008) which incorporates the unidentifiable fish predation events evenly across other predation events based on the number and species of fish consumed that day. For example, assume 24 fish were caught in one day, 20 identified, and four unidentified. Of the identified fish, 10 were Chinook and 10 steelhead. The four unidentified fish catches would be proportionally distributed to two Chinook salmon and two steelhead. In this manner we provide the adjusted estimate – a parsimonious estimate of how many of each fish species were consumed each day – which is the functional unit utilized to estimate the total number of fish consumed for the season.

Being readily identifiable and not easily mistaken for any other fish in the Columbia River, the Pacific Lamprey was not applied to the adjusted estimates. Therein, Pacific Lamprey consumption estimates reported here are merely expanded for hours not observed and have not been adjusted. It is possible that Pacific lamprey are consumed under-water albeit experienced observers rarely report Pacific Lamprey being brought to the surface in a mostly consumed state. However, since it is possible, the estimates provided here are minimum consumption estimates. Moreover, based on the tendency for Pacific Lamprey to pass at night time and the lack of night-time monitoring there is potential for Pacific Lamprey predation to go unrecorded, again indicating that the estimates provided herein, are minimal estimates.

Sampling Design for Predation Estimates

As in previous years, a Stratified Random Sampling design (SRS) (Cochran 1977) was implemented to account for hours not observed across the three tailraces of the dam each week (Madson et al. 2017). This season we elected to consistently apply a systematic sampling design with even coverage within each strata week, a design that is different from last season which involved a combination of simple and stratified random sampling within weeks. We describe the methods and assumptions of these designs below.

Each seven-day week (arbitrarily assigned as Sunday-Saturday) served as a stratum. There were 21 strata (weeks) during the study period between January 10 and June 2. Five of seven days (Monday-Friday) were sampled during each stratum with the exception of federal holidays or periods when the dam was inaccessible due to harsh winter weather (n = 15 days). These missing samples were incorporated with weighting (sampling effort to sample total) to the predation estimate. Given the diel foraging activity of the pinnipeds at BON, the sample coverage for each stratum was based on civil twilight (morning), sunrise, sunset, and civil twilight (night) for Cascade Locks, OR (six miles east of BON). We conducted observations for the maximum number of two conjoined 30 minute sampling units between morning and night. If the 60 minute sampling unit was ≥ 15 minutes before or after civil twilight, the first 30 minute interval was removed from the daily sample and the next 30 minute sample block was used to sample for 60 minutes. Doing so ensured enough light to facilitate positive identification of both pinniped and fish species and maximized the potential to randomly select a sampling unit during all hours of daylight. The sample rate, expressed as the percentage of daylight hours sampled per total daylight hours available in the week (i.e. stratum), was 23.8% for the FSP.

The distribution of observations was selected by assigning a number to each tailrace and randomly selecting one of the tailraces for sampling. Once the initial tailrace was selected, the sampling occurred in a systematic step-wise progression across each tailrace for that day. The process was then repeated for every Monday – Friday of each week for the entire season. This random systematic process, when sampled by a two-person team of observers working each tailrace independently, facilitates two important components of the sampling design: first, it eliminates travel between sites which, therefore, allows assumptions of equal and complete coverage to be upheld, and second, ensures equal and random assignment of sampling to all tailrace areas during all daylight hours.

Given that the levels of pinnipeds and fish fluctuate across the five-month sampling season (i.e. high heterogeneity), but remain relatively consistent within weeks (i.e. high homogeneity), we utilized a bootstrap resampling method, a technique widely applied to provide more robust measures of confidence for stratified sampling designs (Efron 1982), to estimate the mean catch and associated confidence intervals (CI) of fish consumed during the focal sampling period.

We elected to bootstrap across the entire sample due to the highly stochastic runs of fish and pinniped numbers. We treated the hourly observation samples as the target population and sampled, with replacement, 999 times from the observations over the focal sampling period to measure the population parameter of interest, the mean number of (adjusted) fish consumed. With this approach, some data points can appear at multiple times during the resampling. Among the 999 resampled data sets, the entire sample (all observation data) and the total observations during each week were kept constant. For example, if there were 35 and 40 observations during week 1 and week 2, respectively, our resampling maintained the same observation size for each of the 21 weeks (e.g., 35 for week 1, 40 for week 2, etc).

We estimated the total catch of every resampled table (999 estimates) and calculated the confidence intervals for the true mean (μ) using the distribution of delta [$\delta^* = \overline{x}^*$ -$\overline{x}$)]. $\overline{x}^*$is the mean of the bootstrap sample and $\overline{x}$ is the sample mean The bootstrap 95% confidence intervals for μ is as: [$\overline{x} - \delta^*_{0.025}, \overline{x} - \delta^*_{0.975}$].

In doing so, we provide the bootstrap estimated number of each fish caught by pinniped species with bootstrapped measures of variance for each estimate. If confidence intervals overlapped zero as a result of small sample sizes, we report the estimated number of fish consumed as the lower bound of variation and the calculated 95% confidence boundary as the upper level of predation.

All calculations and comparisons of consumptions were conducted with the adjusted consumption data unless otherwise noted. For comparison to previous years, we report the expanded consumption data as supplementary materials.

Calculation of predation estimates for percent of run taken

To facilitate inter-year comparisons and determine the estimated totality of predation by pinnipeds, we present the percentage of fish species taken by each species of pinniped calculated as the estimated number of salmonids consumed divided by the total passage count (e.g. fish over the dam and the estimated number of fish consumed by sea lions) from January 1 through June 2, multiplied by 100. Note that previous seasons ended on May 31, but this season and the coming season's sampling will occur and calculations of impact will be made, based on the run through the last day of the week containing May 31 or the last day pinnipeds are present. Salmon count data (daytime counts, all adult salmonids including jacks) were obtained from the USACE Fish Counts and Reports adult fish count website (WWW.FPC.ORG). Spring Chinook were defined as Chinook passing BON between March 14 and June 15. Summer and winter steelhead runs overlap in run chronology during the FSP and were treated together for analyses as all steelhead that crossed the dam between January 1 and June 2.

Lamprey passage accounts have historically been drawn from the day and nighttime passage through fish ladders at BON. However, Lamprey Passage Structures (LPS) monitored by Fisheries Field Unit staff have increasingly been passing fish not counted in the fish ladders. As such, and to provide a more realistic account of the impact pinniped predation may be having on the species, we present predation accounts as a function of lamprey counted in all BON fish ladders (day and night) and all corrected count data produced from the LPSs from January 1- June 2. For details of LPS systems and counts, see the 2017 Lamprey report produced by the Fisheries Field Unit at BON (Zorich et al. *in prep*.).

Evaluation of Clepto-parasitism

Clepto-parasitism – the act of one animal taking prey from another – occurred this year and has been documented in previous years. Here we present the number of occurrences of the behavior with respect to the species of pinniped. However, the confounding effects of sampling effort to data resolution described above for abundance and recurrence estimates, holds true for clepto-parasitism. Thus, these numbers are likely biased low relative to previous years that had all daylight hours observed.

DETERRENTS AND MANAGEMENT ACTIVITIES

Deterrents to fish predation

A variety of methods have been implemented to deter pinnipeds from eating salmonids near priority areas (Jefferies and Scordino 1997, Gotz and Janik 2013, Schakner and Blumstein 2013). Presently, hazing and physical exclusion devices are used in concert to deter pinnipeds at BON. Hazing consists of a combination of non-lethal deterrents including cracker shells (small charges of explosive ordinance), rubber buckshot, boat chasing, and underwater percussive devices known as seal bombs. USDA personnel haze from the face of the dam to deter pinnipeds from approaching the fish ladder entrances and boat-based CRITFC crews haze the pinnipeds downstream from the dam tailraces. We report the descriptive statistics of these efforts and discuss their use throughout the season.

Due to the repeated entry of pinniped to the fish ladders at BON, physical exclusion devices were constructed starting in 2006 to block pinnipeds but allow fish passage. Specially designed gates called Sea Lion Exclusion Devices (SLEDs) are now installed throughout the season at all eight fishway entrances of BON (Appendix A). In addition to the eight SLEDS, there is smaller physical exclusion grating installed on the 16 Floating Orifice Gates (FOGs) along the face of PH2 that allow fish to enter the collection channel and pass via the Washington shore fishway. The FOGs at PH2 provide additional fishway entry points for migrating adult salmonids, but the installed gratings are sized to preclude pinniped entry. Temporary Sea Lion Incursion Barriers (SLIBs) were constructed for the purpose of providing additional height on top of the FOGs. We detail the chronology of installation and efficacy of these physical exclusion devices below.

Management activities

Pursuant to the Section 120 authorization of the Marine Mammal Protection Act issued to the States, and to facilitate detailed studies of pinniped population dynamics at BON, the USACE supported the States operation of floating pinniped traps in the tailrace and forebay of the dam. From these traps, alpha numeric "hot" brands were placed on otherwise non-branded CSLs and SSLs. The traps also serve to allow for lethal removal of CSLs listed for removal. Here, we enumerate the basic operations conducted during the season, and direct attention to the involved agencies for further details about sea lion management activities (e.g. http://www.dfw.state.or.us/fish/sealion/).

DATA ANALYSIS AND REPORTING

Where statistical tests were used, measures of variance and normality were assessed (e.g. F-test and Shapiro – Wilk test) and the appropriate analyses performed. Statistical significance was evaluated at the $P < 0.05$ level. Descriptive statistics are reported throughout with the mean and associated standard error as the measure of spread (i.e. $\overline{x} \pm$ S.E.). Adjusted estimates of predation are reported as the bootstrapped mean with associated 95% confidence intervals (CI). Analyses were performed with JMP (version 12) and Program R (version 3.3.2).

RESULTS

All pinnipeds left BON by May 30, during the 2016 FSP. Soon after the 2016 FSP, sporadic observations of one to two pinnipeds were made between June 22 and August 15, 2016 after which time ≥ six SSLs were documented on a daily basis. Daily abundance point counts were conducted until the last pinniped, a CSL, left BON on June 2, 2017. Sampling of abundance and fish predation occurred throughout the FSP of January – June 2, 2017. The following sections detail the results of each aspect of the abundance, predation, and deterrence monitoring.

ABUNDANCE

Annual Individual Pinniped Abundance

We documented a total of 92 individual CSLs, 63 SSLs, and one harbor seal in the tailrace areas of BON during the FSP (Table 1).

Table 1. Minimum estimated number of individual pinnipeds observed at Bonneville Dam tailrace areas and the hours of observation during the focal sampling period, 2002 to 2017.

Year	Total Hours Observed	California Sea Lions	Steller Sea Lions	Harbor Seals	Total Pinnipeds
2002	662	30	0	1	31
2003	1,356	104	3	2	109
2004	516	99	3	2	104
2005*	1,109	81	4	1	86
2006	3,650	72	11	3	86
2007	4,433	71	9	2	82
2008	5,131	82	39	2	123
2009	3,455	54	26	2	82
2010	3,609	89	75	2	166
2011	3,315	54	89	1	144
2012	3,404	39	73	0	112
2013	3,247	56	80	0	136
2014	2,947	71	65	1	137
2015	2,995	195	69†	0	264
2016	1,974	149	54†	0	203
2017	1,142	92	63†	1	156

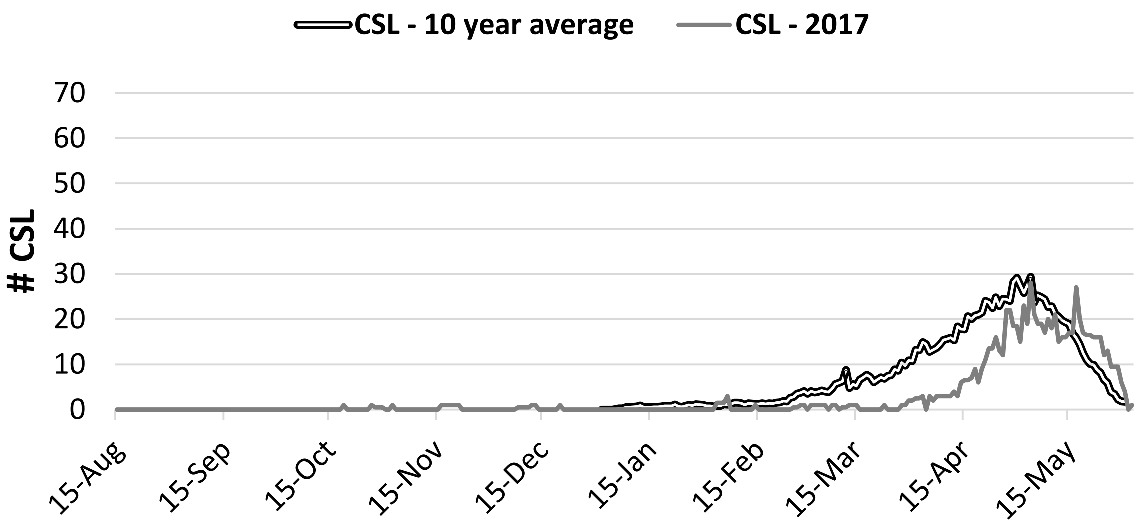
* Observations did not begin until March 18 in 2005.
† In 2015, 2016, and 2017 the minimum estimated number of Steller sea lions (SSL) was 55, 41, 32 respectively. These counts were less than the maximum number of Steller sea lions observed on one day, so the maximum number observed on one day was used as the minimum estimated number. This difference is driven by a focus on CSLs and lack of brands or unique markers on SSL.

