ANNUAL REPORT:
PINNIPED MONITORING AT WILLAMETTE FALLS, 2019-2020

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Photo: C. Owen

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INTRODUCTION

The Marine Mammal Protection Act (MMPA) of 1972 provides federal protection to 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winter steelhead and spring Chinook salmon attempting to pass the Falls (Oregon Department of Fish and Wildlife [ODFW], unpublished data).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 (NMFS 2018). This report summarizes the second year of monitoring under that authority and the seventh consecutive year overall.

METHODS

Study area

The study area was located from Willamette Falls on the Willamette River down to the mouth of the Clackamas River, although formal observations were only conducted in the immediate vicinity of the falls (sites 1-6; Figure 1). The falls are located approximately 42 km (26 mi) upriver from the confluence with the Columbia River and approximately 206 km (128 mi) from the ocean. It is the second largest waterfall in the United States by volume after 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, although their numbers and duration of occurrence are declining due to the success of recent management actions. California sea lions in Oregon belong to the U.S. stock for which the most recent (2014) estimate was approximately 257,606 animals (minimum population size estimate = 233,515 individuals) (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 and in increasing numbers 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 (2015) estimate 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 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 (hatchery) and unmarked (wild) 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 and summer 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 counts

We estimated pinniped abundance in the study area based on a combination of direct observations throughout the study area as well as imagery from automated time-lapse cameras at the Sportcraft Landing haulout area (Figure 1). During formal observations at Willamette Falls (i.e., sites 1-6, Figure 1), observers recorded the number and species of pinnipeds in their viewing area at the beginning of each observation bout as well as any identifying marks such as brands. Automated cameras at the haulout area took pictures approximately every hour, 24 hours a day, and 7 days a week. 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. For the fall and early winter period before formal observations began we only used camera counts to estimate weekly abundance. Daily maximum count data were smoothed using local weighted regression (loess).

In addition to conducting pinniped counts immediately below Willamette Falls, we also conducted periodic boat-based surveys of the Willamette River in order to determine how much pinniped activity we might be potentially missing below the formal study area. Surveys were typically conducted in a single 24-ft closed cabin boat travelling downstream at approximately 5 knots with a minimum of two staff per survey. Surveys began in Oregon City below Willamette Falls and proceeded downriver, typically to the confluence with the Columbia River (42 km; 26 mi). Staff recorded the number, behavior, and location of each species of pinnipeds observed, which were also photographed when possible. Observations were generally only recorded while traveling downriver since the upriver return trip was made at higher speeds.

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 weekends/holidays, 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 2016-2019 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 PST (8.5 hours) in January to 0600-1900 PDT (13 hours) in May (Figure 2).

There were 1,329 half-hour observation units (i.e., elements) in the sample out of a sampling frame of 19,710 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.

Additional activities

The predation monitoring design in 2020 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

River conditions

River height and temperature near Willamette Falls are summarized in Figure 3. The most notable hydrologic events during the study included water levels nearly reaching action stage in late January followed by relatively low water levels the remainder of the season.

Salmonid fishway passage

Salmonid passage and run composition over Willamette Falls is summarized in Figures 4 and 5, respectively. ESA-listed winter steelhead and unmarked spring Chinook salmon both had their second highest levels of escapement thus far over the past seven years of sea lion monitoring. Fish passage was comprised almost entirely of winter steelhead during the first three months of the study before switching over to almost entirely spring Chinook salmon. Summer steelhead continued to be well below their long term average.

Pinniped counts

Pinniped counts based on automated cameras and incidental observations by staff at the Sportcraft haulout area began the last week of August 2019 and continued through early June 2020 when all of the sea lions had migrated out of the study area. Counts based on formal observations at Willamette Falls began the second week of January 2020 and continued through the last week of May 2020. Boat-based river surveys began late November 2019 and continued periodically through May 2020.

<u>California sea lions</u>—There were no confirmed sightings of California sea lions in the study area during the fall and winter of 2019, with the first confirmed sighting occurring on 3/9/2020 (Figure 6, top panel). California sea lion numbers were highest in April and May, with a maximum single-day count of eight individuals occurring on 4/19/2020, 4/27/2020, 4/30/2020, and 5/15/2020. The last sighting of a California sea lion in the study area occurred on 5/28/2020. Boat-based surveys of the Willamette River suggested that there was little or no missed California sea lion activity downriver of the study area (Figure 7).

Ten individually-identifiable California sea lions were documented at Willamette Falls in 2020 (three branded, seven with natural or temporary marks) (Appendix C). Of these ten, at least two were confirmed to have been present in the study area in previous years although it is possible some or all of the unbranded animals had been there before. It is very likely, however, that the two new branded animals (U902 and X520) were indeed new recruits to the area given that they were each branded at least three years earlier. The eight potentially new animals to Willamette Falls brings the 7-year cumulative total of identifiable animals at Willamette Falls to 85 (58 branded, 17 flipper-tagged, 10 naturally or temporarily marked).

Steller sea lions—The first confirmed sighting of a Steller sea lion in the study area occurred on 12/25/2019 (Figure 6, bottom panel). Steller sea lion numbers were highest in late December and early January, with a maximum single-day count of eight individuals occurring on 12/30/2019. The last sighting of a Steller sea lion in the study area occurred on 4/20/2020. In contrast to California sea lions, boat-based surveys of the Willamette River suggested that there was considerable Steller lion activity downriver of the study area, including during at least three weeks prior to their occurrence in the formal study area (Figures 6 and 7). The number of individually-identifiable Steller sea lions that have occurred at Willamette Falls remains seven (Appendix D), although adding this season's single day maximum of at least eight unmarked animals brings the cumulative project total to at least fifteen over the past seven years.

