ANNUAL REPORT:
PINNIPED MONITORING AT WILLAMETTE FALLS, 2018-2019

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Photo: C. Owen

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

The Marine Mammal Protection Act (MMPA) of 1972 provides federal protection of all marine mammal species in U.S. waters. As one result of this wide-scale conservation legislation, the U.S. stock of California sea lions (*Zalophus californianus*) has increased to the point that it is now likely within its optimum sustainable population range (carrying capacity), thus meeting the conservation objective of the MMPA for this species (Laake et al. 2018). Over this same period, many salmon and steelhead (*Oncorhynchus* spp.) populations in the Pacific Northwest have experienced significant declines in abundance and have been subsequently listed as threatened or endangered under the Endangered Species Act (ESA). While pinniped predation is not the ultimate cause of these declines, in areas where salmonid abundance is low and California sea lion numbers are high, increased predation levels can result in serious and significant negative impacts to the survival and recovery of individual salmonid populations.

One such area where the effects of localized marine mammal predation is apparent is at Willamette Falls on the Willamette River, approximately 206 km (128 mi) upriver from the Pacific Ocean. While the first known record of a California sea lion at Willamette Falls was of a single animal in the 1950s (Beach et al. 1985), by the mid-1990s there were frequent observations of California sea lions foraging there for winter steelhead and spring Chinook salmon attempting to pass the Falls (Oregon Department of Fish and Wildlife [ODFW], unpublished data). Concerned that Willamette Falls would become another "Ballard Locks"—a site in Washington where California sea lions effectively extirpated a run of steelhead (*O. mykiss*) (Fraker and Mate 1999)—ODFW began a predation monitoring program at Willamette Falls in 1995, as well as a California sea lion marking program at Astoria in 1997 to identify and track California sea lions in the Columbia River basin.

Intermittent predation monitoring at the falls by ODFW occurred from 1995-2003, after which the agency's limited resources were shifted to Bonneville Dam on the Columbia River where California sea lion predation on salmonids also began increasing (e.g., Keefer et al. 2012, Tidwell et al. 2019). Attention soon returned to Willamette Falls, however, as winter steelhead passage declined and sea lion activity increased. This led ODFW to conduct non-lethal hazing at the falls in 2010, 2011, and 2013 in an attempt to deter sea lions from consuming threatened winter steelhead near the fish ladder entrances. However, as has been seen elsewhere (e.g., see review in Scordino 2010), non-lethal deterrents had only limited and short-term effects as pinnipeds eventually adapted to or ignored them.

Hazing was discontinued after 2013 in order to shift limited resources to a rigorous monitoring effort (e.g., see Wright et al. 2018). That effort showed that California sea lion abundance had increased from the late 1990s and early 2000s and that California sea lion predation had become particularly acute for threatened winter steelhead populations. In addition, Steller sea lions (*Eumatopias jubatus*) also began showing notable increases in abundance and residency starting in 2017. Partially based on the results of this monitoring, the state of Oregon requested lethal removal authority for California sea lions under Section 120 of the MMPA, which was subsequently granted on November 14, 2018. This report summarizes the sixth year of pinniped monitoring at the falls; results from the first year of California sea lion management are presented in a separate report (see Steingass et al. 2019).

METHODS

Study area

The study area was located from Willamette Falls on the Willamette River, down to the mouth of the Clackamas River (Figure 1), although formal observations were only conducted in the immediate vicinity of the falls (i.e., sites 1-6). The falls are located approximately 42 km (26 mi) upriver from the confluence with the Columbia River and 206 km (128 mi) from the ocean. It is the second largest waterfall in the United States by volume behind Niagara Falls (ECONorthwest 2014).

Pinniped species accounts

Three pinniped species have been known to occur seasonally at Willamette Falls: California sea lions, Steller sea lions, and Pacific harbor seals (*Phoca vitulina*).

<u>California sea lions</u>—California sea lions are currently the most common and abundant pinniped observed at Willamette Falls. California sea lions in Oregon belong to the U.S. stock for which the most recent estimate (2014) was 257,606 animals (Laake et al. 2018, Carretta 2019). The stock is not listed as "endangered" or "threatened" under the ESA, nor as "depleted" or "strategic" under the MMPA (Carretta et al. 2019). California sea lions in the Pacific Northwest are seasonal migrants that arrive in August and depart in June of each year on their way back and forth from the breeding grounds in southern California and Mexico (Wright et al. 2010, Elorriaga-Verplancken et al. 2014). This seasonal population is comprised almost exclusively of ≥3 year old males, numbering approximately 50,000-75,000 in total (Mate 1975, Maniscalco et al. 2004, Laake et al. 2018, ODFW unpublished data).

<u>Steller sea lions</u>— Steller sea lions have been observed sporadically at Willamette Falls over the last decade, albeit more consistently in recent years. Steller sea lions in Oregon belong to the eastern Distinct Population Segment (DPS). Not accounting for animals at sea, the most recent estimate (2015) of the eastern DPS was 19,423 pups and 52,139 non-pups, with Oregon-based animals comprising approximately 10% of each count (Muto et al. 2018). The stock is not listed as "endangered" or "threatened" under the ESA, nor as "depleted" or "strategic" under the MMPA (Muto et al. 2018).

<u>Harbor seals</u>—Harbor seals, while common and abundant throughout coastal Oregon, are relatively rare and inconspicuous visitors to upriver sites such as Willamette Falls. Harbor seals in Oregon belong to the Oregon/Washington coastal stock. The most recent estimate (1999) of the total stock was 16,165 animals (Carretta et al. 2014). The stock is not listed as "endangered" or "threatened" under the ESA nor as "depleted" or "strategic" under the MMPA (Carretta et al. 2014).

Fish species accounts

Fish species primarily preyed upon by pinnipeds at Willamette Falls are winter and summer steelhead, marked and unmarked spring Chinook salmon (*O. tschawytscha*), Pacific lamprey

(*Entosphenus tridentatus*), and white sturgeon (*Acipenser transmontanus*). All of these species are of conservation or management concern and two—winter steelhead and wild spring Chinook salmon—are listed as "threatened" under the ESA.

Winter steelhead—All naturally produced winter-run steelhead populations in the Willamette River and its tributaries above Willamette Falls to the Calapooia River are part of the ESA-listed Upper Willamette River (UWR) steelhead DPS (National Marine Fisheries Service [NMFS] 2016). These fish pass Willamette Falls from November through May, co-occurring to some extent with introduced marked summer steelhead that pass the falls from March through October. While there is no directed fishery for winter-run steelhead in the upper Willamette River, hatchery-origin summer steelhead are not ESA-listed and support popular recreational fisheries in the Santiam, McKenzie and Middle Willamette subbasins.

Spring Chinook salmon—All naturally produced populations of spring Chinook salmon in the Clackamas River and in the Willamette Basin upstream of Willamette Falls are part of the ESA-listed UWR Chinook salmon Evolutionary Significant Unit (ESU) (NMFS 2016). These fish pass Willamette Falls from about April to August and co-occur with a more abundant run of hatchery-origin spring Chinook salmon. Hatchery-produced spring Chinook salmon support economically and culturally important fisheries in the lower Columbia and Willamette rivers, part of which takes place in the study area below Willamette Falls.

Migrating salmonids pass Willamette Falls by entering one of four entrances to three fishways through the falls. Video cameras and time lapsed video recorders are used to record fish passage, which is later, reviewed to produce passage counts. Salmonid species are partitioned by run (e.g., winter/summer, unmarked/marked) based on passage date and the presence or absence of a hatchery fin clip.

Pinniped predation estimation

While pinnipeds can consume small prey underwater, they usually must surface to manipulate and consume larger prey such as an adult salmonid (Roffe and Mate 1984). We utilized this aspect of their foraging behavior (i.e., surface-feeding), in conjunction with standard statistical sampling methods (e.g., Lohr 1999) to estimate the total number of adult salmonids consumed by sea lions over a spatio-temporal sampling frame.

The variable of interest was a surface-feeding event whereby a sea lion was observed to initiate the capture and/or consumption of prey within a given spatio-temporal observation unit. We included both predation on free swimming fish as well as depredation of hooked fish in the recreational fishery (collectively referred to as "predation" hereafter unless specifically noted). We assumed that the probability of detecting an event, given that it occurred, was one. Surface-feeding observations were conducted from shore by visually scanning a given area with unaided vision and/or binoculars. For each event, trained observers recorded the time, site, sea lion species, prey species, and whether the fish may have been taken from an angler. If prey appeared to escape without mortal wounds then the event was noted but not included in the tally used for estimation.