Daily Pinniped Abundance

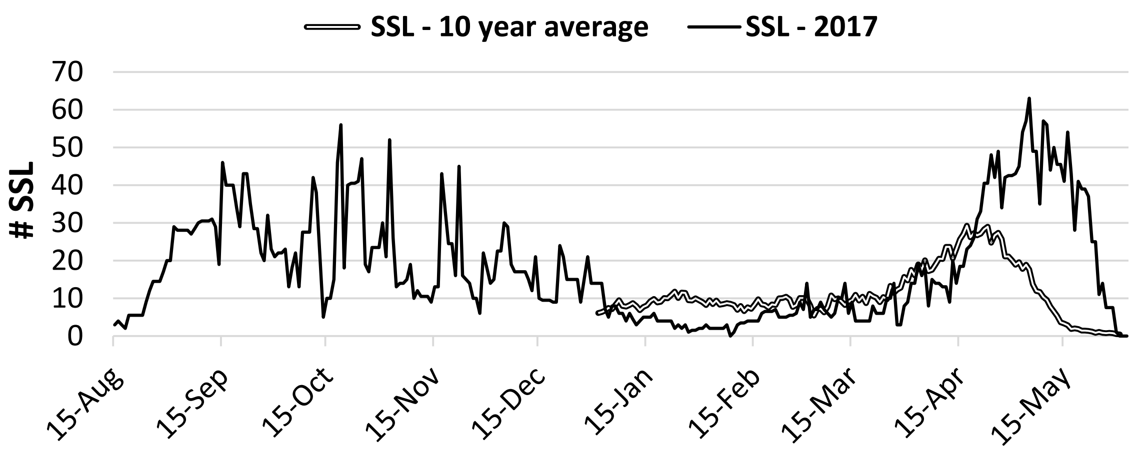
The first CSLs were observed on October 17, 2016, and fluctuated in low numbers (i.e. less than three) until March 31, 2017 when their presence steadily increased to a peak on May 4 (28 animals) and then declined to one animal that left on June 2 (Figure 2.A). The first SSLs were observed on August 15, 2016, after which the species oscillated in relatively high numbers through the fall with two peaks (Sept. 15, n = 46, Oct. 19, n = 56), then slowly increased to a maximum on May 5, 2017 (n = 63), then declined to zero SSLs by May 31, 2017 (Figure 2. B). Across the FSP CSLs averaged 5.1 ± 0.6 animals per day, whereas, SSLs averaged 15.4 ± 1.3 (Supplementary Table 1).

Visual inspection of the 2017 daily abundance data relative to the 10-year average shows that CSLs were below average in March and April, but SSLs surpassed the 10-year average in May (Figure 2). We tested for inter-month differences between 2017 data and the 10-year average with a series of pairwise Mann-Whitney U tests and found the number of CSLs in April were significantly lower than the 10-year average ($Z = 5.928$, $P < 0.0001$) but no different during the months of April and May ($Z = -2.32, -1.62$, all $P < 0.0001$) (Figure 2.A). Similarly, SSLs were below average from January through March ($Z = -5.55, -6.06, -3.89$, all $P < 0.0001$), but significantly above the 10-year average in May ($Z = 5.33$, $P < 0.0001$) (Figure 2.B).

Descriptive statistics facilitating inter- and intra-year comparisons of daily pinniped abundance are available in Supplementary Table 1. Of particular interest is the differential abundance of each species in recent years, wherein since 2009 the mean and median numbers of SSLs are far greater than CSLs (Supplementary Table 1). Given the high level of stochasticity in the daily counts of pinnipeds (Figure 2), the median counts, rather than mean, may provide a clearer indication of general abundance of each species. Inspection of the data reveal an increasing temporal distribution and abundance of SSLs at BON since 2008, wherein the median number of days present has increased, and the number of days without SSLs has decreased to almost zero (Supplementary Table 1, Figure 3).



A



B

Figure 2. Maximum daily count of pinnipeds by species (SSL: Steller sea lions, CSL: California sea lions) at Bonneville Dam from August 15, 2016 through June 2, 2017 compared to the 10-year maximum daily average. One harbor seal was observed during the season on January 10.

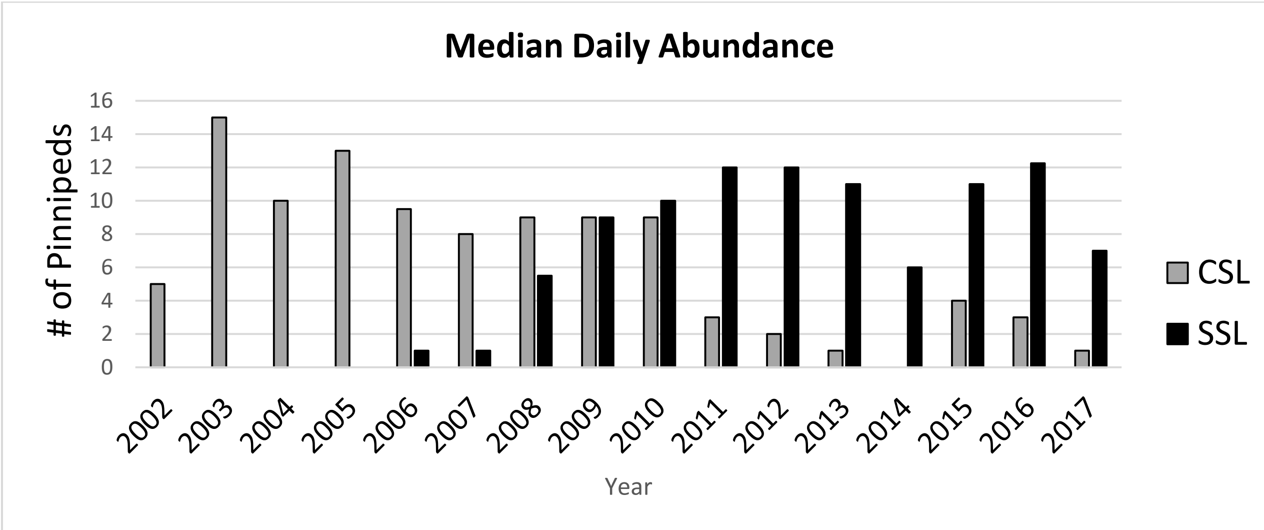


Figure 3. Annual median daily abundance of Steller sea lions (SSL) and California sea lions (CSL) at Bonneville Dam between January 1 and June 2 from 2002 to 2017.

Residence Times

Our use of the new metric "potential numbers of days on project" as a measure of residency of individual CSLs found that CSLs could be on site for much longer periods of time than the traditional method of reporting only the days observed. We found that the number of observed days averaged 5.1 ± 1.0 days, whereas, the potential average was 15.5 ± 5.0 days (Table 2). Moreover, the potential number of days present had a greater spread than that of the observed (i.e. 1 – 91 days vs 1 – 25, respectively).

Logically, removed individuals had decreased residency relative to the rest of the sample, but of the animals removed, the year of branding had an influence. Individuals branded in previous years were more often removed relative to the individuals branded in 2017 (Table 2). Observed residency did not differ for previously branded animals that were removed this year and those not removed, however, the potential number of days at BON for animals not removed was twice as large as the observed days (Table 2).

Residency times for individual SSLs is not reported due to low sample size (i.e. few branded/known individuals). However, anecdotal accounts suggest that many of the individuals were consistently at the dam with some individuals documented almost every observation day from August – May 31, 2017.

Table 2. Residency (i.e. number of days observed and potential number of days present) in reference to year branded and removed for individual California sea lions (CSL) at Bonneville Dam from January 1 to June 2, 2017.

	Days Observed			Potential Days Present		
	$\bar{x}$ ± S.E.	Range	*n*	$\bar{x}$ ± S.E.	Range	*n*
All CSL						
	5.1 ± 1.0	1 - 25	92	15.5 ± 5.0	1 - 91	92
All CSL Removed in 2017						
Yes	5.3 ± 0.9	1 - 17	24	10.8 ± 8.5	1 - 25	24
No	6.7 ± 0.7	1 - 25	68	17.2 ± 1.8	1 - 91	68
Branded in 2017						
Removed	13 ± 1.0	12 - 14	2	20.0 ± 0.0	20	2
Not Removed	8.4 ± 1.9	1 - 25	16	15.2 ± 2.8	1 - 38	16
Branded prior to 2017						
Removed	4.6 ± 0.8	1 - 17	22	9.9 ± 1.8	1 - 31	22
Not Removed	6.1 ± 2.5	1 - 17	52	17.8 ± 2.2	1 - 91	52

Recurrence

We documented the recurrence of 72 previously identified CSLs using brand re-sight data. Of these 72, 78.3% had been documented at BON previously and 38.9% had been observed ≥ the three years previous (Table 3). Of the 24 CSLs removed by the States, 21 were documented at BON previously, and 10 had been documented for ≥ 3 seasons (Table 3).

There were at most 63 SSLs on project this year based on the highest point count during the season. We documented 32 individuals, 17 of which can be confirmed to have been at the dam in previous seasons, and four of them for 10 seasons or more (Table 3).

It must be noted that brands are placed on animals at BON and other locations downstream. Pinnipeds arriving to BON can forage at, haul-out on, and leave Bonneville tailraces without being marked or identified. Therefore, the recurrence of individuals, especially SSLs – given the small number of brands – is intrinsically biased low and should be viewed as the minimum measure of recurrence.

Table 3. The number of years that California sea lions (CSL) and Steller sea lions (SSL) identified in 2017 were observed at Bonneville Dam. Of the identified CSLs in 2017, the number of CSLs removed and listed for removal is shown. Individuals observed for one year were defined as newly identified animals in 2017.

Number of Years Observed	All Identified SSL	All Identified CSL	Listed for Removal CSL	Removed CSL
11	1	0	0	0
10	3	0	0	0
9	0	0	0	0
8	0	0	0	0
7	0	0	0	0
6	5	0	0	0
5	2	0	0	0
4	3	1	1	1
3	0	27	18	9
2	3	44	22	11
1	15	20	9	3
Totals	32	92	50	24

Observations upstream of the dam

Historically, pinnipeds have been documented transiting the navigation locks of BON to the forebay and this year was no exception. We documented four CSLs that transited between the tailrace and forebay. Three were branded habitual users of the navigation lock and listed for removal, one was not branded. Two of these animals have previously been observed foraging at The Dalles Dam with one of them remaining there year round. One CSL who was trapped and transported out of the forebay in 2016 was again observed foraging in the forebay. This animal qualified for removal, was trapped in the tailrace, and was euthanized by the States.

PREDATION

We recorded 1,142 independent one hour (i.e. paired 30 minute intervals) observation periods during the 21 week FSP. Below we present predation on all salmonid species combined, then delineate predation impact for each fish species by pinniped species. All predation estimates are presented as the bootstrap calculated adjusted estimate (i.e. raw count data expanded for missing hours and adjusted for unidentified fish catches) and are followed by their associated 95% confidence bounds to display the spread. For reference to previous years' estimates, we present just the expanded estimates of predation in Supplementary Table 2.

Chronology of Fish Passage

The salmonids passing BON during the FSP had to contend with high water flow and cold temperatures during the 2017 season. Relative to the 10-year average, the river was much colder and moving significantly more water during the 2017 FSP (Figure 4). These co-factors contributed to a delayed run of spring Chinook.