Predation

California sea lions—Observers documented 205 predation events by California sea lions during the 2020 field season (Table 1). This includes predation events seen at pre-assigned, probability-based sample units, as well as all anecdotal observations. Salmonids were the most frequently observed prey item (81%), followed by lamprey (16%), and other or unknown prey (3%). Based on the subset of these observations that occurred during probability sampling, we estimated that a total of 702 salmonids were consumed by California sea lions across the sampling frame (Table 2). Partitioning this total to run based on Monte Carlo modeling, we estimated that California sea lions consumed 22 winter steelhead (0.4% of potential escapement), 34 summer steelhead (0.7% of potential escapement), 151 unmarked spring Chinook salmon (1.7% of potential escapement above falls), and 495 marked spring Chinook salmon (1.9% of potential escapement) (Table 3).

Steller sea lions—Observers documented 54 predation events by Steller sea lions during the 2020 field season (Table 1). This includes predation events seen at pre-assigned, probability-based sample units, as well as all anecdotal observations. Sturgeon were the most frequently observed prey item (50%), followed by salmonids (26%), and other or unknown prey (24%). Based on the subset of these observations that occurred during probability sampling, we estimated that a total of 75 salmonids were consumed by Steller sea lions across the sampling frame (Table 2). This estimate was highly uncertain, however, due to the low number of observed events in the frame and we therefore did not further partition the total into run-specific estimates.

DISCUSSION

The predation estimates presented in this report (i.e., Tables 2 and 3) are based solely on 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 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 formal 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 during the 2018-2019 season (see Steingass et al. 2019) continued to result in substantial decreases in predator abundance (Figure 6) and associated salmonid predation (Figure 8) compared to pre-management years. However, since there was no California sea lion management during the 2019-2020 season due to safety concerns related to the COVID-19 pandemic, this necessarily resulted in a setback in our efforts to eliminate sea lion predation on listed salmonids in the Willamette River. Nonetheless, management efforts thus far have proven to be successful. For example, there was no recruitment of new California sea lions into the "fall/winter" cohort which that had been entirely removed the previous year. As a result, nearly two-thirds of the entire listed winter steelhead run was able to pass the falls before the first California sea lion arrived.

While winter steelhead predation by California sea lions was nearly eliminated, some winter steelhead were likely lost to Steller sea lions during the peak in their abundance in December and January. However, since Steller sea lions primarily forage downstream of the falls, their predation activity remains largely uncaptured by the sampling design (see Figures 1 and 7). And while for the time being their preferred prey still appears to be white sturgeon, they may switch to salmonids, perhaps after depleting the local sturgeon population, as has been documented at Bonneville Dam (e.g., see Tidwell et al. 2019).

At the time of this writing, and with the start of the 2020-2021 season already underway, there have been no confirmed sightings of either California sea lions or Steller sea lions at Willamette Falls or in the Willamette River. As soon as either species occurs, however, management work will resume (under COVID-19 safety protocols), but this time under a new permit authorizing the intentional taking of both California Sea Lions and Steller Sea Lions on the waters of the Columbia River and its tributaries (NMFS 2020). And as a condition of the new permit we will continue our monitoring work for an eighth season beginning in January 2021.

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We also wish to acknowledge and congratulate three colleagues who retired in 2020 that have worked on salmon and sea lion issues in the Columbia River Basin for decades and for whom we owe a great debt of gratitude: Tom Murtagh (ODFW), Steve Jeffries (WDFW), and Bob DeLong (NMFS). And, more sadly, we note the passing of two long-time colleagues in 2020 who were also instrumental in salmon conservation and sea lion work in the Columbia River Basin: Bobby Begay (CRITFC) and Dan Heiner (PSMFC). For all five of these colleagues we can truly say that if we are successful in our work then it will be by building on the strong foundation that they have laid.