Observers followed a schedule of when and where to observe based on a probability sample generated from a three-stage cluster sampling design, with repeated systematic samples at each stage (see Figures 1 and 2, and Appendices A and B, for descriptions of the design; see Lohr 1999 for background on sampling; see Wright et al. 2007 for implementation of this design elsewhere). The first stage or primary sampling units (PSUs) were "days of the week" (i.e., Sunday, Monday, etc.). The second stage or secondary sampling units (SSUs) were "site-shifts" within a day of the week (e.g., 0700-1530 at specified site(s)). The third stage or tertiary sampling units (TSUs) were 30-min observation bouts within a site-shift (i.e., three out of every four 30-min periods at a given site). Due to constraints imposed by work schedules (e.g., lunch breaks, days off), some deviations from a truly randomized design were unavoidable. However, since there is no reason to believe that sea lion foraging behavior should vary systematically with observer breaks or days off, then imposing some restrictions on randomization is unlikely to introduce bias into estimation.

The spatial component of the sampling frame consisted of six sites in a single stratum (Figure 1). This is identical to the 2016-2018 studies but in contrast to the 2014-2015 studies that had sites spread over two strata (Figure 2). Sites 1-6 were each approximately 0.9 ha in area and occurred immediately below the falls where predation activity is typically greatest. The temporal component of the sampling frame consisted of a subset of daylight hours, ranging from 0800-1630 (8.5 hours) on January 7 to 0600-1900 (13 hours) on June 2 (Figure 2).

There were 1,327 half-hour observation units (i.e., elements) in the sample out of a sampling frame of 19,764 units, resulting in an element-wise sampling fraction of 6.7%; the cluster-wise sampling fraction was also 6.7% (120 clusters out of 1792; see Appendix A). The sampling weight was 14.93, meaning that each observed predation event represented itself and 13.93 additional unobserved events. Based on previous pilot testing of the design against simulated data it was anticipated that the total salmonid predation estimate would have a coefficient of variation (CV) of 10% or less (estimates with CVs over 33% are generally considered unreliable). Missing elements (e.g., due to holidays, missed assignments, etc.) were assumed to be missing-completely-at-random but were imputed as zeros, which likely contributed to small negative bias in the predation estimates.

Observed salmonid predation events were assigned to a run (i.e., summer/winter steelhead, unmarked/marked spring Chinook salmon) based on a combination of field observations, fishway window counts, and Monte Carlo methods. We did this using a two-step approach. In the first step, we either used observer identification of salmonids to species (if available), or we treated all salmonid as unknown regardless of whether they may have been identified in the field to species. In the second step, we assumed prey consumption was proportional to the run composition derived from window counts which we computed by pooling counts over 1, 7, or 14 days subsequent to an observed event (see Keefer et al. 2004).

As an example, if a steelhead was killed on Monday and the window count composition for steelhead on Tuesday was 50% winter steelhead and 50% summer steelhead, then the observed kill would be assigned to a run based on a metaphorical coin toss. For the case of "unknown" salmonids, if a salmonid was killed on Monday and the window count composition on Tuesday was 90% winter steelhead, 5% summer steelhead, 4% marked spring Chinook salmon, and 1%

unmarked spring Chinook salmon, then the observed kill would be assigned to a run based on a metaphorical toss of a 100-sided die where 90 sides were winter steelhead, 5 were summer steelhead, etc.

Each of the six models was run for 1000 iterations and the resultant means were computed for run-specific total predation and associated measures of uncertainty. Predation relative to potential escapement was calculated as the estimated predation total divided by the sum of escapement and estimated predation.

Pinniped abundance estimation

Due to the complexity and cost of obtaining unbiased estimates of pinniped abundance for a given place and time, we therefore used the following index of abundance. First, observers recorded the number and species of pinnipeds in their viewing area during their shift. Second, pictures of pinnipeds hauled out near Sportcraft Landing were taken using automated cameras from which pinnipeds were later counted. Both types of counts were then added together when appropriate (i.e., at the same time but different places) to obtain hourly counts from which a maximum count was retained to represent the abundance for that day. Alternatively, if the tally of individual animals observed over a given calendar day was greater than the maximum hourly count then that number was used for that day. The maximum daily count for each week was then retained to use as an estimate of weekly abundance since daily sampling effort and camera coverage often varied by day and week.

Diet analysis

Besides direct observation of surface feeding events, we determined sea lion diet based on scat (fecal) and spew (vomitus) samples from the haul out area at Sportcraft Landing. Samples were collected and processed following methodology described in Lance et al. (2001). Briefly, undigested remains were washed through a series of nested sieves (2mm, 1mm and .05mm) and all parts were retained for later identification. Samples were identified using a dissecting microscope to the lowest possible taxonomic level by comparing all identifiable prey remains (e.g., bones, otoliths, cartilaginous parts, lenses, teeth and cephalopod beaks) against a reference collection of fish from the northeastern Pacific Ocean and Oregon estuaries. Prey were enumerated by pairing of skeletal structures (otoliths, tail structures, mouthparts, etc.) to achieve the greatest number of prey in the sample. Enumeration takes into account both left and right sides of paired structures and size of recovered prey remains.

Additional activities

The predation monitoring design in 2019 was implemented using a crew of two full-time staff. However, due to the nature of random sampling, as well as limits on how long one can sustain intense concentration, not all hours of every day were devoted to conducting sample-based observations. Any time not needed for sample-based observations was used for administrative tasks, conducting anecdotal predation observations and haul-out counts, and photographing brands.

RESULTS

Salmonid abundance and river conditions

Salmonid passage and run composition over Willamette Falls is summarized in Figures 3 and 4, respectively. Although winter steelhead escapement, and to some extent unmarked spring Chinook salmon, were notably higher than the previous two years, they were still generally lower than those in 2014-2016. Marked spring Chinook escapement over Willamette Falls, however, was notably lower than the previous five years while summer steelhead continued to show annual variation.

River height and temperature near Willamette Falls are summarized in Figure 5. The most notable hydrologic event occurred in early April when the Willamette River nearly reached minor flood stage above the falls. The effects of this event on fish passage and pinniped occurrence should be noted when interpreting data contained in the figures and tables below.

Pinniped abundance

While formal monitoring did not start until early January 2019, California sea lions and Steller sea lions were documented returning to Willamette Falls as early as 8/15/2018 and 10/25/2018, respectively (Figure 6). During the January-June monitoring period the single-day maximum counts of California sea lions and Steller sea lions were 15 (on 4/30/2019, 5/1/2019, and 5/6/2019) and 10 (on 1/18/2019 and 2/13/2019), respectively.

Thirty-nine identifiable California sea lions were documented at Willamette Falls in 2019 (44 if fall 2018 observations are included), bringing the 6-year total to 77 identifiable California sea lions (56 branded, 17 flipper-tagged, 4 naturally marked) (Figure 7). In addition, four branded Steller sea lions were observed this year, bringing the 6-year total to six, along with an unknown number of unmarked individuals of both species. At least a third of all brands seen at Willamette Falls are of animals either branded at Bonneville Dam or observed there at least once.

Predation

Observers documented 473 predation events over the course of the project (Table 1). This includes predation events seen at pre-assigned, probability-based observation units, as well as all anecdotal observations. Salmonids were the most frequently observed prey item (58%), followed by sturgeon (21%), lamprey (17%), and unknown or other fish (4%). California sea lions accounted for 70% of the total observed predation events but Steller sea lions accounted for 100% of the observed sturgeon kills.

An estimated 1,120 salmonids were consumed by California sea lions within the sampling frame from January 7 to June 2, 2019 (Table 2). Lamprey predation events were insufficient for reliable estimation but were included for comparison to previous reports. Since these estimates only apply to the sampling frame depicted in Figure 2, they are minimum estimates due to spatial and temporal undercoverage (i.e., incomplete overlap) of the target population.

Salmonid predation by run

Estimates of salmonid predation by run (winter/summer steelhead, marked/unmarked spring Chinook salmon) are presented in Table 3. Averaging across the six run assignment models yielded run-specific predation estimates of: 478 marked spring Chinook salmon (4% of potential escapement above falls), 253 unmarked spring Chinook salmon (4% of potential escapement), 109 summer steelhead (2% of potential escapement), and 280 winter steelhead (8% of potential escapement). For comparison, run-specific estimates for 2014-2018 are included in Appendices C-G. As noted before, these estimates only apply to the sampling frames depicted in Figures 2 and are therefore minimum estimates due to spatial and temporal undercoverage of the target population.

Scat analysis

Twenty-eight scat were collected at Willamette Falls from 10/11/2018 to 4/29/2019, of which 27 contained identifiable remains (Table 4). Scat collected during the period of significant overlap between Steller sea lions and California sea lions (approximately December 2018 through March 2019) was not definitely attributed to either species. Adult salmonid remains were recovered from 17 scat representing at least 2 adult Chinook salmon, 10 adult steelhead, and 12 unidentified adult salmonids. Juvenile salmonids were recovered in 9 scat representing at least 111 fish. Sturgeon were recovered in 8 scat representing at least 8 fish. Additional prey included Pacific lamprey, unidentified lamprey, unidentified Cyprinidae, unidentified perch, unidentified rockfish, and Pacific herring.