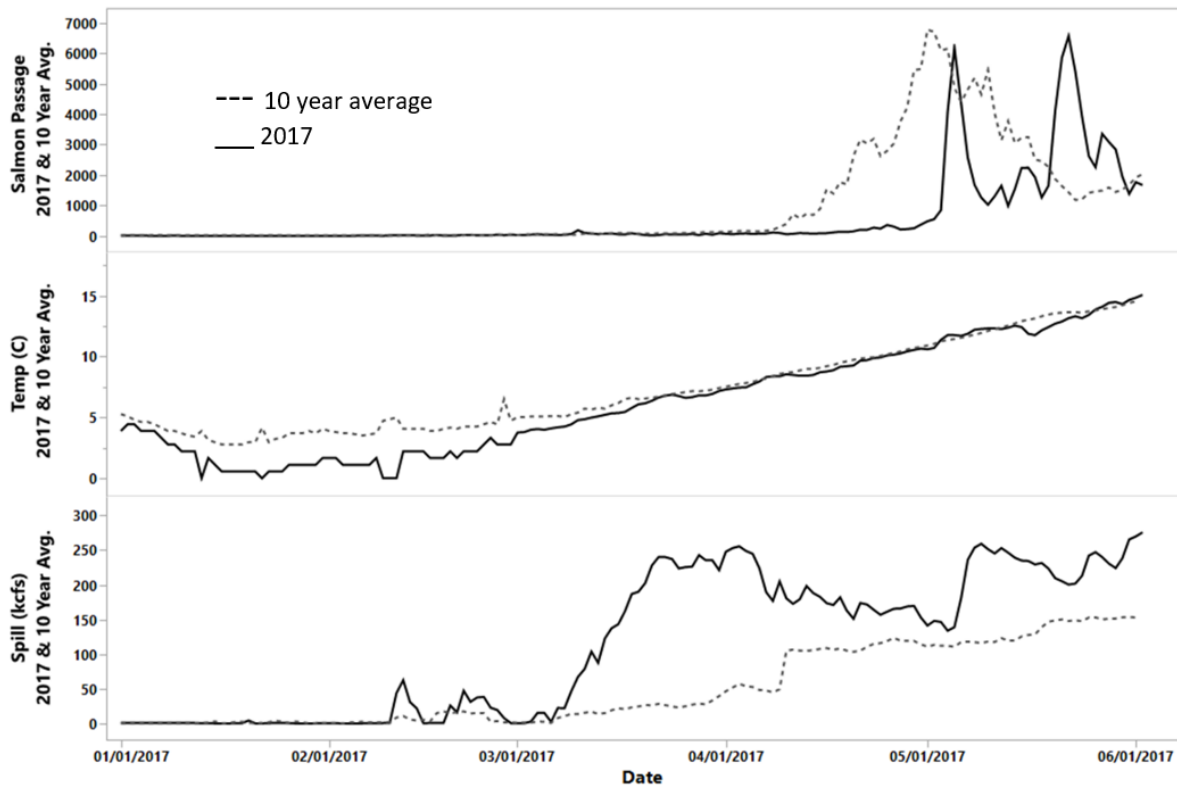


Figure 4. Chronology of salmonid passage, temperature, and spill at Bonneville Dam during the focal sampling period. Solid black lines indicate the 2017 season and dashed grey lines denote the 10-year average for each variable.

Predation on Adult Salmonids

An estimated 5,384 (4,671 – 6,042) adult salmonids were consumed by both pinniped species in 2017, which equates to 4.7% of the salmonids that passed during the FSP. Of these, SSLs consumed 3,242 (2,841 – 3,624) which equates to 2.8% of the run, and CSLs consumed 2,142 (1,831 – 2,419), which was 1.9% of all adult salmonids (Table 4, Figure 5). No depredation by harbor seals was documented.

Table 4. Adjusted consumption estimates on adult salmonids (including adults and jacks) by California and Steller sea lions at Bonneville Dam between January 1 and June 2nd, 2002 to 2017.

		California Sea Lions		Steller Sea Lions		All pinnipeds	
Year	Bonneville Dam Salmonid Passage	Adjusted Salmonid Consumption Estimates	% Run	Adjusted Salmonid Consumption Estimates	% Run	Adjusted Salmonid Consumption Estimates	% Run
2002	284,732	1,010	0.4%	0	0.0 %	1,010	0.4 %
2003	217,934	2,329	1.1%	0	0.0 %	2,329	1.1 %
2004	186,771	3,516	1.9%	7	0.0 %	3,533	1.9 %
2005	81,252	2,904	3.5%	16	0.0 %	2,920	3.4 %
2006	105,063	3,312	3.1%	85	0.1 %	3,401	3.1 %
2007	88,474	4,340	4.7%	15	0.0 %	4,355	4.7 %
2008	147,558	4,735	3.1%	192	0.1 %	4,927	3.2 %
2009	186,056	4,353	2.3%	607	0.3 %	4,960	2.7 %
2010	267,167	5,296	1.9%	1,025	0.4 %	6,321	2.4 %
2011	223,380	2,689	1.2%	1,282	0.6%	3,970	1.8%
2012	171,665	1,067	0.6%	1,293	0.7%	2,360	1.4%
2013	120,619	1,497	1.2%	1,431	1.2%	2,928	2.4%
2014	219,929	2,747	1.3%	1,874	0.8%	4,621	2.1%
2015	239,326	8,324	3.3%	2,535	1.0%	10,859	4.3%
2016	154,074	6,676	4.1%	2,849	1.7%	9,525	5.8%
2017	109,040	2,142	1.9%	3,242	2.8%	5,384	4.7%

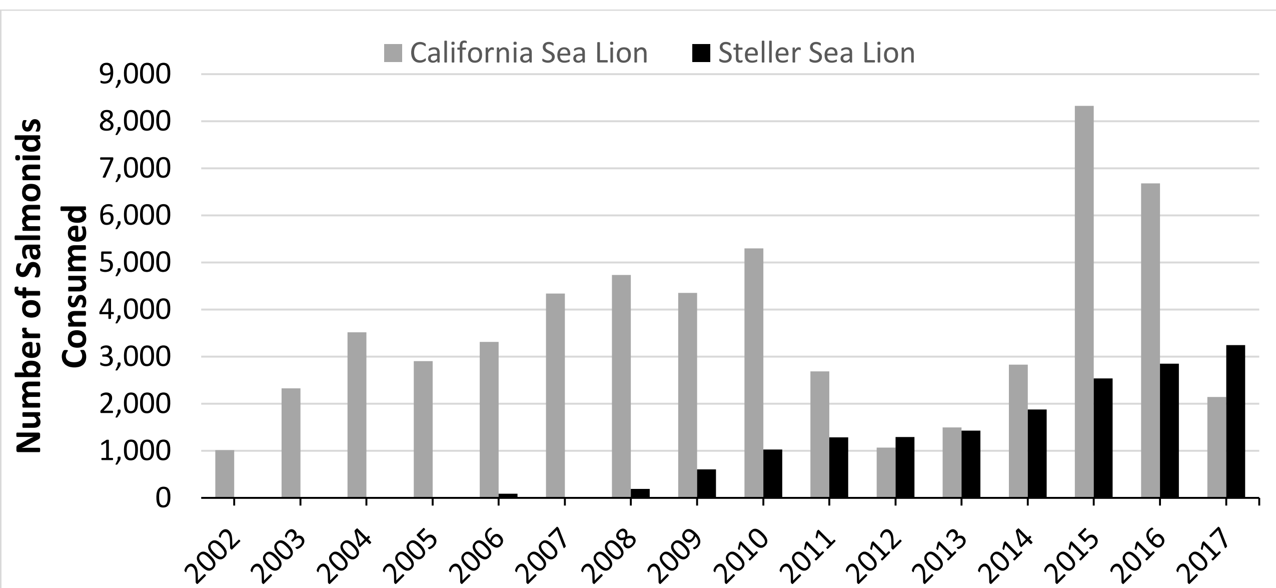


Figure 5. Adjusted estimates of salmonid consumption by California and Steller sea lions at Bonneville Dam, from January 1 to June 2, 2002 to 2017.

Predation on Chinook Salmon

An estimated 4,951 (4,276 – 5,585) spring Chinook were consumed, which equates to 4.5% of the run. Of these, SSLs consumed 2,860 (2,494 – 3,211) which equates to 2.6% of the run, and CSLs consumed 2,091 (1,781 – 2,374) which was 1.9% of the spring Chinook run (Table 5).

Table 5. Consumption of spring Chinook salmon by pinnipeds at Bonneville Dam tailrace from January 1 through June 15th, 2002 to 2017. Passage counts of Chinook salmon includes both adult and jack salmon.

Year	Bonneville Dam Spring Chinook Passage	Chinook Consumption Estimate	% Run
2002 [x]	316,468*	880 [†]	0.3 %
2003 [x]	247,059	2,313	0.9 %
2004 [x]	210,569	3,307	1.5 %
2005 [x]	102,741	2,742 [‡]	2.6 %
2006 [x]	130,014	2,580	1.9 %
2007 [x]	101,068	3,403	3.3 %
2008	143,139	4,500	3.0 %
2009	181,174	4,360	2.3 %
2010	257,036	5,909	2.2 %
2011	218,092	3,634	1.6 %
2012	165,681	1,960	1.2 %
2013	117,165	2,710	2.3 %
2014	214,177	4,576	2.1 %
2015	233,794	10,622	4.3 %
2016	148,360	9,222	5.9 %
2017	105,583	4,951	4.5 %

[x] Adjusted estimates did not start until 2008 (Tackley et al. 2008), as such these values are expanded estimates.

* Fish counts did not start until March 15 in 2002. Chinook passage from January 1 through March 15 was minimal in all other years.

[†] From March 15 through April 25, used fish passage count split between Chinook salmon and Steelhead to estimate Chinook proportion of unidentified salmonid catch. After April 25, we used observed catch distribution to divide unidentified salmonid consumption.

[‡] In 2005, observations did not start until March 18.

Predation on Winter and Summer Steelhead

An estimated 322 (144 – 454) summer and winter steelhead were consumed during the FSP, which equates to 9.0% of the combined run (Table 6). Of these, SSLs consumed 269 (124 – 374) which equates to 7.6% of the run, and CSLs consumed 53 (20 – 81) which was 1.5% of the winter and summer steelhead run.

Table 6. Consumption of summer and winter Steelhead by pinnipeds at Bonneville Dam tailrace from January 1 through June 2nd, 2007 to 2017.

Year	Bonneville Dam Steelhead Passage	Adjusted Steelhead Consumption Estimate	% Run
2007[x]	5,188	609 [x]	10.5 %
2008	4,367	391	8.2 %
2009	4,829	599	11.1 %
2010	9,972	413	4.0 %
2011	5,279	336	6.0 %
2012	5,904	400	6.3 %
2013	3,394	218	6.0 %
2014	5,696	128	2.2 %
2015	5,217	237	4.3 %
2016	5,262	302	5.4 %
2017	3,241	322	9.0 %

[x] Adjusted estimates did not start until 2008 (Tackley et al. 2008), as such this value is an expanded estimate.

Predation on White Sturgeon

White Sturgeon were first documented as prey of SSLs in 2005, and by 2006 were the primary prey item consumed by the species. Annual consumption increased until 2011 after which the numbers of sturgeon consumed dropped considerably (Table 7). This season an estimated 24 (24 – 38) White Sturgeon were consumed by both species of pinnipeds. Of these, SSLs consumed 20 (20 – 35), and CSLs consumed 4 (4 – 8). The size of consumed sturgeon ranged from 2 – 5 feet in length. Three-quarters of the predation events occurred in the PH2 tailrace, and the balance in the tailrace of PH1. No predation events were recorded in the spillway.

Table 7. Consumption of White Sturgeon by pinnipeds at Bonneville Dam tailrace from January 1 through June 2, 2006 to 2017.

Year	Total Hours Observed	Observed Sturgeon Catch	Adjusted Sturgeon Consumption Estimate
2005	1,109	1	N/A
2006	3,650	265	413
2007	4,433	360	664
2008	5,131	606	1,139
2009	3,455	758	1,710
2010	3,609	1,100	2,172
2011	3,315	1,353	3,003
2012	3,404	1,342	2,498
2013	3,247	314	635
2014	2,947	79	146

2015	2,995	24	44
2016	1,974	30	90
2017	1,142	6	24

Predation on Pacific Lamprey

An estimated 191 (126 – 256) Pacific Lamprey were consumed by both species of pinnipeds in 2017. Of these, SSLs consumed 46 (46 – 82), and CSLs consumed 145 (145 – 210) (Table 8). Two-times as many Pacific Lamprey were consumed in the PH1 tailrace as in the tailrace of PH2. No predation events were recorded in the spillway. The first predation event was documented on April 26, 2017, and was followed by increasing levels of predation (i.e. > 5 fish per day) throughout the month of May (Supplementary Figure 1A). The temporal distribution of Pacific Lamprey consumption was primarily documented in the crepuscular hours as observed in Supplementary Figure 1B.