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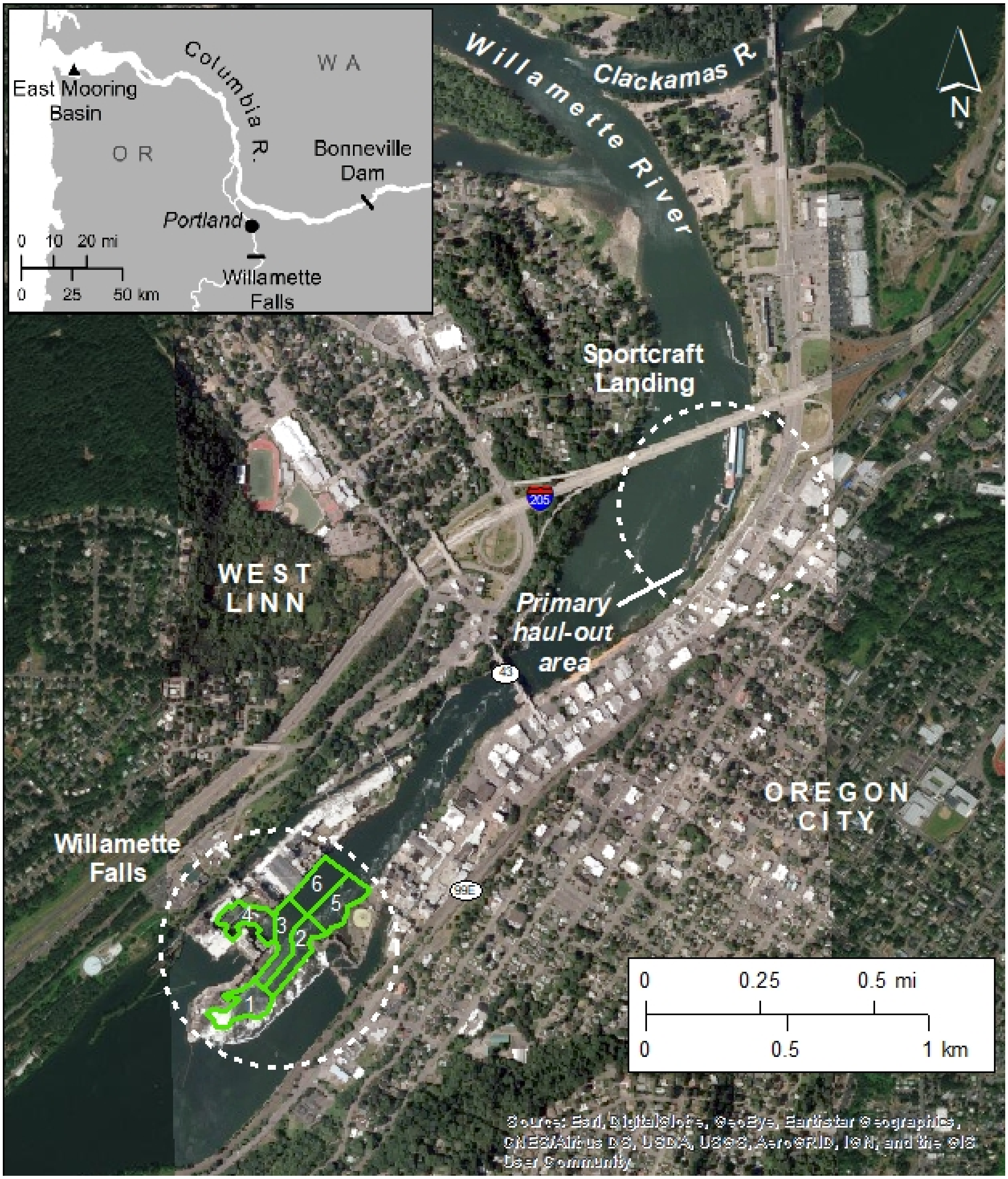


Figure 1. Illustration of the spatial component of the sampling frame for 2016-2020. Sites 1-6 ("Falls" stratum) were each approximately 0.9-ha in area.