DISCUSSION

The predation estimates presented in this report (i.e., Table 2) were based solely on sampling units from the three-stage cluster sampling design and do not include anecdotal observations. The 95% confidence intervals reflect the sampling error in the estimates, which arises from taking a sample rather than a census of the population. A different sample would have produced a different estimate and confidence interval, but 95 times out of 100 the procedure will correctly capture the true population total within the interval. Non-sampling errors, however, are often a greater source of uncertainty than sampling errors. In this study, the non-sampling error of greatest concern is likely that of undercoverage (see Figure 2 and Appendix A for design details).

As in previous years, spatial and temporal undercoverage in our sampling frame likely resulted in our estimates of predation being biased low. Spatial undercoverage occurred because, as in 2016-2017, we only had sufficient staffing to cover the "falls" strata whereas we know predation occurs in the "river" strata as well in the nearby Clackamas River. Temporal undercoverage also occurred because, as in prior years, sea lions were already present prior to the start of our study and were also know to forage outside of our daily sampling times (i.e., before sunrise and after 7 p.m.).

Despite the undercoverage issues noted above, it was clear from the monitoring results that the first year of California sea lion management (see Steingass et al. 2019) resulted in substantial decreases in predator abundance and associated salmonid predation. When compared to the previous year, maximum single-day California sea lion abundance in 2019 decreased by 57% and estimated California sea lion predation on salmonids decreased by 67%. Continued monitoring through subsequent seasons will help determine whether these removals are successful in reducing future recruitment of new California sea lions to the area and whether they increase the probability of survival for listed Willamette River salmonids.

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LITERATURE CITED

Beach, R. J., A. C. Geiger, S. J. Jeffries, S. D. Treacy, and B. L. Troutman. 1985. Marine mammals and their interactions with fisheries of the Columbia River and adjacent waters, 1980-1982. NMFS-AFSC Processed Report 8504.

Carretta, J. V., et al. 2014. U.S. Pacific Marine Mammal Stock Assessments: 2013. NOAA-TM-NMFS-SWFSC-532.

Carretta, J. V., et al. 2018. U.S. Pacific Marine Mammal Stock Assessments: 2018. NOAA-TM-NMFS-SWFSC-617.

ECONorthwest. 2014. Willamette Locks economic potential report. Portland, OR. http://www.econw.com/media/ap_files/V3.LocksReport.pdf (last accessed 2016-09-08).

Elorriaga-Verplancken, F. R., M. T. Tennis, and R. F. Brown. 2014. Unprecedented resighting in Mexico of a male California Sea Lion (*Zalophus californianus*) from Oregon during the 2014 breeding season. Aquatic Mammals 40:364-367.

Fraker, M. A., and B. R. Mate. 1999. Seals, sea lions, and salmon in the Pacific Northwest. Pages 156-178 *in* J. R. Twiss Jr. and R. R. Reeves, editors. Conservation and management of marine mammals. Smithsonian Institution Press, Washington, D.C., USA.

Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Stuehrenberg. 2004. Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake Rivers. Transactions of the American Fisheries Society, 133:1413-1439.

Keefer, M. L., R. J. Stansell, S. C. Tackley, W. T. Nagy, K. M. Gibbons, C. A. Peery, 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 141:1236-1251.

Laake, J.L., M.S. Lowry, R.L. DeLong, S.R. Melin, and J.V. Carretta. 2018. Population growth and status of California sea lions. Journal of Wildlife Management 82:583-595.

Lance, M. M., A. J. Orr, S. D. Riemer, M. J. Weise, and J. L. Laake. 2001. Pinniped food habits and prey identification techniques protocol. AFSC (Alaska Fisheries Science Center) Proc. Rep. 2001-04, 36 p. Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

Lohr, S. 1999. Sampling: Design and Analysis, Duxbury.

Maniscalco J. M, K. Wynne, K. W. Pitcher, M. B. Hanson, S. R. Melin, and S. Atkinson. 2004. The occurrence of California sea lions (*Zalophus californianus*) in Alaska. Aquatic Mammals 30:427-433.

Mate B. R. 1975. Annual migrations of the sea lions *Eumetopias jubatus* and *Zalophus californianus* along the Oregon coast. Rapports et Proce`s-Verbaux des Réunions 169:455-461.

Muto, M. M., et al. 2018. Alaska marine mammal stock assessments, 2017. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-378.

National Marine Fisheries Service (NMFS). 2016. 2016 5-year review: summary and evaluation of upper Willamette River steelhead, upper Willamette River Chinook. http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_steelhead/2016/2016_upper-willamette.pdf (last accessed 2016-09-15).

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

Scordino, J. 2010. West coast pinniped program investigations on California sea lion and Pacific harbor seal impacts on salmonids and other fishery resources. Pacific States Marine Fisheries Commission. 205 SE Spokane Street, Suite 100, Portland, OR 97202.

Steingass, S., B. Wright, M. Brown, S. Valentine, D. Heiner, S. Riemer, Z. Kroneberger, E. Nass, B. Sorenson, B. Tripplet, J. Burco, and C. Gillin. 2019. Annual report: pinniped managment at Willamette Falls, 2018-2019. Oregon Department of Fish and Wildlife. 13 pp.

Tidwell, K.S., B. A. Carrothers, K. N. Bayley, L. N. Magill, and B.K. van der Leeuw, 2019. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2018. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR.

Wright, B. E., M. J. Tennis, and R. F. Brown. 2010. Movements of male California sea lions captured in the Columbia River. Northwest Science 84:60–72.

Wright, B. E., S. D. Riemer, R. F. Brown, A. M. Ougzin, and K. A. Bucklin. 2007. Assessment of harbor seal predation on adult salmonids in a Pacific Northwest estuary. Ecological Applications 17:338–351.

Wright, B. E. and T. Murtagh. 2018. Willamette Falls pinniped monitoring project, 2018. Oregon Department of Fish and Wildlife, Corvallis, Oregon.

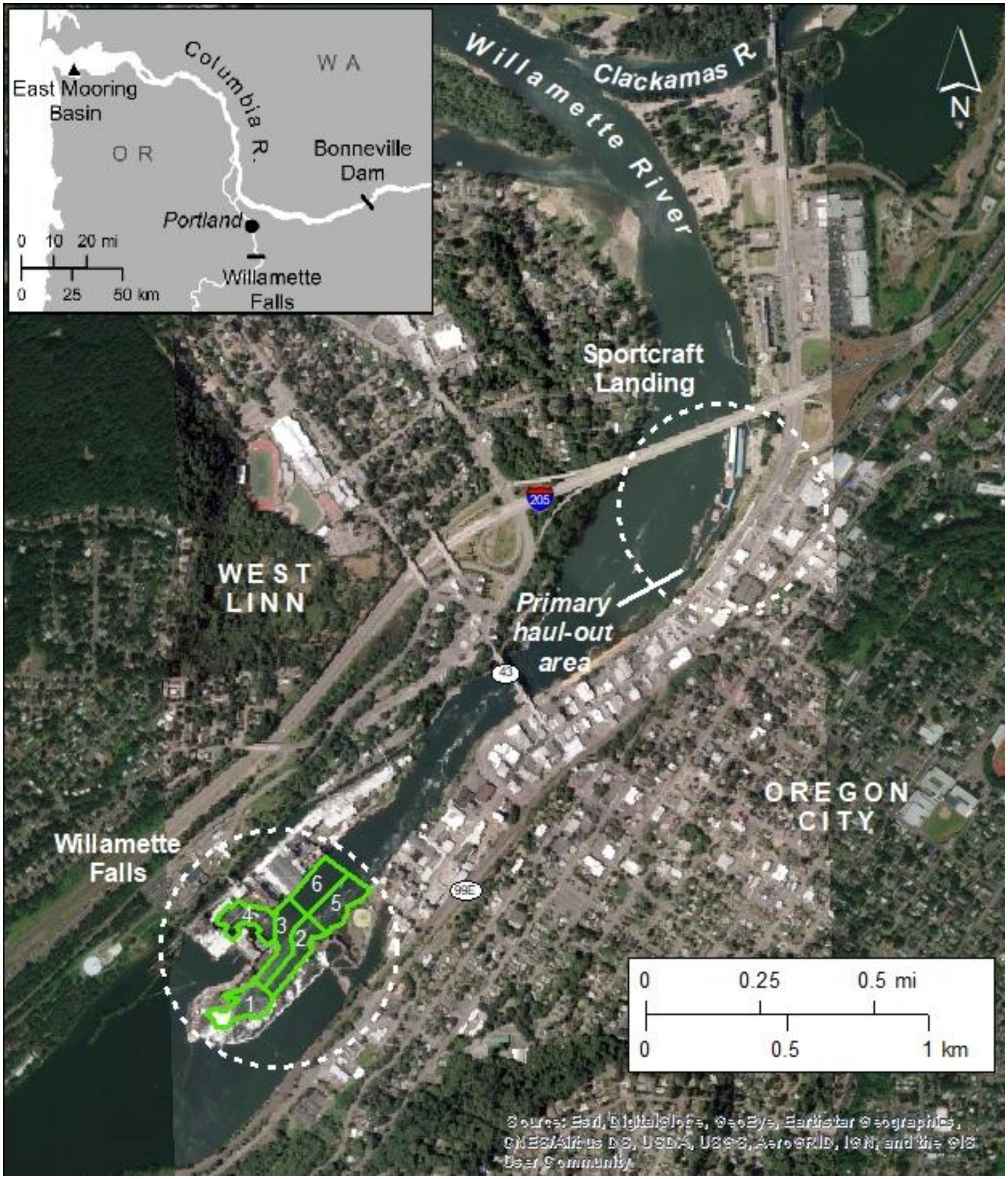

Figure 1. Illustration of the spatial component of the sampling frame for 2016-2019. Sites 1-6 ("Falls" stratum) were each approximately 0.9-ha in area.