Table 8. Consumption of Pacific Lamprey by pinnipeds at Bonneville Dam tailrace from January 1 through June 2nd, 2002 to 2017.

Year	Total Hours Observed	Observed Pacific Lamprey Catch	Expanded Pacific Lamprey Consumption Estimate	Percent of Total Observed Fish Catch
2002	662	34	47	5.6%
2003	1,356	283	317	11.3%
2004	516	120	816	12.8%
2005	1,109	613	810	25.1%
2006	3,650	374	424	9.8%
2007	4,433	119	143	2.6%
2008	5,131	111	145	2.0%
2009	3,455	64	102	1.4%
2010	3,609	39	77	0.7%
2011	3,315	16	33	0.4%
2012	3,404	40	79	1.4%
2013	3,247	38	66	1.7%
2014	2,947	41	85	1.5%
2015	2,995	108	196	1.6%
2016	1,974	232	501	4.8%
2017	1,142	41	191	1.7%

Temporal Distribution of Salmonid Predation Events

An estimated 109,040 salmonids passed during the FSP of 2017, a smaller run estimate compared to the 10-year average of 160,382. Review of Figure 6 indicates the spring Chinook run began much later than the 10-year average and had two large pulses peaking on May 5 (spring Chinook n = 6,177, steelhead n = 28), and on May 22 (spring Chinook n = 6,539, steelhead n = 37).

Predation by pinnipeds started prior to the increase of fish crossing the dam, a trend that holds consistent over the last 10 years (Figure 6). Salmonid predation by pinnipeds tracked the pulsatile fish runs described above, with two inter-species differences that are recognized in Figure 6 and merit comment: first, SSLs had an initial increase in salmonid predation at the end of January that the CSLs did not display, and second, SSLs predation on salmonids began to increase three weeks earlier than CSL predation.

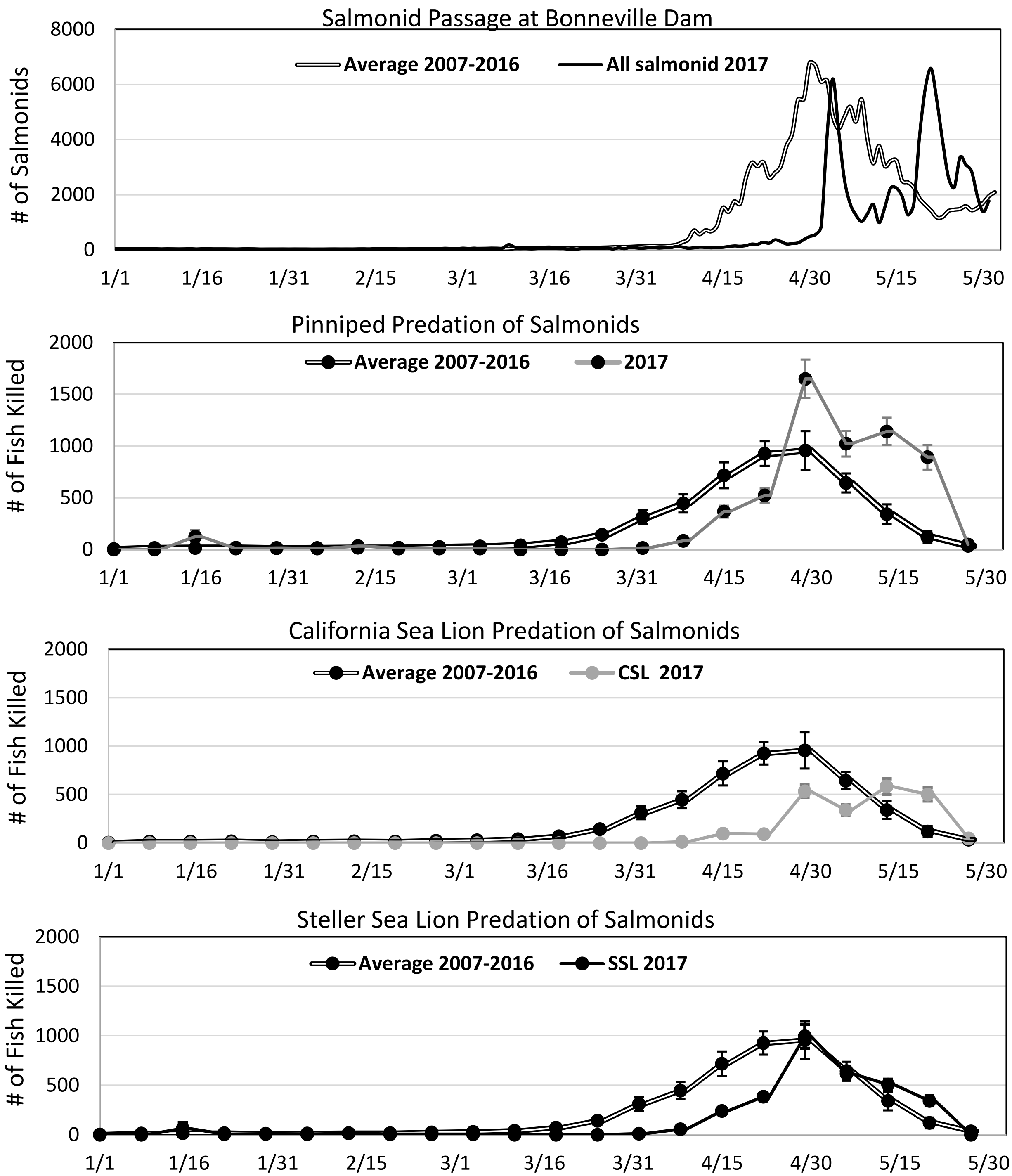


Figure 6. Temporal distribution of all salmonids that crossed Bonneville Dam and weekly adjusted predation estimates (i.e. # of fish killed) of these salmonids by Steller sea lions (SSL) and California sea lions (CSL) between January 1 and June 2, 2017 at Bonneville Dam. The predation data labeled “Average 2007 – 2016” is the combined weekly average predation by both pinniped species over the last ten years. All error bars represent the Standard Error of the estimates.

Spatial Distribution of Monitoring and Salmonid Predation Events

We observed for 364 hours at PH1, 392 hours at SPW, and 386 hours at PH2. During this time, there were 1,144 observed salmonid predation events distributed across all sampling areas of the dam's tailraces. Similar to all other years, the bulk of the predation was concentrated in the near-dam areas of the tailrace that have fish ladder entrances (Figures 7 & 8).

Predation on adult salmonids was highest at the powerhouses. The combined spatial distribution of observed salmonid predation events by pinnipeds was 42.5% (n = 487) at PH1, 41.2% (n = 472) at PH2, and 16.1% (n = 185) at SPW.

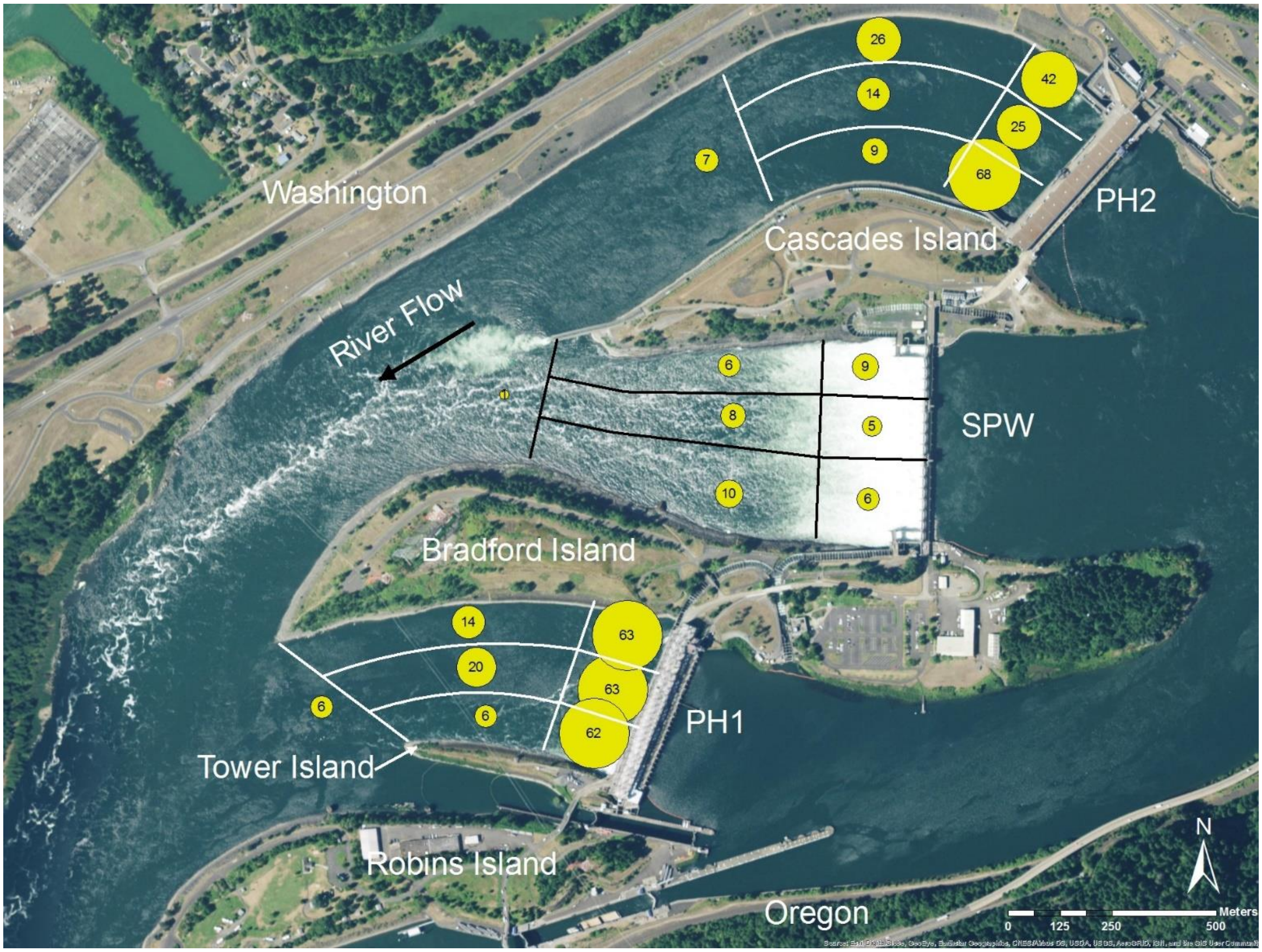


Figure 7. Spatial distribution of observed salmonid predation by California sea lions at Bonneville Dam from January 10 through June 2, 2017.