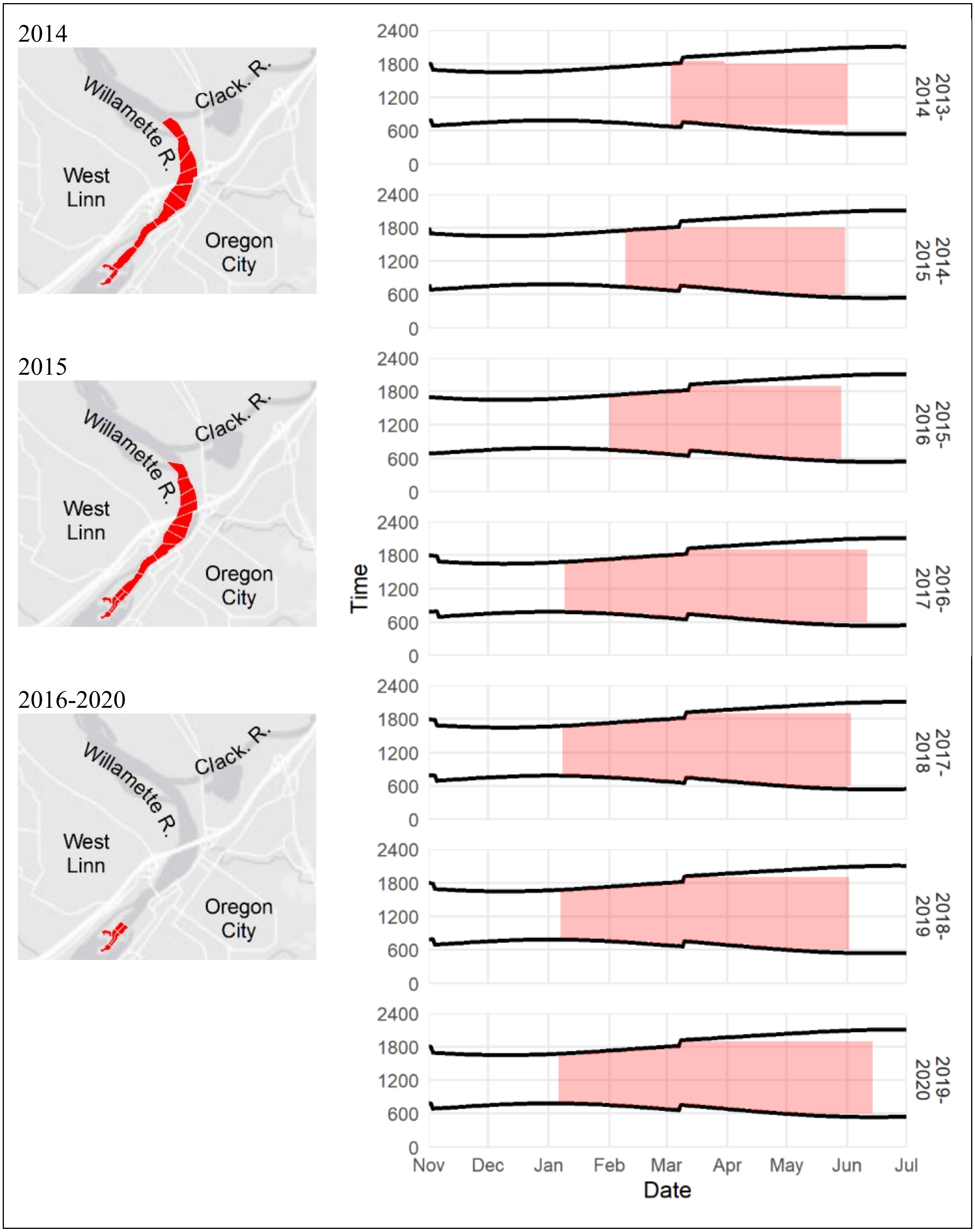


Figure 2. Illustration of the spatial (left) and temporal (right) coverage of the sampling frame by season. Red shaded areas depict time and area included in the sampling frame; dark black lines on the graph at right indicate sunrise and sunset, adjusted for daylight savings.

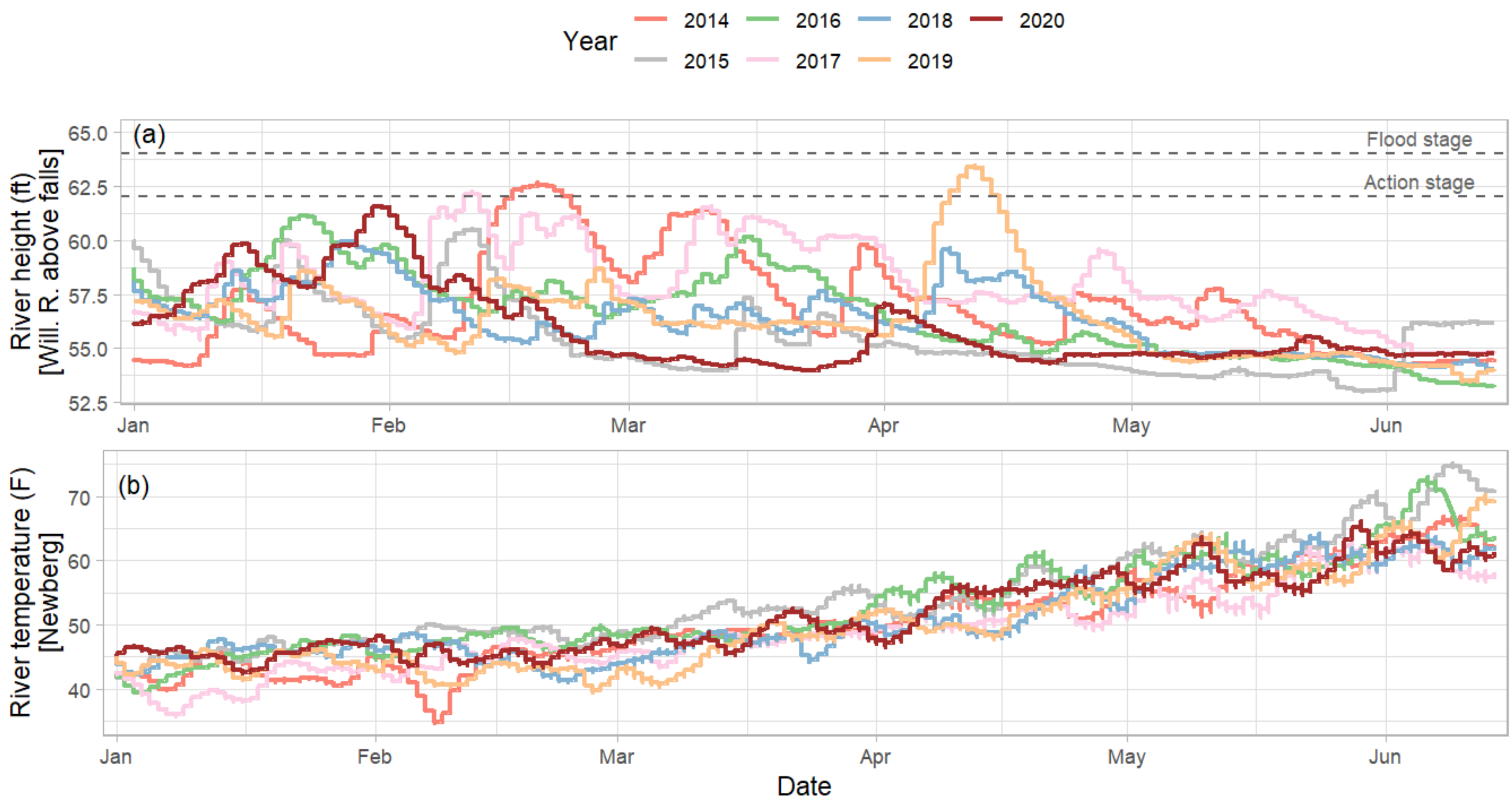


Figure 3. Height (a) and temperature (b) of the Willamette River upstream of Willamette Falls by year.