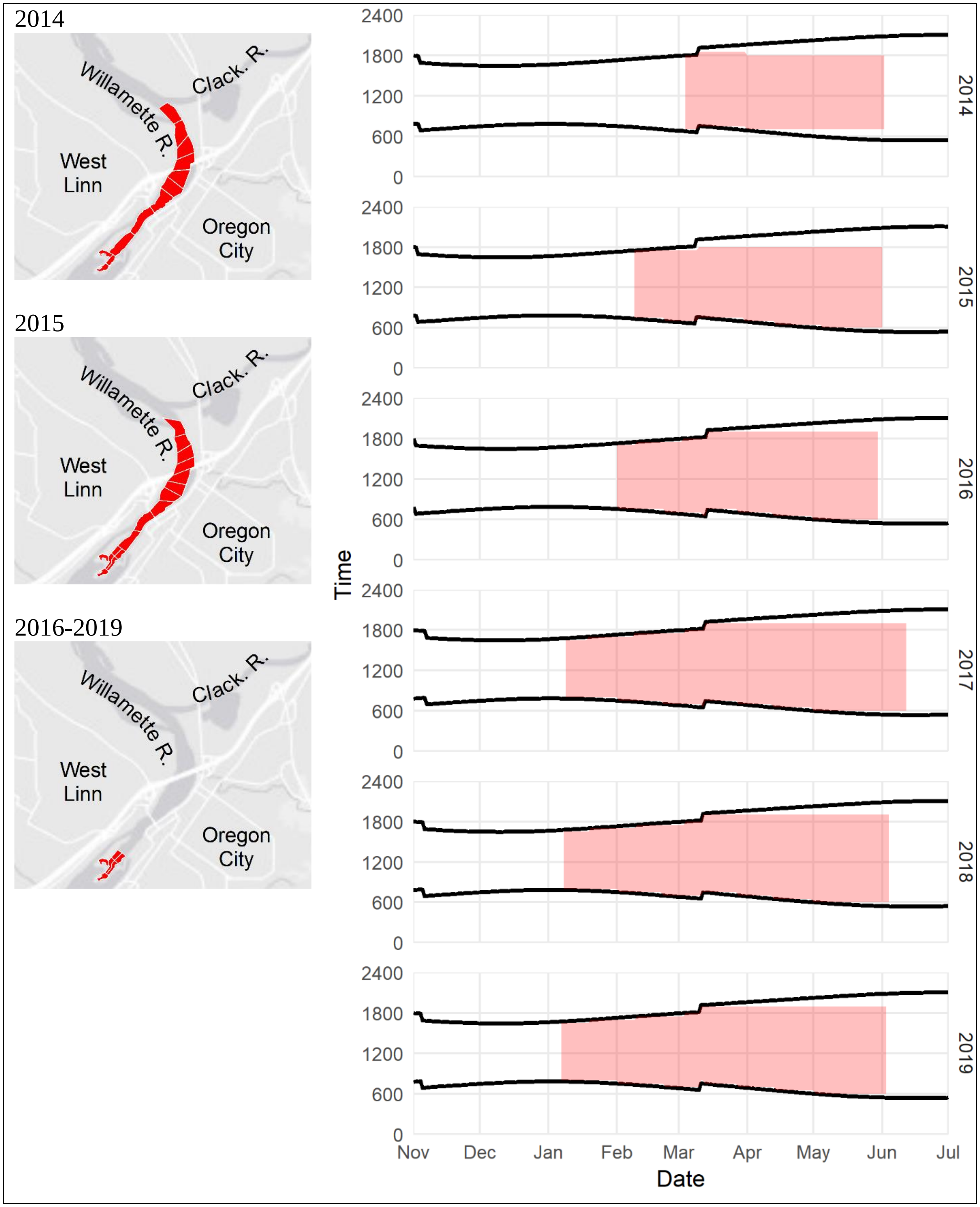

Figure 2. Illustration of spatial (left) and temporal (right) coverage of sampling frame by year. Red shaded areas depict time and area included in frame; dark black lines on the graph at right indicate sunrise and sunset, adjusted for daylight savings.

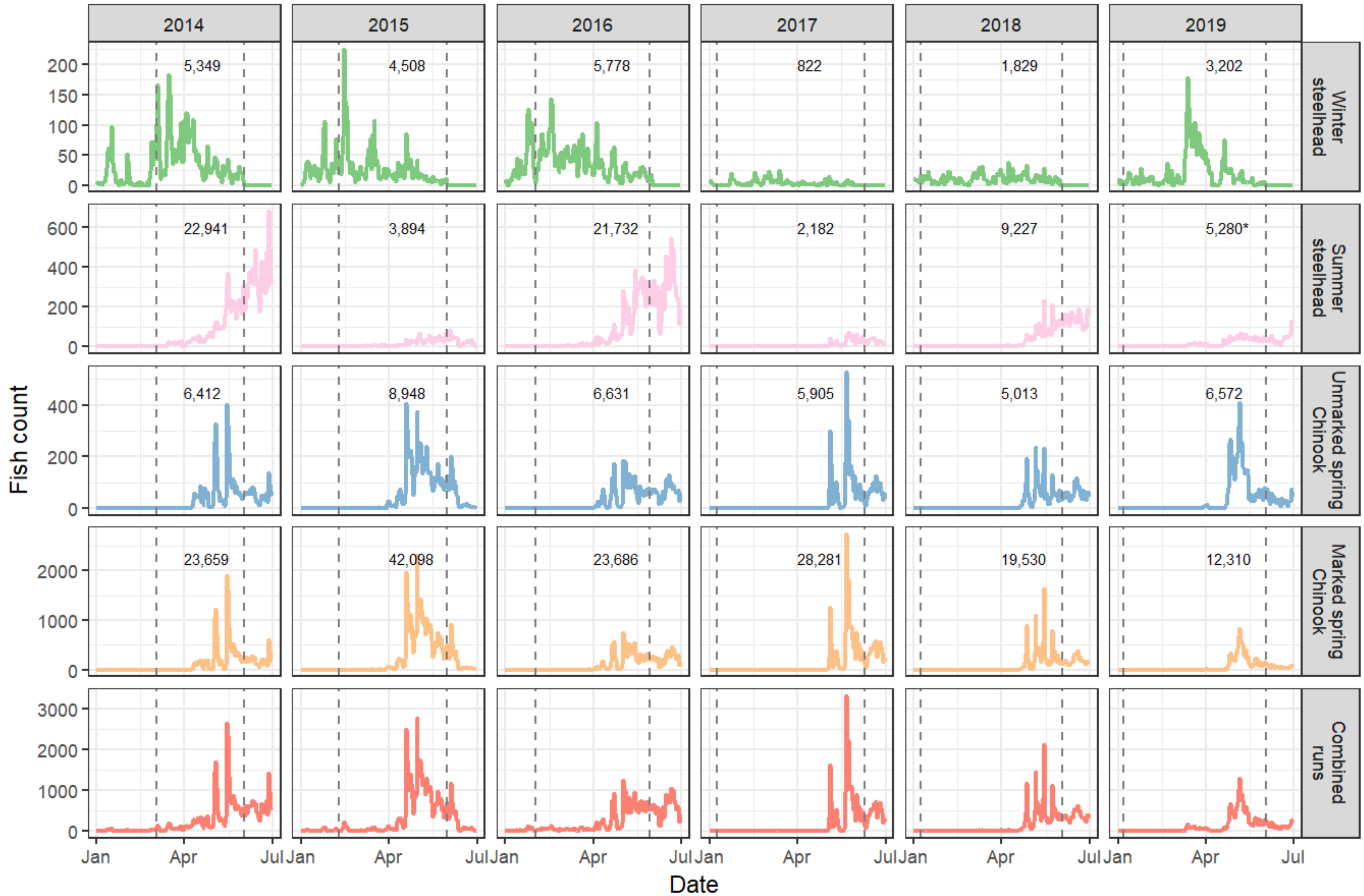

Figure 3. Daily fish counts at Willamette Falls by run and year. Vertical lines indicate study start and end dates; final escapement over falls is inset upper left of each graph (*summer steelhead escapement as of 9/30/2019).