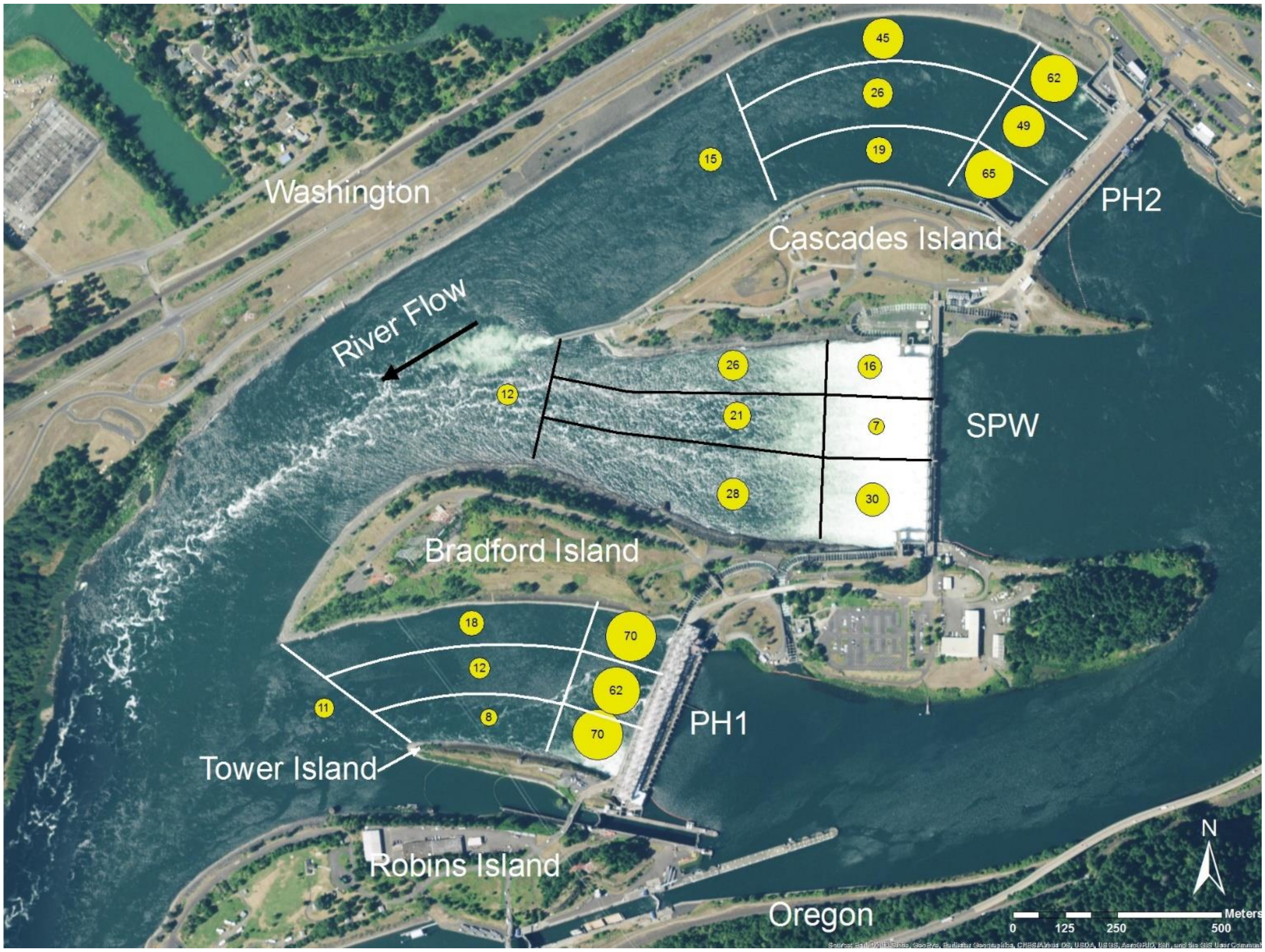


Figure 8. Spatial distribution of observed salmonid predation by Steller sea lions at Bonneville Dam from January 10 through June 2, 2017.

Clepto-parasitism

A total of 75 clepto-parasitism events occurred – SSLs stole 11 fish from other SSLs, and 62 fish from CSLs, while CSLs stole no fish from SSLs and two fish from other CSLs. For comparison, historical accounts of clepto-parasitism are presented in Supplementary Table 3.

DETERRENTS AND MANAGEMENT ACTIVITIES

Physical Barriers

Metal grating installed in front of fish ladder entrances called Sea Lion Exclusion Devices (SLEDs) were deployed at all fishway entrances for the duration of the monitoring period. Floating orifice gates (FOGs) with bars, plywood on top of FOGs and SLEDs continue to be effective at keeping pinnipeds out of the fish ladders, as none were observed in fish ladders this season.

Non-Lethal Harassment

Boat-based hazing was not feasible in the spillway given the highly turbulent water conditions, as such boat-based hazing occurred only in Powerhouse 1 and 2 tailraces. Boat-based hazing by CRITFC began on March 7 and ended May 19. A total of 29 days of hazing were conducted. A two-week gap of sampling between April 9 and April 22 occurred due to a tragic boating accident on April 7 involving the CRITFC research vessel where fisheries technician Greg George lost his life. During the season, CRITFC boat-based hazers deployed 1,487 cracker shells and 824 “Seal Bombs” (e.g. small charges of explosive that detonate under water) (Brown et al. 2017).

Dam-based hazing of pinnipeds by USDA began on March 7 and continued on a daily basis through May 31. Working eight hours per day, dam based hazers worked 1,696 hours actively hazing pinnipeds from the dam’s tailrace. Dam hazers used 2,535 explosive cracker shells (SSL = 1,852, CSL = 683), and 110 rubber buckshot (SSL = 59, CSL = 51) on pinnipeds within the tailrace areas.

Trapping and Removal

The States conducted trapping operations in the tailrace area from early April to late May during which time they permanently removed 24 CSLs under the State's MMPA Section 120 LOA. In addition, 18 CSL were branded and released in the tailrace at BON (Brown et al. 2017). As both SSL and CSL use the traps as a haul-out location, SSL are often captured along with CSL during trapping operations. This season, 12 of the smaller SSLs were captured and branded with a unique identifiable brand (Table 9). Traps were closed and moved to storage in late May. For additional information about these activities see Brown et al. (2017).

Table 9. Summary of California sea lion (CSL) branding and removals (captivity, euthanasia, accidental mortality) and Steller sea lion (SSL) branding at Bonneville Dam, 2007 to 2017. Note: CSL removals include all animals removed by the States under the Section 120 LOA of the MMPA.

Year	CSL Authorized for removal	CSL Branded	CSL Removed	SSL Branded
2007		8	N/A	N/A
2008	85	4	11*	N/A
2009	85	3	15	N/A
2010	85	9	14	8
2011	85	9	1	9
2012	92	6	13	19
2013	92	11	4	3
2014	92	21	15	0
2015	92	131	34*	0
2016	92	50	59	0
2017	92	18	24	12
Total	800	270	190	51

* Does not include 2 accidental mortalities of CSL not listed for removal.

Impact of individual California Sea Lions

The highest number of adult salmonids observed to be consumed by an identified individual CSL in 2017 was 23 fish which is the lowest on record for a fully sampled season (see Table 10 for details). This individual was observed for 22 days and recorded eating 23 salmonids, which contributes to 13.8% of all of the fish observed eaten by individual CSLs (Table 10).

Table 10. Maximum number of salmonids observed consumed by an individual California sea lion (CSL) at Bonneville Dam between January 10 and June 2nd, 2002 to 2017.

Year	Maximum Number of Salmonids Caught by an Individual CSL	Percentage of Salmonid Catches Attributed to Individual CSLs
2002	51	85.6%
2003	52	67.7%
2004	35	54.3%
2005	11*	8.9%*
2006	79	43.0%
2007	64	28.1%
2008	107	42.6%
2009	157	62.1%
2010	198	51.9%
2011	125	41.7%
2012	41	53.0%
2013	59	42.1%
2014	59	26.3%
2015	28	14.1%
2016	25†	12.5%†
2017	23†	13.8%†

* In 2005, the observation season began late therefore we didn’t have an opportunity to train observers on individual CSL identification.

† In 2016 and 2017 all three tailraces were not observed simultaneously thus decreasing observation time for individual CSL.

DISCUSSION

We documented several unique developments this pinniped monitoring season in regards to species composition and salmonid depredation. Chief among them: an increasingly high number of SSLs which preyed heavily on a smaller and delayed run of spring Chinook salmon. Moreover, we documented an increase in steelhead consumption, despite reduced run size which equated to a large impact for the steelhead runs. For evaluation of this year's data relative to previous, we contrast inter- and intra-year trends of each metric of the monitoring program by presenting percent change relative to the previous year (i.e. Madson et al. 2017) and, where possible, the 10-year average.

Abundance

The number of SSLs in the fall and winter months was greater than previously documented (Stansell 2014, FFU 2016). The individuals that returned in the fall and winter remained at the dam through the FSP which contributed to the growing number of SSLs during the FSP. The annual abundance of SSLs during the FSP was 15.0% greater than last year, and 8.0% greater than the 10-year average.

We documented a 38.0% reduction in CSL abundance relative to last year, and a 7.0% reduction relative to the 10-year average. Albeit CSLs were first documented at BON in October this season, the species did not begin aggregating at the dam with frequency until the end of March 2017, a phenomena that was three weeks later than previous years and synchronous with the late spring Chinook run. Whether the decline in CSL abundance this year is a trend or a function of the previous two years record high CSL abundance cannot be ascertained at this time and merits attention in coming years.

Reduced CSL residency times are corollary to the States' removal efforts which likely explain the reduction in the number of days individual CSLs stay at BON. Residency rates display a similar trend. However, both of these metrics are impacted by the ability to identify individuals (i.e. the number of brands).

One strategy to better understand residency in light of this apparent confound of effort and data resolution is to include the novel measurement – potential number of days observed – as a metric of residency. The differential in residency times between the observed days and potential number of days observed suggests that individuals could be at BON almost twice as many days as they are actually observed prior to removal or listing for removal. These findings illuminate the uppermost bounds of potential residency, and thus salmonid predation potential by CSLs, and highlight the constraints associated with the current monitoring system. Evaluation of the influence of these factors on the States' removal efforts and the resultant effects on pinniped residency would benefit managers and perhaps streamline monitoring and removal efforts.

Recurrence of habitual BON CSLs increased by 18.3% relative to last year albeit abundance declined 38.0%. However, the number of individuals recurring for three or more years also declined relative to last year. Collectively these data suggest that fewer animals returned, but of the recurring animals, few had been to the dam for more than three years. The decline in long-term recurrence is likely a function of the State’s removal authorization. Recurrence at BON is a measure of site fidelity, and has been suggested to be a learned trait that is socially transmitted from previously educated individuals to naive animals downstream of BON (Schakner et al. 2016). The trends documented here may be linked to the removal of reoccurring individuals and the delay between occurrence, listing for removal, and removal. Alternatively, it may be a result of the increased social transmission due to the previous two seasons of record high CSL abundance. Disentangling these competing hypotheses would be difficult due to the confounding nature of removal of individuals and the construct of social transmission.

The recurrence of SSLs is difficult to monitor given the low numbers of branded SSLs. However, high site fidelity is assumed based on one individual being observed for 11 consecutive years, and the majority of the identifiable animals observed for five or more years. Although individual accounts are difficult to obtain, the high daily point counts, consistent inter-year abundance estimates, and lack of removal all suggest that the same unbranded individuals are likely returning every year. If that is true, SSL recurrence is very high for most animals observed at BON. Continued branding will provide clarity to these issues.

Our use of photo archival from known haul-out locations and ethologically informed point counts undoubtedly bolstered the resolution of the residency and recurrence data this season. Notwithstanding the benefit of total sample coverage as previously employed, we conclude that our current methods, in conjunction with adjusted metrics – like the potential number of days observed – allow comparable data to be collected with less resources and we advocate for similar streamlining methods to be explored in respect to the qualification and removal criteria protocols.

Predation

The delayed run of spring Chinook was likely a result of the high water volumes passing the dam and cold water temperatures, both co-factors that have been found to delay the run chronology of spring Chinook in the Columbia River (Keefer et al. 2008b). Moreover, the spring Chinook and combined summer and winter steelhead runs were the third smallest, and all-time lowest (respectively) since pinniped monitoring began in 2002. These factors undoubtedly influenced the predation of these runs this season.

By salmonid species, spring Chinook comprised the majority of the pinniped prey items and SSLs consumed the most. Consumption of this run by SSLs was 0.8% greater than the previous year, and CSL consumption was 2.3% less than the previous year. Relative to the combined pinniped 10-year average of spring Chinook consumption, SSLs consumption was up 0.4% and CSL consumption was down 0.3%. Thus, total spring Chinook consumption, inclusive of all pinniped species, was 0.1% greater than the 10-year average.

Pinnipeds consumed an estimated 9.0% of the combined Columbia River summer and winter steelhead runs during the FSP. Consumption was two times greater than last year’s combined summer and winter steelhead run. Depredation by SSLs was 4.6% greater than the previous year, while CSL was 0.9% lower than last year. Relative to the combined pinniped 10-year average, SSL consumption was up 1.4% and CSL consumption was down 4.7%.

Pinniped impact to the steelhead runs in 2017 was alarming. Steelhead have historically been reported as two distinct varieties: the winter run, defined as those steelhead crossing BON between November 16 and March 31, and the summer run which cross after March 31 (Withler 1966, Busby et al. 1996). This season we elected to present the consumption estimates for both runs of steelhead regardless of run composition. We did so for two reasons: first, we anticipated the small number of predation events on each steelhead run would not allow the probability sampling design used to confidently estimate total predation, and second, we believe future analyses that capture the entirety of the runs will provide a more realistic view of pinniped impact on this sensitive species. The USACE FFU recently received directives from NOAA to monitor predation on steelhead in the fall and winter.