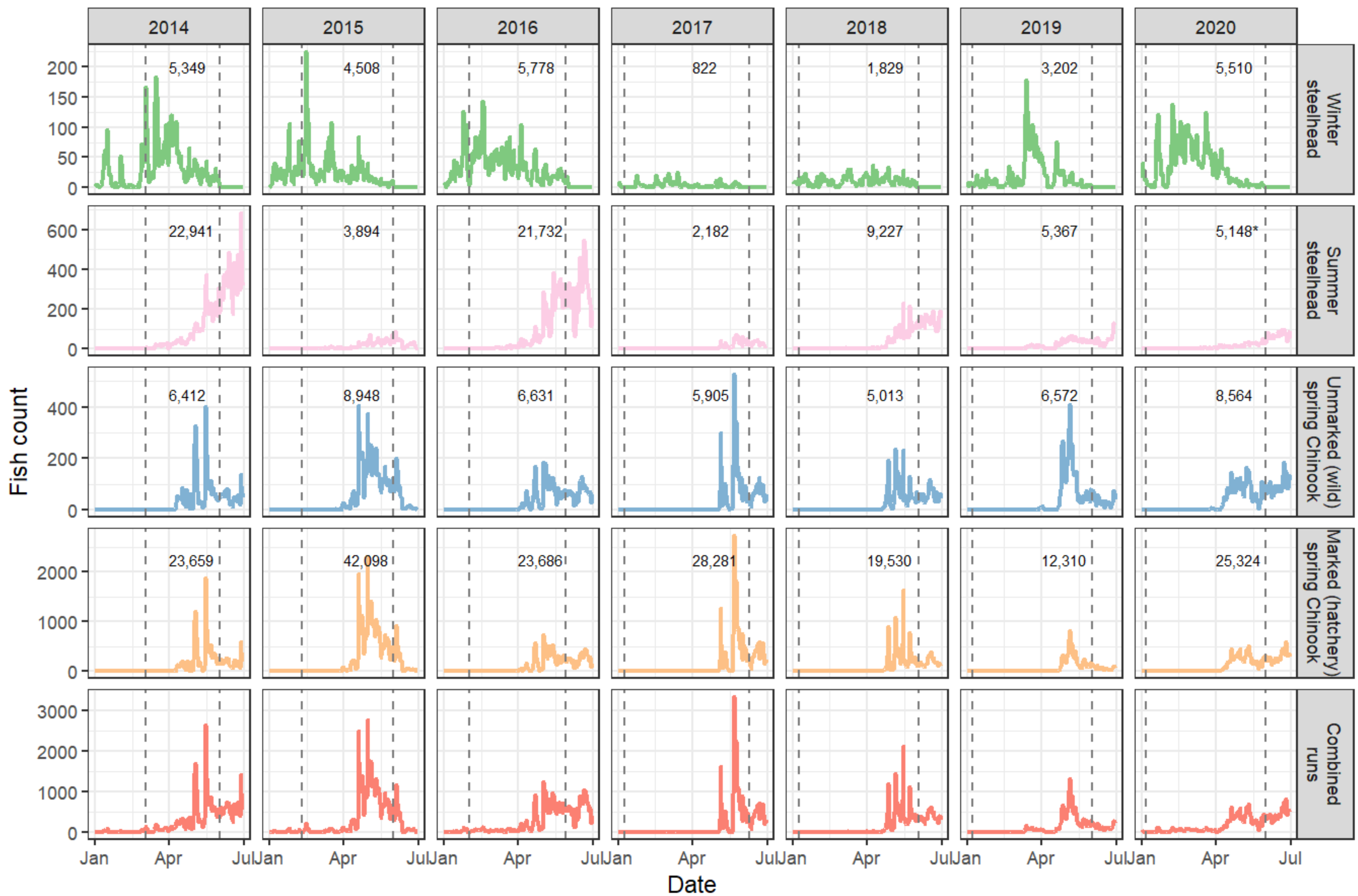


Figure 4. Daily fish counts at Willamette Falls by run and year. Vertical lines indicate study start and end dates; final escapement over falls is inset upper left of each graph. *Summer steelhead escapement through 9/27/2020.

Figure 5. Daily passage composition over Willamette Falls by year. Dashed lines indicate study dates. (Leap days not shown).