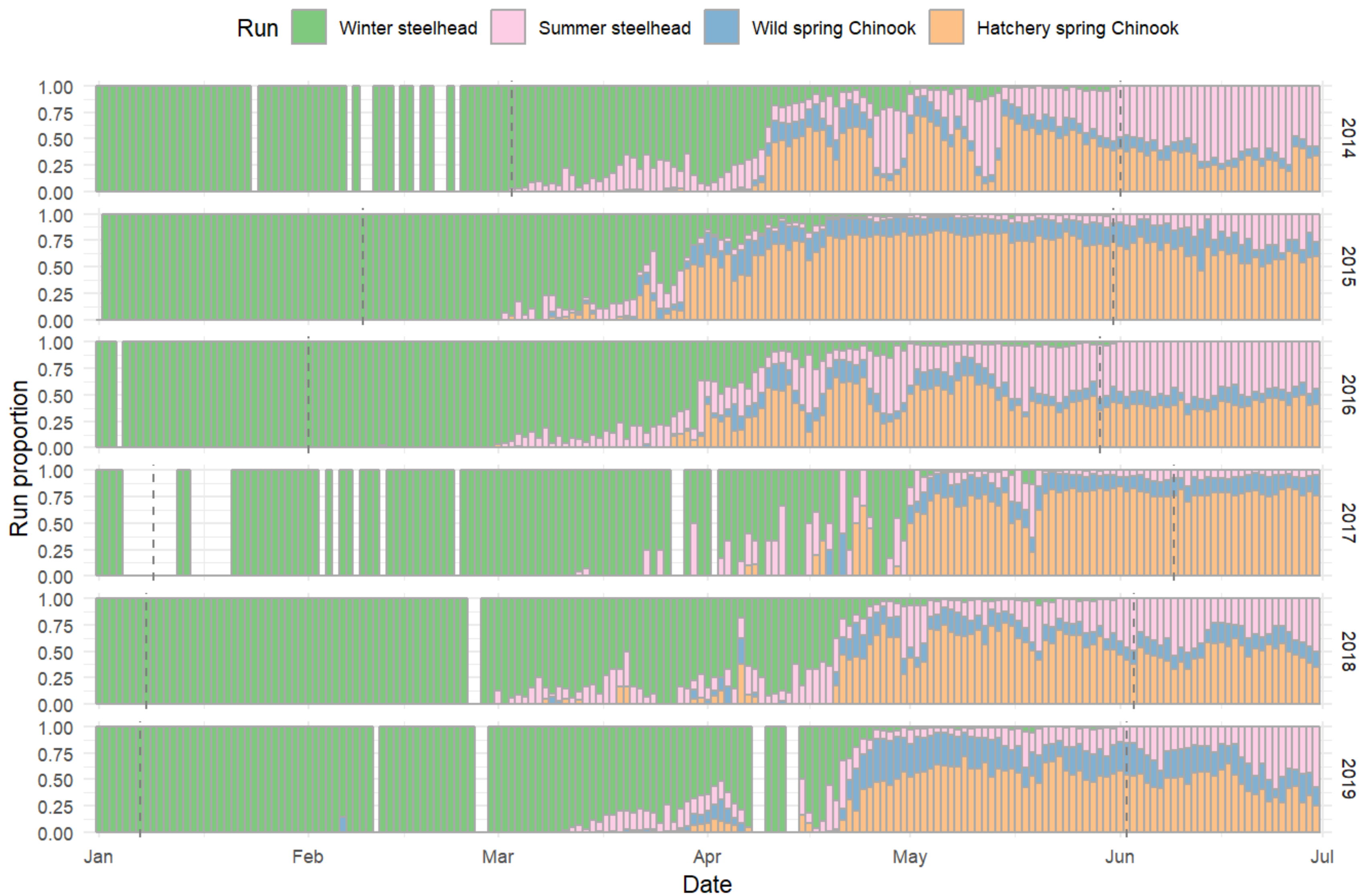

Figure 4. Daily run composition at Willamette Falls by year. Dashed lines indicate study dates. (Leap day 2/29/2016 not shown).

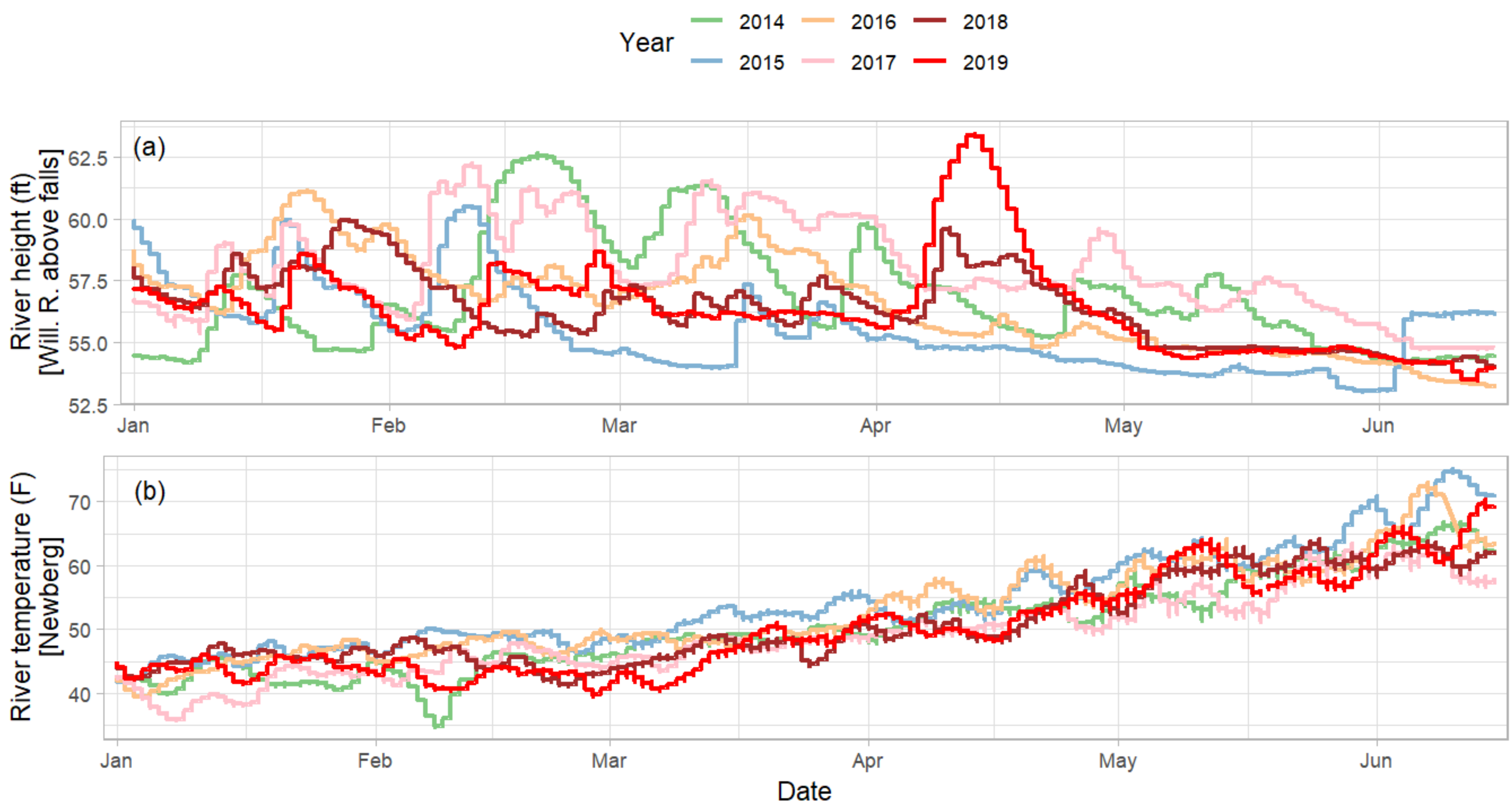

Figure 5. Willamette River height (a) and temperature (b) by date and year.