Both pre- and post-spawn steelhead kelts are vulnerable to pinniped predation at BON. Due to the magnitude of the kelt outmigration from the Snake and Columbia rivers (Evans et al. 2004, Colotelo et al. 2014), and because each Powerhouse at BON has effective (i.e. fish:flow) adult downstream passage routes (Wertheimer 2007), it is plausible that the large number of adults consumed in each Powerhouse tailrace includes some kelts. Thus, forthcoming work will better enumerate estimates of predation across the run of winter steelhead. That said, the increasing SSL abundance and residency during the fall - winter period and the two fold increase in steelhead consumption documented this season suggests that the impacts to steelhead, particularly ESA-listed winter and B-run summer steelhead may be biologically significant.

Predation on all species of adult salmonids was 1.1% less than last year and was 0.04% less than the 10-year average. Such minimal inter-year differences could suggest that little change has occurred, however more finite analyses reveal that salmonid consumption by each pinniped species is in flux. Of the adult salmonid run consumed this year, SSLs consumed 1.1% more of the run than the previous year, and increased run-consumption by 76.6% relative to the 10-year average, whereas CSLs this year consumed 1.3% less of the run than the previous year, and decreased salmonid run consumption by 9.1% relative to the 10-year average. These changes are likely due to the increasing number of SSLs, decreased number of CSLs relative to the last two years, and the small spring Chinook salmon run this season.

The stark increase in SSL adult salmonid consumption is seemingly driven by the increasing number of animals and the evolving diet shift of the species. Wherein, prior to 2010, ≤ 39 SSLs consumed less than 1,000 salmon per year and more than 1,000 White Sturgeon. This season, 63 SSLs consumed more than 3,000 salmon and ≤ 20 White Sturgeon. Since 2011, White Sturgeon predation has declined by an average of 67.0% per year while salmon consumption has continued to increase.

The mechanisms behind this dietary shift are unknown and should be of particular interest to future research. Plausible hypotheses explaining the dietary shift may include: decreased White Sturgeon preference for the BON tailrace during the FSP, behavioral conditioning to prefer the easier to consume and more nutrient rich salmonids, or alterations of individual SSL preferences as a result of recruitment of new animals.

Alternative to these behavioral shifts is the hypothesis that there simply are not as many White Sturgeon in the BON tailrace area as there once was. Testing these competing hypotheses would be of benefit to managers as the outcome, regardless of mechanism, would contribute to understanding pinniped behavior and/or the state of Columbia River White Sturgeon fish stocks. The latter hypothesis is most likely based on the recent harvest restrictions (ODFW 2015), and if true, posits reason for concern given the enormity of change that may be occurring.

Pacific Lamprey predation was 3.0% less than the previous year and 0.3% less than the 10-year average. The bulk of Pacific Lamprey predation continues to be by CSLs, which this season consumed 76.0% of the documented predation events. Some CSLs appear to consume more Pacific Lamprey than others, as evidenced by one euthanized CSL dietary tract that was dissected and found to contain the mouth parts of 26 Pacific Lamprey at the time of death (Brown et al. 2017).

The prolonged presence of SSLs prior to and during the FSP raises concern for winter steelhead and early arriving spring Chinook salmon stocks. As discussed by Keefer et al. (2012), early arriving spring Chinook stocks are likely composed primarily of ESA-listed fish. Moreover, the winter steelhead, which now have a run chronology that entirely overlap pinniped presence at BON, are ESA-listed. Assessing pinniped impacts on each stock crossing the dam is paramount to informing management of how predation may be changing over time and would highlight the true impacts of pinnipeds to each ESA-listed run.

Deterrence and Management Actions

The recurrence of pinnipeds following a bout of hazing continues to be an issue. The results herein indicate that an order of magnitude more tactile and acoustic deterrent ordinances were deployed than the total number of pinnipeds documented this season. Thus, it is highly likely that every pinniped was hazed numerous times. Pinnipeds can be hazed for a duration of time and immediately return to foraging when the hazing pressure ceases (Jefferies and Scordino 1997, Schakner and Blumstein 2013). Albeit arguments concerning naive animal exposure to, and subsequent dispersal from, the hazed area are valid (Brown et al. 2017), our data calls into question the effectiveness of these treatments. Recently branded CSLs (i.e. newly recruited individuals [potentially naive] and individuals not previously branded) that were not removed this season spent the same number of days (both observed and the potential number of days present) as those animals branded prior to 2017. Suggesting that some newly recruited individuals, once marked and exposed to hazing, spend the same length of time foraging at BON as habituated animals that have been hazed for the last three years.

Indeed the most functional benefit of current hazing techniques are for the brief moment of time when active hazing is occurring which has been found to dissuade active foraging behaviors (Gotz and Janik 2013). Dam-based hazing is seemingly most effective when conjoined with boat-based hazing to effectively haze animals away from the fish ladder entrances and “drive” hazed animals downstream, therein, providing a period of time when no pinnipeds are at the fish ladder entrances. Observations indicate that this period of time is commonly less than 20 minutes (KST unpublished data). Habituation to current hazing techniques is most notably observed by SSLs that have been at the dam for years. These individuals can endure many bouts of hazing prior to moving downstream and out of range of the hazing implements. The short term effects of hazing call to question the relative value of such techniques and begs for better, more effective alternatives.

Physical barriers at fish ladder entrances (i.e. SLEDs, FOGs) continue to be the most effective deterrent mechanism currently employed. They successfully excluded all pinnipeds from entering the fish ladders this season despite higher than normal water levels. Given the near year-round residency of SSLs, permanent installation of these devices is warranted.

Evaluating the efficacy of CSL removal is difficult due to the dynamic interplay of fluctuating fish runs, pinniped numbers, and the fact that the LOA removal quota has never been fulfilled for CSLs. If considered through the lens of abundance metrics, we observe that CSL removal has decreased residency and abundance for most branded animals, save for the record high numbers the previous two years (i.e. 2015 and 2016). Recurrence metrics have declined sharply as a result of removal and reveal that only nine branded CSLs have been documented every year for the last three years. However, habitually recurring animals have increased in residency (potential number of days present) relative to the average. These individuals have either not met the removal qualifications or have yet to be captured and removed. Thus, in short the removal efforts have decreased most metrics of CSL abundance.

Through the lens of fish predation, we observe that the proportion of fish runs consumed this year by CSLs is similar to previous years but less than the last two years. Based on the 2017 report of management activities at BON, the States found almost every CSL removed in 2016 and 2017 had salmonid remains in their digestive tracts (Brown et al. 2017), affirming that CSLs are at BON to consume migrating salmonids. The removal of 24 predatory CSLs this year undoubtedly allowed more fish to pass, but the rate of removal has been hypothesized to be too low to significantly impact the rate of recruitment to the BON CSL population (Schakner et al. 2016).

Removal of predatory CSLs through the Section 120 LOA of the MMPA has requirements of observation that are difficult to meet for some individual CSLs. Some CSLs have been documented in previous years, captured repeatedly, but cannot be added to the list due to foraging in locations that make observation dangerous or unfeasible (e.g. areas near turbulent water with poor footing or areas like the SPW where observations in turbulent water are difficult), having tendencies to conceal prey items, or are sporadically foraging in BON tailraces proper and thus difficult to monitor. This issue is best exemplified with this season's trapping and release rates published by the States, wherein, 80 instances of previously branded animals were trapped but not removed due to not being on the removal list (Brown et al. 2017). Improvements to these issues are beyond the scope of this report, and may require re-evaluation of LOA requirements and the directed monitoring program protocol.

Closing remarks

The culmination of prolonged interspecific competition for endangered Pacific salmonids between humans and marine mammals in the Columbia River has produced a dynamic interplay of anthropogenic impact and ecosystem response – the balance of which is difficult to cultivate. The precipitous decline of SSL-White Sturgeon predation events and the increasing number of SSLs at BON is concerning and warrants continued monitoring and enhanced investigation of total impact and novel deterrent technologies. The impact SSLs have on salmonid passage continues to increase and this year surpassed the impact CSLs were having when the LOA for removal of CSLs was granted to the States in 2008. The near-record low runs of ESA-listed winter and summer steelhead and small run of ESA-listed spring Chinook

that passed BON had to contend with record high numbers of SSLs and numbers of CSLs similar to years past.

As the winter steelhead passing Ballard Locks are now functionally extinct, in part, due to pinniped predation, the UWR winter steelhead are reportedly facing the same challenges due in part to pinniped predation. Managers need to take action and develop plans to ensure the continued existence of endangered and protected species. This should entail a review of the current CSL management plan, and the development of an equitable SSL management plan. For it is now through adaptive management that an ecological balance of interspecific competition can be found to ensure the continued survival of ESA-listed Pacific salmon. Without such management, anthropogenic and pinniped predatory pressures may synergistically function to extirpate runs of a vital prey resource.

ACKNOWLEDGEMENTS

We acknowledge and thank all of our agency partners who continue to coordinate and assist in the conduct of this work, providing valuable services and information on pinniped abundance and distribution for the 2016 - 2017 monitoring season. Thanks to:

- CRITFC: Doug Hatch, Bob Lessard, John Whiteaker, Bobby Begay, Tyler Simmons, Greg George, Maria Jim, and Sara Thompson.
- NOAA: Robert Anderson, Robert DeLong, and Garth Griffin.
- ODFW: Robin Brown, Bryan Wright, Julia Burco DVM, Colin Gillin DVM, Chris Kern, David Fox, Rick Hargrave, Susan Riemer, and Greg Davis.
- PSMFC: Matt Tennis and Dan Heiner
- USDA Wildlife Services staff
- WDFW: Steven Jeffries, Josh Oliver, Chris Golden, and Shay Valentine.

We would also like to thank the fisheries crew from BON, Ben Haussmann, Ida Royer, Brian Bissell, and Andrew Derugin, and at The Dalles Dam, Jeff Randall, Gabriel Forrester, and Erin Kovalchuk for assisting with information on pinniped sightings, and the BON rigging crew for handling the SLED operations. We are especially grateful to our pinniped observers who along with the authors of this report collected essential data for this project. As such, we would like to acknowledge efforts by: Karen Austin, Roger Rohl, Thomas van Hevelingen, and Dalin D’Alessandro. Thanks also to our FFU staffers, Nathan Zorich, Karrie Gibbons, and Darren Gallion for assisting with field observations. Dr. Shubha Pandit gave guidance and assistance to the bootstrap sampling techniques and analysis; we appreciate his professionalism and support.

REFERENCES

Beddington, J.R., R.J.H. Beverton, and D.M. Lavigne. 1985. Marine mammals and fisheries. George Allen and Unwin, London, UK.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. *Status review of west coast steelhead from Washington, Idaho, Oregon, and California*. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division.

Boehme, L., A. Baker, M. Fedak, M. Arthun, K. Nicholls, P. Robinson, D. Costa, M. Biuw, and T. Photopoulou. 2016. Bimodal winter haul-out patterns of adult Weddell Seals (*Leptonychotes weddellii*) in the southern Weddell Sea. *PloS one*, *11*(5), e0155817.

Brown, R., S. Jeffries, D. Hatch, B. Wright, and S. Jonkers. 2014. Field Report: 2014 Pinniped research and management activities at Bonneville Dam. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Ave. Corvallis, OR 97330.

Brown, R., S. Jeffries, D. Hatch, and B. Wright. 2017. Field Report: 2017 Pinniped research and management activities at Bonneville Dam. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Ave. Corvallis, OR 97330.

Chasco, B. E., I. C. Kaplan, A.C. Thomas, A. Acevedo-Gutiérrez, D. P. Noren, M.J. Ford, M.B. Hanson, J.J. Scordino, S.J. Jeffries, K.N. Marshall, and A.O. Shelton. 2017. Competing tradeoffs between increasing marine mammal predation and fisheries harvest of Chinook salmon. *Scientific Reports*, 7.

Cochran, W. G. 1977. Sampling Techniques, 3rd edition. Wiley, New York.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 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.