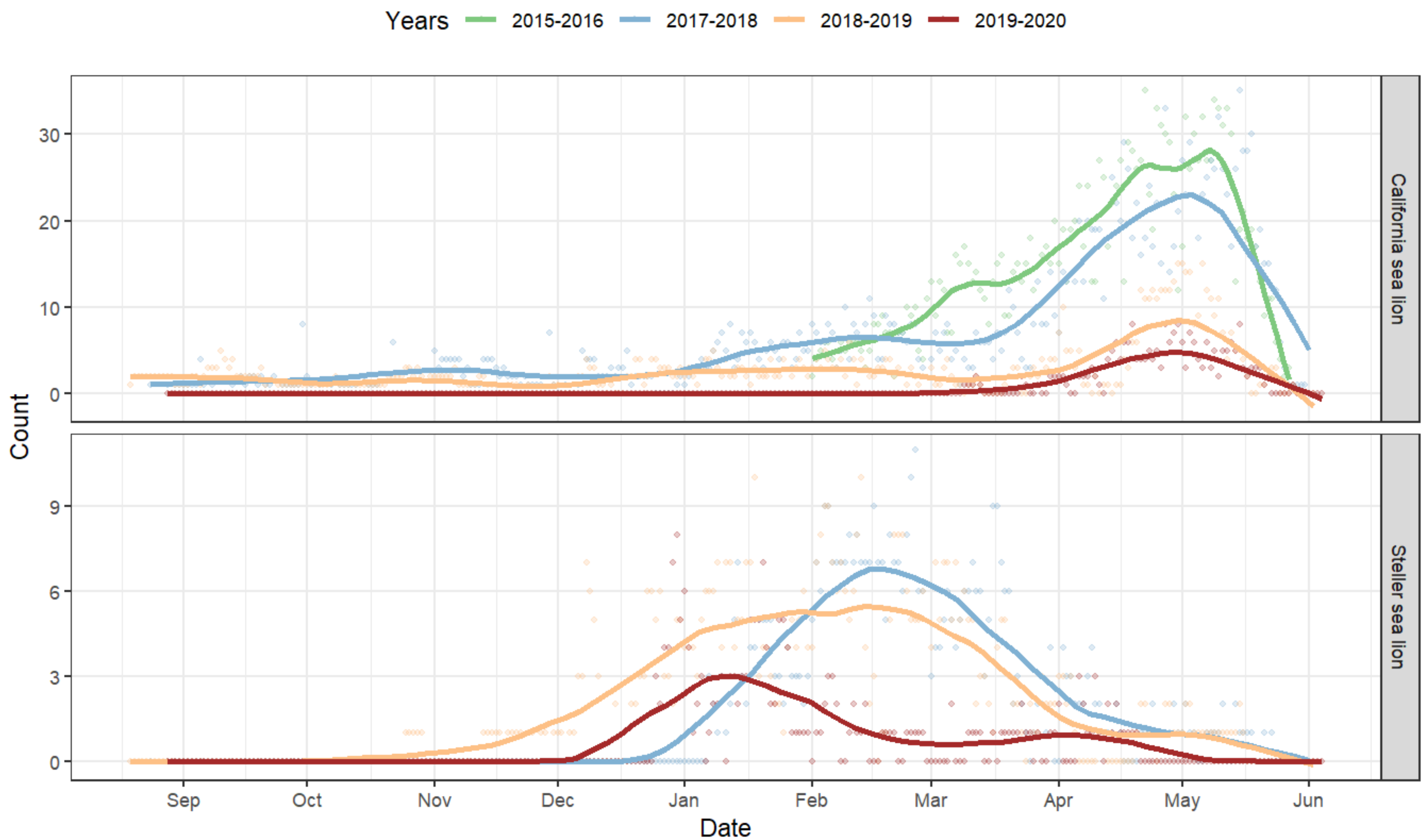
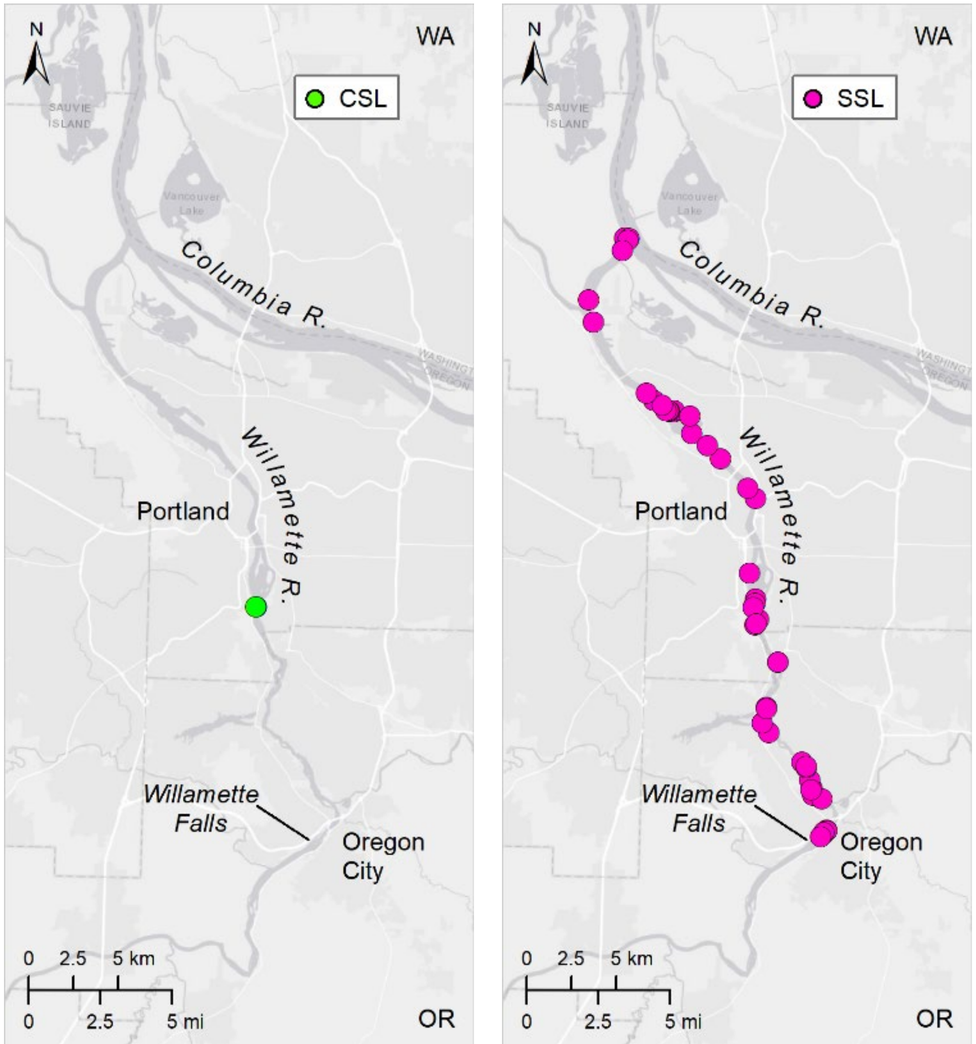


Figure 6. Local weighted regression (span = 0.2, degree = 1) of daily counts of California sea lions (top) and Steller sea lions (bottom) below Willamette Falls by date and year.