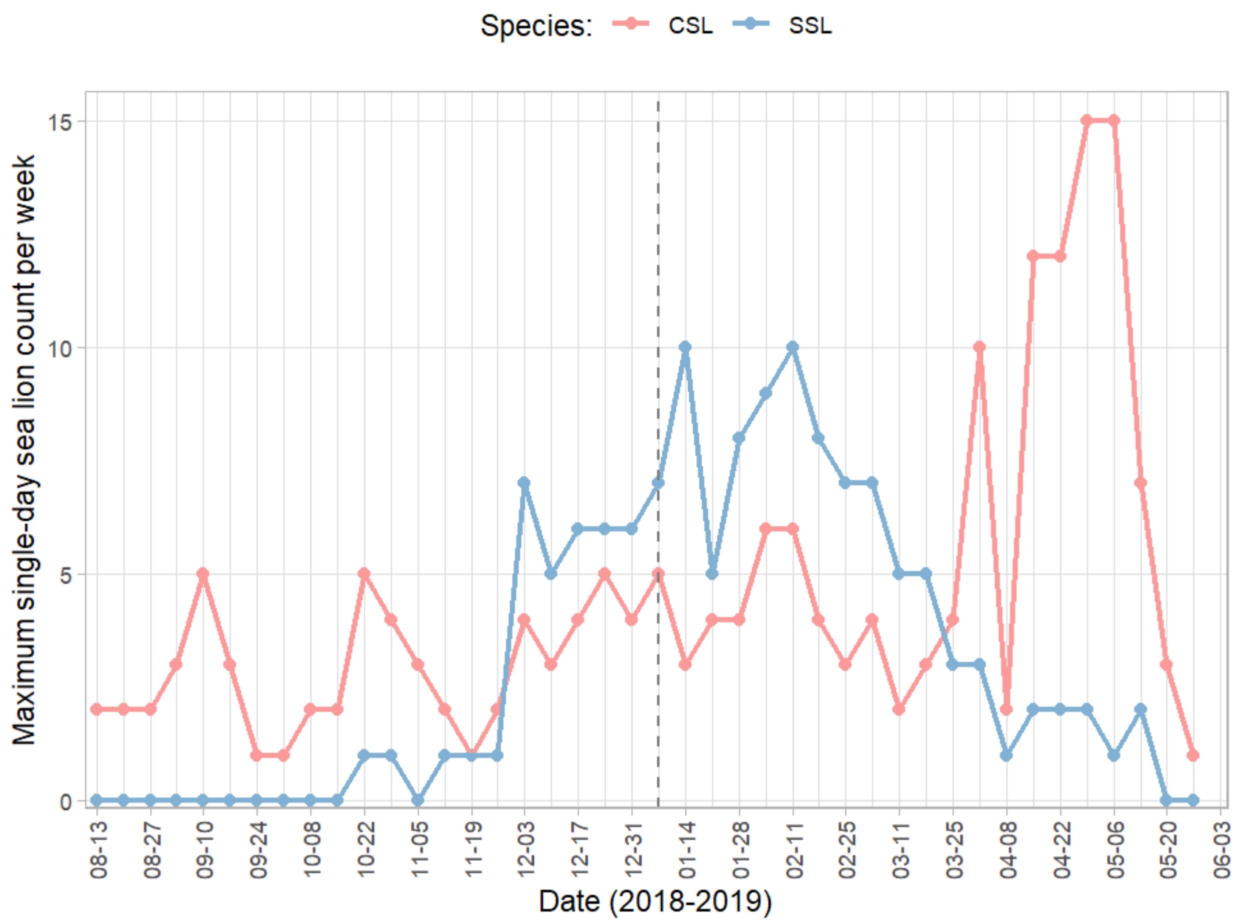

Figure 6. Maximum weekly counts of California sea lions (CSL) and Steller sea lions (SSL) below Willamette Falls. Counts were plotted on the first day of each statistical week; dashed vertical line denotes start of the predation monitoring project.

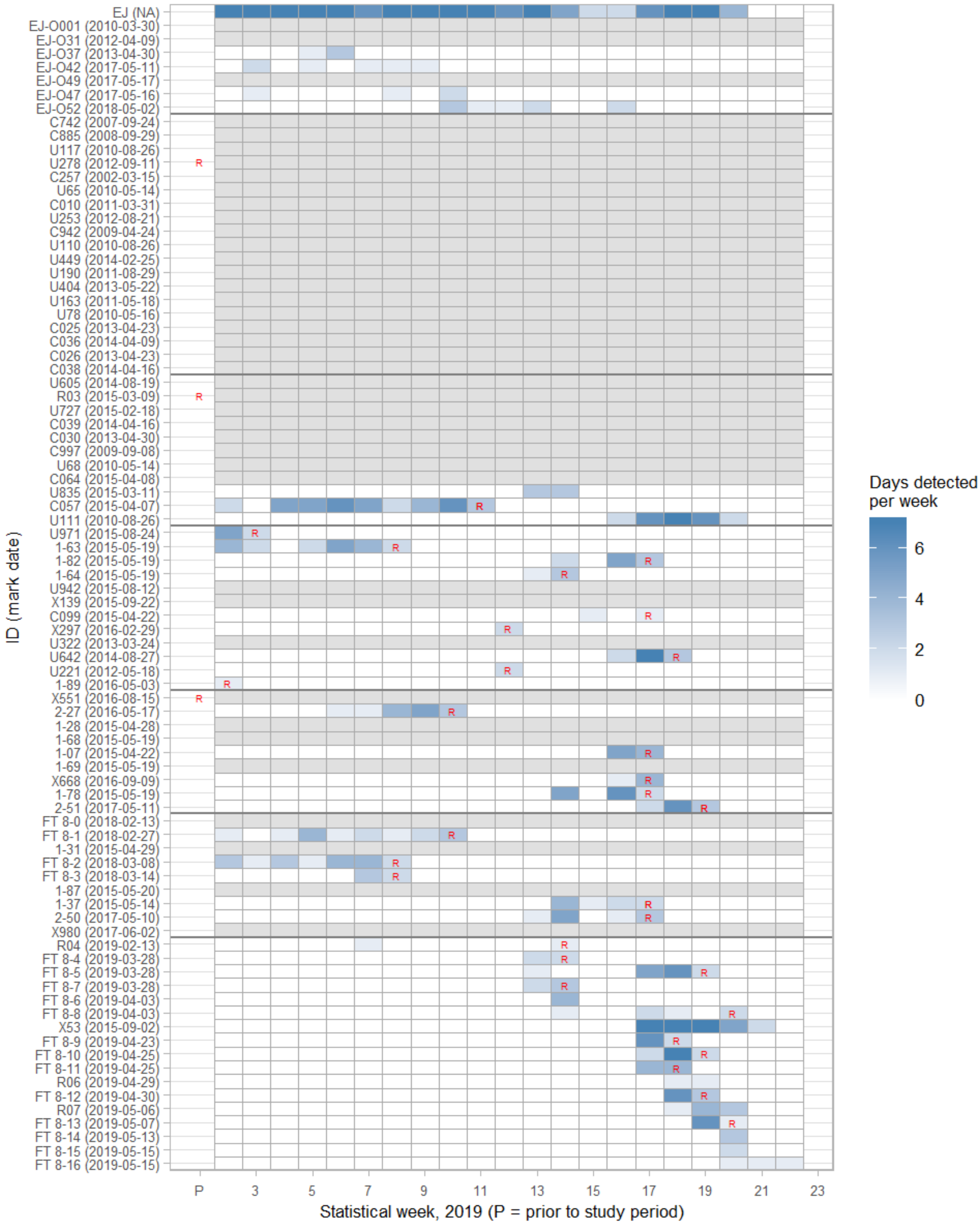

Figure 7. Weekly occurrence of Steller sea lions and California sea lions at Willamette Falls, sorted by date of first detection from 2014-2019. Steller sea lions are indicated by prefix 'EJ' where the first row indicates presence of marked or unmarked individuals. "R" indicates when an individual was trapped and removed; grey cells indicate an animal that was observed in previous years but not in 2019.

Table 1. Summary of all predation events observed below Willamette Falls from January 7 to June 2, 2019. Includes events from anecdotal observations as well as those seen during probability-based sampling assignments.

Prey	California sea lion	Steller sea lion	Total
Chinook salmon	126	12	138
Unknown salmonid	72	11	83
Steelhead	52	2	54
Lamprey	70	11	81
Sturgeon	0	98	98
Unknown/other fish	12	7	19
Total	332	141	473

Table 2. Summary of estimated predation by California sea lions below Willamette Falls from January 7 to June 2, 2019 based on the three-stage cluster sampling design. These estimates only apply to the sampling frame for 2019 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Prey	Observed total	Estimated total	Standard error	Coefficient of variation	95% confidence interval	
					Lower bound	Upper bound
Salmonids	75	1,120	80	0.07	963	1,277
Lamprey	34	508	199	0.39	118	897

Table 3. Estimated California sea lion predation on salmonids at Willamette Falls by run, 2019. These estimates only apply to the sampling frame for 2019 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Escapement over falls	Run assignment model	Pooled lag-days	Estimated predation (means from 1000 simulations)					% of potential escapement*		
			Total	SE	CV	95% CI LB	95% CI UB	Total	95% CI LB	95% CI UB
Marked spring Chinook salmon (12,310)	Window count only	1	433	69	0.16	298	569	3%	2%	4%
		7	487	69	0.14	351	623	4%	3%	5%
		14	506	68	0.14	371	640	4%	3%	5%
	Observer ID then window count	1	455	66	0.15	327	584	4%	3%	5%
		7	485	65	0.14	357	613	4%	3%	5%
		14	501	65	0.13	373	628	4%	3%	5%
	Mean		478			346	609	4%	3%	5%
Unmarked spring Chinook salmon (6,572)	Window count only	1	258	56	0.22	148	367	4%	2%	5%
		7	266	55	0.21	157	375	4%	2%	5%
		14	253	54	0.22	147	358	4%	2%	5%
	Observer ID then window count	1	251	52	0.21	150	353	4%	2%	5%
		7	249	52	0.21	148	350	4%	2%	5%
		14	244	51	0.22	143	345	4%	2%	5%
	Mean		253			149	358	4%	2%	5%
Summer steelhead (5,280**)	Window count only	1	131	41	0.33	51	210	2%	1%	4%
		7	102	35	0.37	33	172	2%	1%	3%
		14	112	37	0.36	39	185	2%	1%	3%
	Observer ID then window count	1	105	39	0.40	27	182	2%	1%	3%
		7	98	40	0.43	19	177	2%	0%	3%
		14	105	42	0.42	22	188	2%	0%	3%
	Mean		109			32	186	2%	1%	3%
Winter steelhead (3,202)	Window count only	1	298	67	0.23	166	430	9%	5%	12%
		7	265	61	0.23	146	383	8%	4%	11%
		14	250	55	0.22	142	358	7%	4%	10%
	Observer ID then window count	1	309	70	0.23	171	446	9%	5%	12%
		7	288	67	0.23	158	419	8%	5%	12%
		14	270	61	0.22	152	389	8%	5%	11%
	Mean		280			156	404	8%	5%	11%

* Percent potential escapement = estimate / (estimate + escapement) x 100
**Summer steelhead escapement through September 30, 2019.