Colotelo, A.H., R.A. Harnish, and BW Jones, and 10 other authors. 2014. *Passage Distribution and Federal Columbia River Power System Survival for Steelhead Kelts Tagged Above and at Lower Granite Dam, Year 2.* PNNL-23051, prepared for the U.S. Army Corp of Engineers, Walla Walla District, Walla Walla Washington, by Pacific Northwest National Laboratory, Richland Washington.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. *Society for industrial and applied mathematics.*

Evans, A.F., R.E. Beaty, M.S. Fitzpatrick, and K. Collis. 2004. Identification and enumerations of steelhead kelts at Lower Granite Dam. *Transactions of the American Fisheries Society* 133:1089-1099.

Evans, A.F., Q. Payton, A. Turecek, B. Cramer, K. Collis, D. D. Roby, P.J. Loschl, L. Sullivan, J. Skalski, M. Weiland, and C. Dotson. 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.

Falcy, M. 2017. Population Viability of Willamette River Winter Steelhead: an assessment of the effect of sea lions at Willamette Falls. ODFW report. Available at: http://people.oregonstate.edu/~falcym/Report.pdf (Accessed November 20, 2017).

Feldkamp, S. D., R. L. DeLong, and G. A. Antonelis. 1989. Diving patterns of California sea lions, Zalophus californianus. *Canadian Journal of Zoology*, *67*(4): 872-883.

FFU (Fisheries Field Unit) 2016. 2015 Field Report: Evaluation of Pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace.

Fleming, I. A. 1998. Pattern and variability in the breeding system of Atlantic salmon (Salmo salar), with comparisons to other salmonids. *Canadian Journal of Fisheries and Aquatic Sciences,* 55(Supplement 1): 59–76.

Fraker, M. A., and B. R. Mate. 1999. Seals, sea lions, and salmon in the Pacific Northwest. In J. R. Twiss Jr. and R. R. Reeves (editors), *Conservation and Management of Marine Mammals*. Smithsonian Institution Press, Washington, DC. pp. 156-178.

Friesen, T. A., and D. C. Ward. 1999. Management of northern pikeminnow and implications for juvenile salmonids survival in the lower Columbia and Snake Rivers. *N. Am. J. Fish. Manage.* 19:406-420

Good, T.P., R.S. Waples, and P. Adams, editors. 2005. Updated status of federally listed ESUs of West Coast salmon and Steelhead. NOAA Technical Memorandum NMFS-NWFSC-66.

Götz, T., and V.M. Janik. 2013. Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. *Marine Ecology Progress Series*, 492:285-302.

Hatch, D., J.M. Whiteaker, and R. Lessard. 2016. Sea Lion Monitoring and Non-Lethal Hazing, 1/1/2015 - 12/31/2015 Annual Report, Columbia River Inter-Tribal Fish Commission (CRITFC), Portland, OR, 97232.

Jeffries, S. J., and J. Scordino. 1997. Efforts to protect a winter Steelhead run from California sea lions at the Ballard Locks. In G. Stone, J. Goebel, and S. Webster (editors), *Pinniped Populations, Eastern North Pacific: Status, Trends, and Issues*. New England Aquarium, Boston, MA and Monterey Bay Aquarium, Monterey, CA. pp.107-115.

Jones, K. E., C.B. Ruff, and A. Goswami. 2013. Morphology and biomechanics of the Pinniped jaw: mandibular evolution without mastication. *The Anatomical Record,* 296:1049–1063.

Keefer, M. L., R. H. Wertheimer, A. F. Evans, C. T. Boggs, and C. A. Peery. 2008a. Iteroparity in Columbia River summer-run steelhead (Oncorhynchus mykiss): implications for conservation. *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(12):2592-2605.

Keefer, M. L., C. A. Peery, and C. C. Caudill. 2008b. Migration timing of Columbia River Spring Chinook Salmon: Effects of temperature, river discharge, and ocean environment. *Transactions of the American Fisheries Society*, 137:1120-1133.

Keefer, M.L., R.J. Stansell, S.C. Tackley, W.T. Nagy, K.M. Gibbons, C.A. Peery, and C.C. Caudill. 2012. Use of radiotelemetry and direct observations to evaluate sea lion predation on adult Pacific Salmonids at Bonneville Dam. *Transactions of the American Fisheries Society*, *141*(5):1236-1251.

Kareiva, P., M. Marvier, and M. McClure. 2000. Recovery and management options for spring/summer Chinook salmon in the Columbia River Basin. *Science*, *290*(5493): 977-979.

Kinsey, W.W. 2007. "*Zalaphus*" (Sea Lion) and "*Oncorhynchus*" (Salmon/Steelhead): Protected Predator Versus Protected Prey. Nat. Res. & Env. 22(2): 36-40.

Laake, J. L., S. R. Melin, A. J. Orr, D. J. Greig, K. C. Prager, R. L. DeLong, and J. D. Harris. 2016. California sea lion sex- and age specific morphometry. U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-312, 21 p. http://dx.doi.org/10.7289/V5/TM-AFSC-312.

London, J., M. Lance, and S. Jeffries. 2002. Observations of Harbor Seal predation on Hood Canal salmonids from 1998 to 2000. Final Report Studies of expanding pinniped populations. NOAA grant number NA17FX1603. 19pp.

Lyman, R.L., J. L. Harpole, C. Darwenti, and R. Church. 2002. Prehistoric occurrence of pinnipeds in the lower Columbia River. *Northwestern Naturalist*, 83:1-6.

Magera, A. M., Flemming, J. E. M., Kaschner, K., Christensen, L. B. and H. K. Lotze. 2013. Recovery trends in marine mammal populations. *PloS One* 8, e77908.

Madson, P. L, B. K. van der Leeuw, K. M. Gibbons, and T. H. Van Hevelingen. 2017. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2016. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR.

McKinney, T. A., D.W. Speas, R.S. Rogers, and W.R. Persons. 2001. Rainbow trout in a regulated river below Glen canyon dam, Arizona, following increased minimum flows and reduced discharge variability. *N. Am. J. Fish. Manage*., 21: 216-222

Mesa, M. G., T.P. Poe, D.M. Gadomski, and J.H. Petersen. 1994. Are all prey created equal? A review and synthesis of differential predation on prey in substandard condition. *Journal of Fish Biology*, *45*(sA):81-96.

Naughton, G. P., M.L. Keefer, T.S. Clabough, M.A. Jepson, S.R. Lee, C.A. Peery, and C.C. Caudill. 2011. Influence of pinniped-caused injuries on the survival of adult Chinook salmon (Oncorhynchus tshawytscha) and Steelhead trout (Oncorhynchus mykiss) in the Columbia River basin. *Canadian journal of fisheries and aquatic sciences*, 68(9):1615-1624.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific Salmon at the Crossroads: Stocks at Risk from California, Oregon, Idaho, and Washington, Fisheries, 16(2):4-21.

Newby, T.C. 1973. Changes in Washington state harbor seal populations, 1942-1972. Murrelet 54:5-6.

NFSC (Northwest Fisheries Science Center). 2015. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest. Available:

https://www.nwfsc.noaa.gov/assets/11/8623_03072016_124156_Ford-NWSalmonBioStatusReviewUpdate-Dec%2021-2015%20v2.pdf. [Accessed December 14, 2017].

NMFS (National Marine Fisheries Service). 1997. Investigation of scientific information on the impacts of California sea lions and Pacific Harbor Seals on salmonids and on the coastal ecosystems of Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-28, Seattle, WA.

NMFS (National Marine Fisheries Service). 2000. Federal Columbia River Power System Biological Opinion.

NMFS (National Marine Fisheries Service). 2008. Federal Columbia River Power System Biological Opinion.

NOAA (National Oceanic and Atmospheric Administration). 2014. Marine Mammal Stock Assessment: Califorinia Sea Lion: U.S. Stock. Available at: http://www.nmfs.noaa.gov/pr/sars/pdf/stocks/pacific/2014/po2014_ca_sea_lion-us.pdf

NOAA (National Oceanic and Atmospheric Administration). 2015. Chronology of events under the Marine Mammal Protection Act Section 120 process for lethal removal authority for problem California sea lions in the Columbia River basin. Available at: http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/removal_chronology.html (Accessed November 12, 2017).

NOAA (National Oceanic and Atmospheric Administration). 2016a. 5-year Review: Summary and Evaluation of Upper Willamette River Steelhead and Upper Willamette River Chinook. Available at: http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_steelhead/2016/2016_upper-willamette.pdf. (Accessed December 14, 2017)

NOAA (National Oceanic and Atmospheric Administration). 2016b. Marine Mammal Stock Assessment: Steller Sea Lion: Eastern U.S. Stock. Available at: http://www.nmfs.noaa.gov/pr/sars/pdf/stocks/pacific/2014/po2014_ca_sea_lion-us.pdf

NOAA (National Oceanic and Atmospheric Administration). 2017. Effectivness review of Marine mammal Protection Act Section 120 implementation under 2012 Letter of Authorization to Washington, Oregon, Idaho. Appendix C. pp. 13.

ODFW (Oregon Department of Fish and Wildlife). 2015. 2015 Sturgeon Sport Fishing Catch Expanded Final Numbers. http://www.dfw.state.or.us/resources/fishing/docs/sportcatch/2015%20Sturgeon%20Expanded%20Catch%20by%20Waterbody%202-F.pdf. (Accessed December 14, 2017)

Patterson, D.A., K.A. Robinson, R.J. Lennox, T.L. Nettles, L.A. Donaldson, E.J. Eliason, G.D. Raby, J.M. Chapman, K.V. Cook, M.R. Donaldson, A.L. Bass, S.M. Drenner, A.J. Reid, S.J. Cooke, and S.G. Hinch. 2017. Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon. *DFO Can. Sci. Advis. Sec. Res. Doc. 010*, pp. ix + 155.

Pearson, J.P. and B.J. Verts. 1970. Abundance and distribution of harbor seals and northern sea lions in Oregon. Murrelet 51(1): 1-5.

Poe, T. P., H.C. Hansel, S. Vigg, D.E. Palmer, and L.A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society*, *120*(4), pp. 405-420.

Quinones, R. M., T.E. Grantham, B.N. Harvey, J.D. Kiernan, M. Klasson, A.P. Wintzer, and P.B. Moyle. 2015. Dam removal and anadromous salmonid (Oncorhynchus spp.) conservation in California. *Reviews in Fish Biology and Fisheries*, *25*(1):195-215.

Roscoe, D. W., and S.G. Hinch. 2010. Effectiveness monitoring of fish passage facilities: historical trends, geographic patterns and future directions. *Fish and Fisheries*, *11*(1):12-33.

Roffe, T. J., and B.R. Mate. 1984. Abundance and feeding habits of pinnipeds in the Rogue River, *Oregon Journal of Wildlife Management, 48*: 1262-1274.

SBFC (State [Oregon] Board of Fish Commissioners. 1889. First and second annual reports of the State Board of Fish Commissioners to the Governor, 1887-1888.

Schakner, Z. A. and D. T. Blumstein. 2013. Behavioral biology of marine mammal deterrents: A review and prospectus. *Bio. Con.*, 167:380-389.

Schakner, Z.A., M.G. Buhnerkempe, M.J. Tennis, R.J. Stansell, B.K. van der Leeuw, J.O. Lloyd-Smith & D.T. Blumstein. 2016. Epidemiological models to control the spread of information in marine mammals. *Proc. R. Soc. B 283*, 2016237.

Schilt, C. R. 2007. Developing fish passage and protection at hydropower dams. *Applied Animal Behaviour Science*, *104*(3):295-325.

Scheffer, V.B. 1950. The food of the Alaska fur seal. *Trans. 15th N. Amer. Wild. Conf.*, pp. 410-421.

Sigler, M.F., D.J. Tollit, J.J Vollenweider, J.F. Thedinga and others. 2009. Steller sea lion foraging response to seasonal changes in prey availability. *Mar Ecol Prog Ser*, 388:243-261.

Sorel, M. H., A.G. Hansen, K.A. Connelly, A.C. Wilson, E.D. Lowery, and D.A. Beauchamp. 2016. Predation by Northern Pikeminnow and Tiger Muskellunge on Juvenile Salmonids in a High-Head Reservoir: Implications for Anadromous Fish Reintroductions. *Transactions of the American Fisheries Society*, 145(3):521-536.

Stansell, R.J. 2004. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2002-2004. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon. 97014.

Stansell, R.J., K. Gibbons, and W. Nagy. 2010. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2008-2010. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon. 45pp.

Stansell, R.J., K.M. Gibbons, W.T Nagy, and B.K. van der Leeuw. 2011. 2011 Field Report: Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon. 29pp.