Date	Survey		Count	
	Start	End	CSL	SSL
2019-11-20	Oregon City	Columbia River	0	0
2019-12-06*	Oregon City	Fremont Bridge	0	2
2019-12-11*	Oregon City	Fremont Bridge	0	7
2020-01-03*	Oregon City	St Johns Bridge	0	8
2020-01-14	Oregon City	Columbia River	0	6
2020-01-23	Oregon City	Columbia River	0	10
2020-02-06	Oregon City	Columbia River	0	7
2020-02-13	Oregon City	Columbia River	0	4
2020-02-20	Oregon City	Columbia River	0	2
2020-02-27	Oregon City	Columbia River	0	3
2020-03-05	Oregon City	Columbia River	0	6
2020-04-29	Oregon City	Columbia River	0	0
2020-05-27	Oregon City	Columbia River	2	1

*Sighting locations not available for these dates.

Figure 7. California sea lion (CSL) and Steller sea lion (SSL) sighting locations and counts from Willamette River boat surveys.

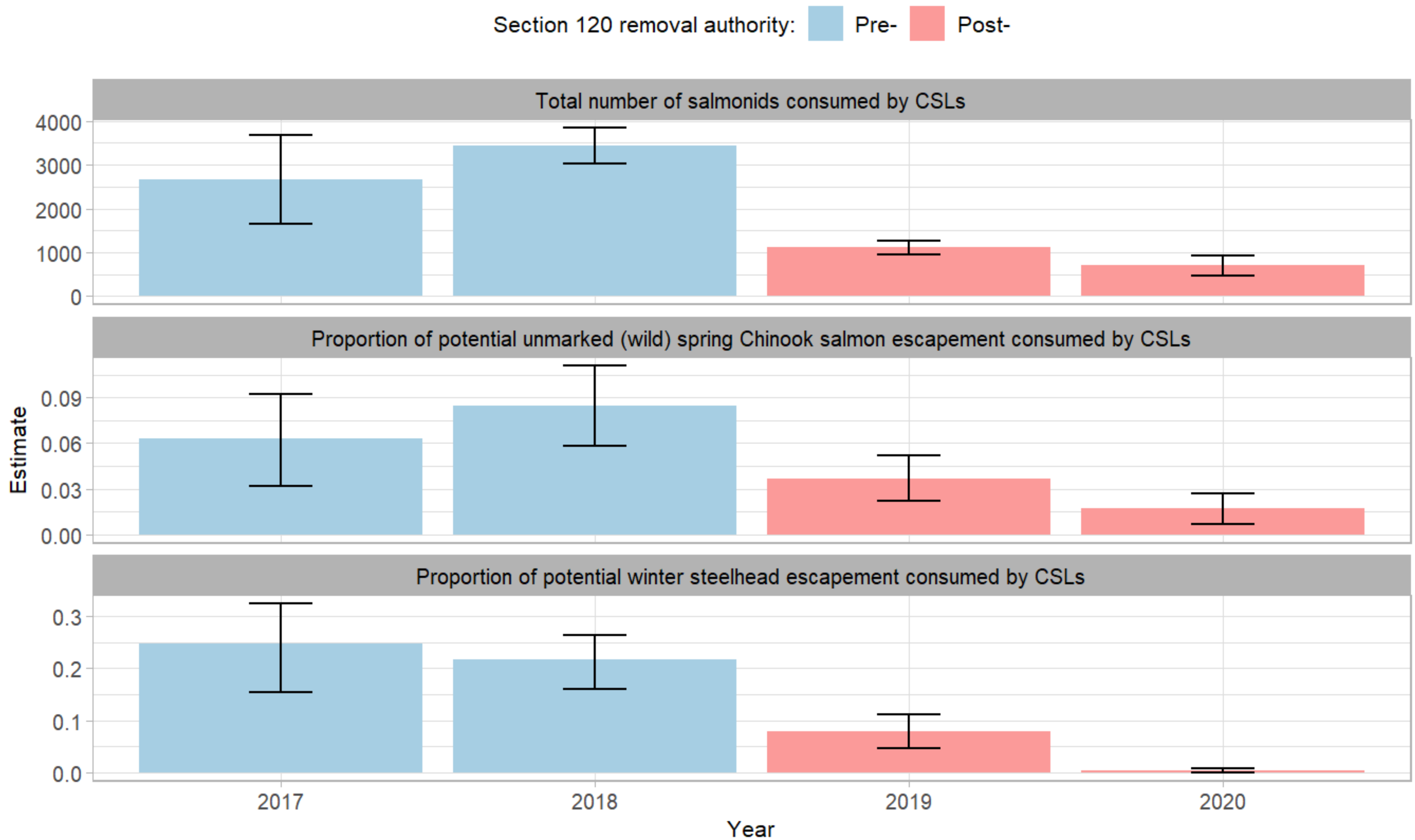


Figure 8. Comparison of estimated predation by California sea lions (CSLs) between years with and without MMPA Section 120 management authority; error bars indicate 95% confidence interval limits.