Table 4. Prey remains identified from scat (fecal) samples collected from California sea lions (CSL) and Steller sea lions (SSL) below Willamette Falls at the Sportcraft Landing haul-out, 2018-2019.

Date	Sea lion spp.	Adult salmonid	Adult Chinook salmon	Adult steelhead	Juvenile salmonid	Sturgeon	Pacific lamprey	Cyprinidae	Lamprey spp.	Perch spp.	Rockfish spp.	Pacific herring
2018-10-11	CSL	1										
	CSL	1							1	1		
2018-10-17	CSL			1								
2018-10-29	CSL	2			1							
2018-10-30	CSL	1		1	1		3					
2018-11-05	CSL							1				
2018-11-13	CSL				36							
2018-11-19	CSL	1			1							
	CSL				39			1				
2018-11-26	CSL	1			3							
2018-12-03	CSL?	1										
	CSL?			1								
2018-12-04	CSL?			1			1					
2019-01-11	SSL?				1	1		1				
2019-02-01	SSL?					1						
2019-02-14	SSL?					1						
2019-02-19	SSL?					1						
2019-02-26	SSL?					1				2		
	CSL?	1		3								
2019-03-06	CSL (2-27)			2								1
	CSL (8-1)			1			2	1				
	SSL?	1				1	1	1				
2019-03-18	SSL?				1	1						
	SSL?					1		1				
2019-04-24	CSL	1	1						1			
2019-04-29	CSL		1		28							
	CSL	1					1				1	
Total		12	2	10	111	8	8	6	2	3	1	1

Appendix A. Design data describing the Willamette Falls sea lion monitoring program, 2014-2019.

Year	Stratum	Sites	Staff	Dates	Weeks	Hours	*N* PSUs	*M* SSUs	*K* TSUs	Frame clusters	*n* PSUs	*m* SSUs	*k* TSUs	Sample clusters	Sampling fraction	Weight	Frame elements	Sample elements	Elements per cluster	Missed elements
2014	F	3	2	Mar 3-Jun 1	13	1,001	7	7	16	784	5	2	12	120	15.3%	6.53	6,006	929	7.66	
	R	9	2	Mar 3-Jun 1	13	1,001	7	20	16	2,240	5	2	12	120	5.4%	18.67	18,018	966	8.04	
			4							3,024				240	7.9%		24,024	1,895		89
2015	F	6	2	Feb 9-May 31	16	1,239	7	14	16	1,568	5	2	12	120	7.7%	13.07	14,868	1,101	9.48	
	R	10	2	Feb 9-May 24	15	1,155	7	22	16	2,464	5	2	12	120	4.9%	20.53	23,100	1,122	9.37	
			4							4,032				240	6.0%		37,968	2,223		53
2016	F	6	2	Feb 1-May 29	17	1,389	7	16	16	1,792	5	2	12	120	6.7%	14.93	16,668	1,114	9.30	45
2017	F	6	2	Jan 9-Jun 9	22	1,750	7	16	16	1,792	5	2	12	120	6.7%	14.93	21,000	1,413	11.71	61
2018	F	6	2	Jan 8 – Jun 3	21	1,653.5	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,842	1,337	11.14	NA
2019	F	6	2	Jan 7 – Jun 2	21	1,647	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,764	1,327	11.05	63

Appendix B. Simplified example illustrating three-stage cluster sampling design. The population estimate is the sum of the observations multiplied by their sampling weights. The estimator is unbiased over all possible samples. Variance, 95% confidence intervals, and CV are calculated using appropriate sampling formulas.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1		1st stage				2nd stage				3rd stage								
2		Primary sampling units (PSUs)				Secondary sampling units (SSUs)				Tertiary sampling units (TSUs)				Observed sample (y)				
3		2	4	5		2	4	5		2	4	5		2		5		
4		2	3	6		2	3	6										
5		8	9	7		8	9	7		8	9	7		8	9			
6																		
7		9	3	9		9	3	9		9	3	9			3	9		
8		3	5	0		3	5	0		3	5	0		3		0		
9		9	1	5		9	1	5										
10										Cells within rows				'=C17*G13*K12	8	n		
11		9	2	6		Rows within tables				K	3			'=C16*G12*K11	27	N		
12		2	4	8		M	3			k	2			'=SUM(N3:P8)	39	sum y		
13		5	9	1		m	2							'=(C16/C17)*(G12/G13)*(K11/K12)	3.38	sampling weight		
14														'=1/O12	0.30	inclusion probability		
15		Tables																
16		N	3											'=O11*O12	131.6	estimated population total		
17		n	2											'=SUM(B3:D13)	136	true population total		
18														'=O15-O16	-4.4	difference		

Appendix C. Estimated California sea lion predation on salmonids at Willamette Falls by run, 2014. These estimates only apply to the sampling frame for 2014 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Escapement over falls	Run assignment model	Pooled lag-days	Estimated predation (means from 1000 simulations)					% of potential escapement*		
			Total	SE	CV	95% CI LB	95% CI UB	Total	95% CI LB	95% CI UB
Marked spring Chinook salmon (23,659)	Window count only	1	1,534	168	0.11	1,204	1,864	6%	5%	7%
		7	1,650	148	0.09	1,359	1,941	7%	5%	8%
		14	1,730	139	0.08	1,457	2,003	7%	6%	8%
	Observer ID then window count	1	1,758	149	0.08	1,467	2,050	7%	6%	8%
		7	1,760	141	0.08	1,483	2,037	7%	6%	8%
		14	1,783	143	0.08	1,502	2,063	7%	6%	8%
	Mean		1,703			1,412	1,993	7%	6%	8%
Unmarked spring Chinook salmon (6,412)	Window count only	1	450	74	0.16	305	594	7%	5%	8%
		7	480	74	0.16	336	625	7%	5%	9%
		14	485	73	0.15	342	628	7%	5%	9%
	Observer ID then window count	1	529	77	0.15	378	679	8%	6%	10%
		7	526	78	0.15	374	678	8%	6%	10%
		14	505	75	0.15	357	652	7%	5%	9%
	Mean		496			349	643	7%	5%	9%
Summer steelhead (22,941)	Window count only	1	794	98	0.12	602	987	3%	3%	4%
		7	751	88	0.12	578	924	3%	2%	4%
		14	747	92	0.12	567	927	3%	2%	4%
	Observer ID then window count	1	621	114	0.18	399	844	3%	2%	4%
		7	656	124	0.19	413	899	3%	2%	4%
		14	701	130	0.19	447	955	3%	2%	4%
	Mean		712			501	923	3%	2%	4%
Winter steelhead (5,349)	Window count only	1	912	130	0.14	657	1167	15%	11%	18%
		7	810	114	0.14	587	1032	13%	10%	16%
		14	728	110	0.15	512	944	12%	9%	15%
	Observer ID then window count	1	782	105	0.13	576	988	13%	10%	16%
		7	748	106	0.14	541	956	12%	9%	15%
		14	702	103	0.15	500	903	12%	9%	14%
	Mean		780			562	998	13%	10%	16%