Stansell, R.J., B.K. van der Leeuw, K.M. Gibbons and W.T. Nagy. 2014. 2014 Field Report: Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon. 97014.

Tackley, S.C., R.J. Stansell, and K.M. Gibbons. 2008. Pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2005-2007. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon. 97014.

Thwaites, R. 1969. Original Journals of the Lewis and Clark Expedition, 1804-1806. Arno Press.

Tollit, D.J., M.A. Wong, and A.W. Trites. 2015. Diet composition of Steller sea lions (*Eumetopias jubatus*) in Fredrick Sound, southeast Alaska: a comparison of quantification methods using scats to describe temporal and spatial variabilities. *Canadian journal of Zoology*, 93:361-376.

U.S. Army Corps of Engineers. Fish Counts and Reports. Adult fish count website, WWW. FPC.ORG (Accessed October 26, 2016).

U.S. Army Corps of Engineers. 2016 Fish Passage Plan. Available at http://www.nwd-wc.usace.army.mil/tmt/documents/fpp/2016/ (accessed on October 23, 2017).

U.S. Office of the Federal Register. 2016. Marine Mammals; Pinniped Removal Authority; Approval of Application (RIN: 0648-XE46). Federal Register 81 FR 44298 (July 7, 2016): 44298-44299.

Weise, M. J., and J. T. Harvey. 2005. Impact of the California sea lion (Zalophus californianus) on salmon fisheries in Monterey Bay, California. *Fishery Bulletin*, 103(4):685-696.

Wertheimer, R. H., and A. F. Evans. 2005. Downstream passage of steelhead kelts through hydroelectric dams on the lower Snake and Columbia rivers. *Transactions of the American Fisheries Society*, *134*(4), 853-865.

Wertheimer, R. H. 2007. Evaluation of a surface flow bypass system for steelhead kelt passage at Bonneville Dam, Washington. *North American Journal of Fisheries Management*, *27*(1): 21-29.

Withler, I. L. 1966. Variability in life history characteristics of steelhead trout (Salmo gairdneri) along the Pacific coast of North America. J. Fish. Res. Board Can. 23(3):365-393.

Wright, B.,S. Jeffries, R. Brown, R. Stansell, D. Hatch, and B. Norberg. 2007. Field Report –Non-lethal pinniped deterrent activities at Bonneville Dam, spring 2006. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Ave. Corvallis, OR 97330.

Wright, B.S., T. Murtagh, and R Brown. 2014. Willamette Falls Pinniped Monitoring Project 2014. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Avenue Corvallis, OR 97330.

Wright, B.S., T. Murtagh, and R. Brown. 2015. Willamette Falls Pinniped Monitoring Project 2015. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Avenue Corvallis, OR 97330.

Wright, B.S., T. Murtagh, and R. Brown. 2016. Willamette Falls Pinniped Monitoring Project. http://www.dfw.state.or.us/fish/SeaLion/docs/Willamette_Falls_2016_sea_lion_report.pdf.

Zorich, N., K. Gibbons, K. Bayley, and B. Carrothers. *In prep*. Use of Lamprey Passage Structures at Bonneville and John Day Dams, 2017 Annual Report. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR.

Appendix A. Sea lion exclusion device (SLED) at Bonneville Dam fishway entrance (A) (Tackley et al. 2008) and installed (B) (photo by Bjorn van der Leeuw, USACE FFU), floating orifice gate (FOG) (C) (unknown source), and sea lion incursion barriers on top of FOGs (D) (photo by Patricia Madson, USACE FFU).

A. 

B. 

C. 

D. 

Supplementary Table 1. Descriptive statistics for Steller sea lion (SSL) and California sea lion (CSL) daily abundance from point counts at Bonneville Dam between January 1 and June 2 for the last 15 years and the ten year average.

SSL	Median	S.D.	Mean	S.E	CV	Range	IQR	n days = 0	Days Observed
2002	0	0	0	0	0	0-0	0	0	59
2003	0	0.36	0.05	0.04	6.90	0-3	0	75	77
2004	0	0.24	0.06	0.03	3.71	0-1	0	92	99
2005	0	0.61	0.27	0.05	2.21	0-3	0	105	131
2006	1	2.19	2.09	0.19	1.05	0-10	4	40	150
2007	1	1.96	2.16	0.16	0.91	0-9	3	32	147
2008	5.5	3.55	5.5	0.28	0.64	0-17	4.5	15	150
2009	9	5.4	9.64	0.45	0.57	0-26	6	11	145
2010	10	11.52	13.21	0.96	0.87	0-53	11.5	2	144
2011	12	5.86	11.98	0.48	0.49	0-32	7	10	145
2012	12	6.86	12.24	0.56	0.56	0-33	7.5	15	152
2013	11	9.25	13.03	0.75	0.71	0-41	9	5	151
2014	6	10.26	9.92	0.84	1.04	0-41	7.5	13	151
2015	11	16.82	18.26	1.37	0.92	0-69	18.2	1	151
2016	12.2	15.12	17.89	1.22	0.85	0-54	25	1	152
2017	7	16.42	15.42	1.33	1.07	0-63	17.5	4	153
10 year	9.5	6.99	11.31	0.56	0.62	0.0 - 29.2	5.95	0	151

CSL	Median	S.D.	Mean	S.E	CV	Range	IQR	n days= 0	Days Observed
2002	5	2.93	5.36	0.38	0.55	0-14	3.5	2	59
2003	15	8.61	13.27	0.98	0.65	0-32	14	5	77
2004	10	10.75	13.73	1.08	0.78	0-37	17.5	4	99
2005	13	11.05	12.9	0.96	0.86	1-42	21	0	131
2006	9.5	13.78	14.3	1.12	0.96	0-44	27	39	150
2007	8	13.47	12.85	1.11	1.05	0-52	18.5	18	147
2008	9	14.08	14.12	1.15	0.99	0-46	26	7	150
2009	9	7.53	10.25	0.63	0.73	1-26	14	0	145
2010	9	6.64	9.28	0.55	0.72	0-26	12	5	144
2011	3	6.41	5.45	0.53	1.18	0-25	9	46	145
2012	2	3.27	3.08	0.26	1.06	0-14	5	46	152
2013	1	4.35	2.96	0.35	1.47	0-21	4	69	151
2014	0	7	4.34	0.57	1.61	0-27	6	84	151
2015	4	21.11	16.57	1.71	1.27	0-70	31.5	0	151
2016	3	14.94	10.63	1.21	1.41	0-66	18	57	152
2017	1	7.42	5.13	0.6	1.44	0-28	9.5	66	153
10 Year	5.6	8.78	8.82	0.71	0.99	0-29	14.2	4	151

Supplementary Table 2. Table of expanded estimates (i.e. not accounting for unidentified fish catches) of pinniped predation on salmonids, by pinniped species at Bonneville Dam, 2002-2017.

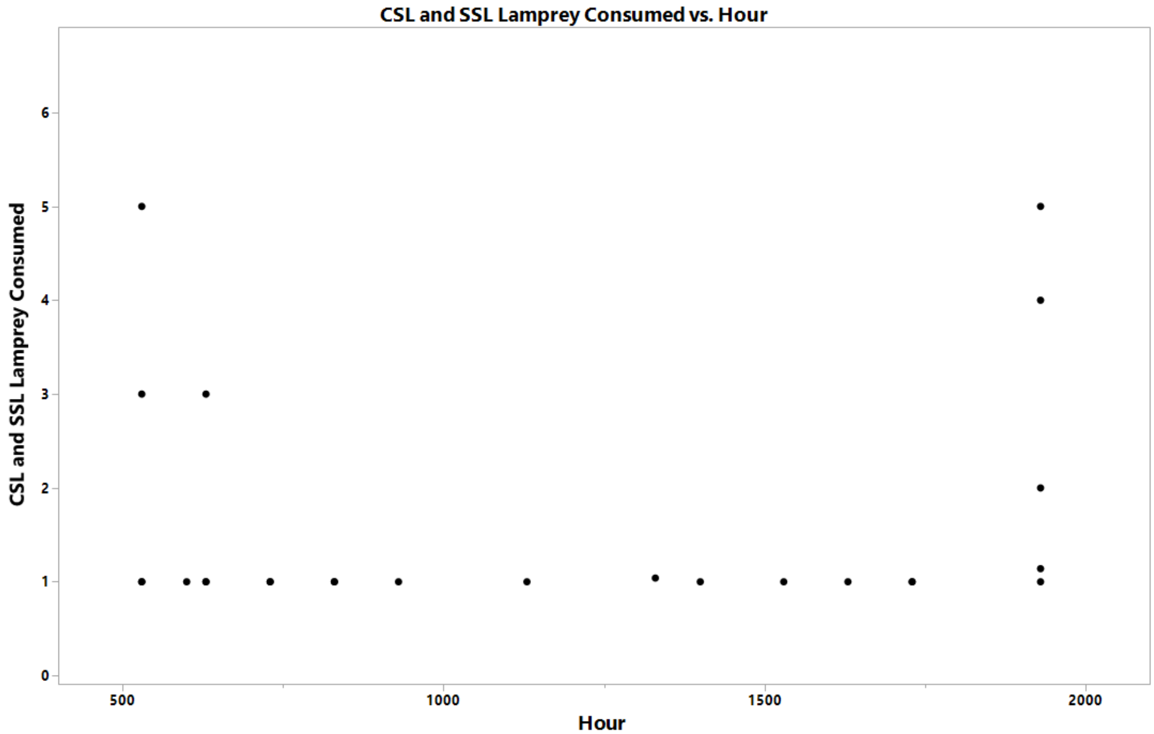
			ALL PINNIPEDS		CALIFORNIA SEA LIONS		STELLER SEA LIONS	
	TOTAL HOURS OBSERVED	TOTAL SALMONID PASSAGE	ESTIMATED SALMONID CATCH	% RUN TAKEN	ESTIMATED SALMONID CATCH	% RUN TAKEN	ESTIMATED SALMONID CATCH	% RUN TAKEN
2002	662	284,732	1,010	0.35%	1,010	0.35%	0	0.00%
2003	1,356	217,934	2,329	1.06%	2,329	1.06%	0	0.00%
2004	516	186,771	3,533	1.86%	3,516	1.85%	7	0.00%
2005	1,109	81,252	2,920	3.47%	2,904	3.45%	16	0.02%
2006	3,650	105,063	3,023	2.80%	2,944	2.72%	76	0.07%
2007	4,433	88,474	3,859	4.18%	3,846	4.17%	13	0.01%
2008	5,131	147,558	4,466	2.94%	4,292	2.82%	174	0.11%
2009	3,455	186,056	4,489	2.36%	4,037	2.12%	452	0.24%
2010	3,609	267,167	6,081	2.23%	5,095	1.86%	986	0.36%
2011	3,315	223,380	3,557	1.57%	2,527	1.11%	1,030	0.45%
2012	3,404	171,665	2,107	1.21%	998	0.57%	1,109	0.64%
2013	3,247	120,619	2,714	2.20%	1,402	1.14%	1,312	1.06%
2014	2,947	219,929	4,314	1.92%	2,615	1.17%	1,699	0.76%
2015	2,995	239,326	9,981	4.00%	7,779	3.12%	2,202	0.88%
2016	1,974	154,074	8,969	5.50%	6,371	3.90%	2,598	1.60%
2017	1,142	109,040	4,949	4.54%	2,024	1.86%	2,925	2.68%

Supplementary Table 3. Summary of clepto-parasitism events by California sea lions (CSL) and Steller sea lions (SSL) observed at Bonneville Dam, 2002 to 2017.

	CSL		SSL		
Year	*From* CSL	*From* SSL	*From* CSL	*From* SSL	Total
2002	0	0	0	0	0
2003	14	0	0	0	14
2004	366	22	0	0	388
2005	22	0	22	0	44
2006	12	0	5	0	17
2007	33	0	4	0	37
2008	161	0	135	4	300
2009	152	4	324	7	487
2010	58	2	801	37	898
2011	2	0	279	12	293
2012	2	0	35	55	92
2013	1	0	67	19	87
2014	0	0	58	4	62
2015	67	7	273	12	359
2016	34	2	393	9	438
2017	2	0	62	11	75

Supplementary Figure 1. Temporal distribution of Pacific Lamprey consumption by California sea lions (CSL) and Steller sea lions (SSL) observed at Bonneville Dam in 2017. Figure 1A depicts the distribution of both species of pinniped across the hours sampled, and Figure 1B shows the distribution across the sampling season by pinniped species.

A.



B.