* Percent potential escapement = estimate / (estimate + escapement) x 100

Appendix D. Estimated California sea lion predation on salmonids at Willamette Falls by run, 2015. These estimates only apply to the sampling frame for 2015 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Escapement over falls	Run assignment model	Pooled lag-days	Estimated predation (means from 1000 simulations)					% of potential escapement*		
			Total	SE	CV	95% CI LB	95% CI UB	Total	95% CI LB	95% CI UB
Marked spring Chinook salmon (42,098)	Window count only	1	3,885	271	0.07	3,354	4,415	8%	7%	9%
		7	4,058	279	0.07	3,511	4,605	9%	8%	10%
		14	4,217	287	0.07	3,654	4,779	9%	8%	10%
	Observer ID then window count	1	4,174	276	0.07	3,633	4,716	9%	8%	10%
		7	4,237	280	0.07	3,688	4,787	9%	8%	10%
		14	4,324	284	0.07	3,768	4,879	9%	8%	10%
	Mean		4,149			3,601	4,697	9%	8%	10%
Unmarked spring Chinook salmon (8,948)	Window count only	1	876	119	0.14	643	1,109	9%	7%	11%
		7	871	114	0.13	647	1,095	9%	7%	11%
		14	859	113	0.13	638	1,081	9%	7%	11%
	Observer ID then window count	1	954	126	0.13	708	1,200	10%	7%	12%
		7	941	119	0.13	707	1,175	10%	7%	12%
		14	891	116	0.13	664	1,119	9%	7%	11%
	Mean		899			668	1,130	9%	7%	11%
Summer steelhead (3,894)	Window count only	1	230	58	0.26	117	343	6%	3%	8%
		7	201	54	0.28	95	307	5%	2%	7%
		14	188	51	0.28	87	289	5%	2%	7%
	Observer ID then window count	1	146	47	0.33	54	238	4%	1%	6%
		7	130	45	0.36	42	217	3%	1%	5%
		14	134	45	0.35	46	222	3%	1%	5%
	Mean		172			74	269	4%	2%	6%
Winter steelhead (4,508)	Window count only	1	785	112	0.14	565	1,005	15%	11%	18%
		7	645	98	0.15	453	838	13%	9%	16%
		14	512	87	0.17	341	682	10%	7%	13%
	Observer ID then window count	1	502	99	0.20	308	695	10%	6%	13%
		7	468	97	0.21	279	657	9%	6%	13%
		14	427	93	0.22	244	609	9%	5%	12%
	Mean		557			365	748	11%	7%	14%

* Percent potential escapement = estimate / (estimate + escapement) x 100

Appendix E. Estimated California sea lion predation on salmonids at Willamette Falls by run, 2016. These estimates only apply to the sampling frame for 2016 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Escapement over falls	Run assignment model	Pooled lag-days	Estimated predation (means from 1000 simulations)					% of potential escapement*		
			Total	SE	CV	95% CI LB	95% CI UB	Total	95% CI LB	95% CI UB
Marked spring Chinook salmon (23,686)	Window count only	1	1,852	232	0.13	1,398	2,306	7%	6%	9%
		7	1,975	227	0.11	1,530	2,419	8%	6%	9%
		14	2,013	231	0.11	1,560	2,466	8%	6%	9%
	Observer ID then window count	1	2,527	288	0.11	1,962	3,093	10%	8%	12%
		7	2,560	282	0.11	2,008	3,112	10%	8%	12%
		14	2,586	289	0.11	2,019	3,153	10%	8%	12%
	Mean		2,252			1,746	2,758	9%	7%	10%
Unmarked spring Chinook salmon (6,631)	Window count only	1	543	101	0.19	345	740	8%	5%	10%
		7	579	100	0.17	384	774	8%	5%	10%
		14	574	100	0.18	377	771	8%	5%	10%
	Observer ID then window count	1	732	123	0.17	490	973	10%	7%	13%
		7	751	120	0.16	515	986	10%	7%	13%
		14	719	114	0.16	495	943	10%	7%	12%
	Mean		650			434	865	9%	6%	12%
Summer steelhead (21,732)	Window count only	1	1,076	144	0.13	793	1,358	5%	4%	6%
		7	1,052	144	0.14	770	1,334	5%	3%	6%
		14	1,137	150	0.13	843	1,432	5%	4%	6%
	Observer ID then window count	1	421	79	0.19	266	575	2%	1%	3%
		7	433	82	0.19	273	593	2%	1%	3%
		14	487	87	0.18	316	657	2%	1%	3%
	Mean		768			544	992	3%	2%	4%
Winter steelhead (5,778)	Window count only	1	1,114	150	0.13	820	1,408	16%	12%	20%
		7	979	152	0.16	680	1,277	14%	11%	18%
		14	860	136	0.16	593	1,128	13%	9%	16%
	Observer ID then window count	1	905	143	0.16	625	1,184	14%	10%	17%
		7	841	143	0.17	561	1,121	13%	9%	16%
		14	793	136	0.17	526	1,060	12%	8%	15%
	Mean		915			634	1,196	14%	10%	17%

* Percent potential escapement = estimate / (estimate + escapement) x 100

Appendix F. Estimated California sea lion predation on salmonids at Willamette Falls by run, 2017. These estimates only apply to the sampling frame for 2017 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Escapement over falls	Run assignment model	Pooled lag-days	Estimated predation (means from 1000 simulations)					% of potential escapement*		
			Total	SE	CV	95% CI LB	95% CI UB	Total	95% CI LB	95% CI UB
Marked spring Chinook salmon (28,281)	Window count only	1	1724	358	0.21	1022	2426	6%	3%	8%
		7	1757	360	0.20	1052	2462	6%	4%	8%
		14	1885	402	0.21	1098	2672	6%	4%	9%
	Observer ID then window count	1	1814	394	0.22	1042	2586	6%	4%	8%
		7	1870	402	0.22	1081	2658	6%	4%	9%
		14	1893	414	0.22	1082	2705	6%	4%	9%
	Mean		1824			1063	2585	6%	4%	8%
Unmarked spring Chinook salmon (5,905)	Window count only	1	402	103	0.26	200	604	6%	3%	9%
		7	381	97	0.26	190	572	6%	3%	9%
		14	385	98	0.26	193	576	6%	3%	9%
	Observer ID then window count	1	445	116	0.26	218	671	7%	4%	10%
		7	398	106	0.27	190	606	6%	3%	9%
		14	383	100	0.26	188	579	6%	3%	9%
	Mean		399			196	601	6%	3%	9%
Summer steelhead (2,182)	Window count only	1	208	68	0.33	75	341	9%	3%	14%
		7	243	78	0.33	89	396	10%	4%	15%
		14	173	53	0.32	68	277	7%	3%	11%
	Observer ID then window count	1	134	47	0.36	41	227	6%	2%	9%
		7	163	48	0.30	68	257	7%	3%	11%
		14	166	50	0.30	68	264	7%	3%	11%
	Mean		181			68	294	8%	3%	12%
Winter steelhead (822)	Window count only	1	339	78	0.23	186	493	29%	18%	37%
		7	293	73	0.25	150	435	26%	15%	35%
		14	231	55	0.24	122	339	22%	13%	29%
	Observer ID then window count	1	281	55	0.20	172	389	25%	17%	32%
		7	243	57	0.24	131	355	23%	14%	30%
		14	231	56	0.24	122	340	22%	13%	29%
	Mean		270			147	392	25%	15%	32%

* Percent potential escapement = estimate / (estimate + escapement) x 100

Appendix G. Estimated California sea lion predation on salmonids at Willamette Falls by run, 2018. These estimates only apply to the sampling frame for 2018 depicted in Figure 2 and therefore are likely minimum estimates due to undercoverage of the target population.

Escapement over falls	Run assignment model	Pooled lag-days	Estimated predation (means from 1000 simulations)					% of potential escapement*		
			Total	SE	CV	95% CI LB	95% CI UB	Total	95% CI LB	95% CI UB
Marked spring Chinook salmon (19,530)	Window count only	1	1834	166	0.09	1508	2160	9%	7%	10%
		7	1954	168	0.09	1624	2283	9%	8%	10%
		14	1944	168	0.09	1615	2273	9%	8%	10%
	Observer ID then window count	1	1939	192	0.10	1562	2315	9%	7%	11%
		7	2012	201	0.10	1618	2405	9%	8%	11%
		14	2016	199	0.10	1626	2407	9%	8%	11%
	Mean		1950			1592	2307	9%	8%	11%
Unmarked spring Chinook salmon (5,013)	Window count only	1	486	84	0.17	322	651	9%	6%	11%
		7	436	75	0.17	289	584	8%	5%	10%
		14	425	74	0.18	279	570	8%	5%	10%
	Observer ID then window count	1	536	92	0.17	355	718	10%	7%	13%
		7	465	81	0.18	307	623	8%	6%	11%
		14	448	80	0.18	292	605	8%	5%	11%
	Mean		466			307	625	9%	6%	11%
Summer steelhead (9,277)	Window count only	1	546	86	0.16	377	715	6%	4%	8%
		7	512	81	0.16	354	670	6%	4%	7%
		14	557	85	0.15	390	724	6%	4%	8%
	Observer ID then window count	1	483	96	0.20	295	670	5%	3%	7%
		7	486	94	0.19	302	671	5%	3%	7%
		14	510	95	0.19	324	697	5%	3%	8%
	Mean		516			340	691	6%	4%	7%
Winter steelhead (1,829)	Window count only	1	568	80	0.14	412	724	24%	18%	28%
		7	533	81	0.15	374	692	23%	17%	27%
		14	509	77	0.15	359	659	22%	16%	26%
	Observer ID then window count	1	477	73	0.15	333	621	21%	15%	25%
		7	471	78	0.16	319	624	20%	15%	25%
		14	460	76	0.17	310	609	20%	15%	25%
	Mean		503			351	655	22%	16%	26%

* Percent potential escapement = estimate / (estimate + escapement) x 100