Table 1. Summary of all predation events observed at Willamette Falls (includes events from anecdotal observations outside sampling frame as well as those seen during probability-based sampling assignments). Sampling design varied from 2014-2016 and therefore only 2017-2020 are directly comparable (see Methods, Figure 2 and Appendix 1 for details).

	Observed California sea lion predation Total events (% by prey type within year)					Observed Steller sea lion predation Total events (% by prey type within year)				
Year	Salmonids	Lamprey	Sturgeon	Other/ unknown	Total	Salmonids	Lamprey	Sturgeon	Other/ unknown	Total
2014	959 (86.7%)	126 (11.4%)	3 (0.3%)	18 (1.6%)	1106	1 (25.0%)	0 (0%)	3 (75.0%)	0 (0%)	4
2015	1167 (85.3%)	175 (12.8%)	2 (0.1%)	24 (1.8%)	1368	2 (14.3%)	0 (0%)	12 (85.7%)	0 (0%)	14
2016	1001 (83.8%)	182 (15.2%)	0 (0%)	11 (0.9%)	1194	9 (52.9%)	0 (0%)	8 (47.1%)	0 (0%)	17
2017	753 (82.7%)	145 (15.9%)	0 (0%)	12 (1.3%)	910	1 (1.3%)	0 (0%)	69 (92.0%)	5 (6.7%)	75
2018	749 (86.3%)	108 (12.4%)	0 (0%)	11 (1.3%)	868	19 (18.3%)	4 (3.8%)	79 (76.0%)	2 (1.9%)	104
2019	250 (75.3%)	70 (21.1%)	0 (0%)	12 (3.6%)	332	25 (17.7%)	11 (7.8%)	98 (69.5%)	7 (5.0%)	141
2020	166 (81.0%)	32 (15.6%)	0 (0%)	7 (3.4%)	205	14 (25.9%)	0 (0%)	27 50.0%)	13 (24.1%)	54

Table 2. Estimated predation by California sea lions and Steller sea lions at Willamette Falls based on the probability sampling design. Sampling design varied from 2014-2016 and therefore only 2017-2020 are directly comparable (see Methods, Figure 2 and Appendix 1 for details). Estimates only apply to the sampling frames and therefore are likely minimum estimates due to undercoverage of the target population.

	Estimated California sea lion predation Total (95% CI)				Estimated Steller sea lion predation Total (95% CI)			
Year	Salmonids	Lamprey	Sturgeon	Other/ unknown	Salmonids	Lamprey	Sturgeon	Other/ unknown
2014	3690	493	19	20	0	0	37	0
	(3321-4059)	(361-624)	(0-54)	(2-37)	NA	NA	(0-108)	NA
2015	5775	758	0	106	0	0	34	0
	(5096-6455)	(531-984)	NA	(36-177)	NA	NA	(0-80)	NA
2016	4585	1254	0	45	15	0	15	0
	(3680-5490)	(696-1813)	NA	(0-111)	(0-43)	NA	(0-43)	NA
2017	2673	747	0	0	0	0	15	0
	(1658-3688)	(415-1078)	NA	NA	NA	NA	(0-43)	NA
2018	3435	687	0	0	75	15	194	0
	(3019-3850)	(515-859)	NA	NA	(22-127)	(0-43)	(28-360)	NA
2019	1120	508	0	0	90	45	60	0
	(963-1277)	(118-897)	NA	NA	(25-154)	(0-90)	(3-117)	NA
2020	702	134	0	30	75	0	60	30
	(479-924)	(37-232)	NA	(0-86)	(0-163)	NA	(10-109)	(0-86)

Table 3. Estimated run-specific salmonid predation by California sea lions at Willamette Falls based on the probability sampling design. Sampling design varied from 2014-2016 and therefore only 2017-2020 are directly comparable (see Methods, Figure 2 and Appendix 1 for details). Estimates only apply to the sampling frames and therefore are likely minimum estimates due to undercoverage of the target population. Percent potential escapement (%PE) = estimate / (estimate + escapement) x 100.

Year	Winter steelhead		Summer steelhead		Unmarked (wild) spring Chinook salmon		Marked (hatchery) spring Chinook salmon	
	Total (95% CI)	%PE (95% CI)	Total (95% CI)	%PE (95% CI)	Total (95% CI)	%PE (95% CI)	Total (95% CI)	%PE (95% CI)
2014	780 (563-998)	12.7% (9.5%-15.7%)	710 (499-922)	3% (2.1%-3.9%)	496 (349-643)	7.2% (5.2%-9.1%)	1704 (1413-1994)	6.7% (5.6%-7.8%)
2015	561 (370-752)	11.1% (7.6%-14.3%)	172 (74-270)	4.2% (1.9%-6.5%)	901 (668-1133)	9.1% (6.9%-11.2%)	4142 (3594-4689)	9% (7.9%-10%)
2016	916 (635-1196)	13.7% (9.9%-17.1%)	767 (543-990)	3.4% (2.4%-4.4%)	651 (436-866)	8.9% (6.2%-11.6%)	2252 (1744-2759)	8.7% (6.9%-10.4%)
2017	270 (148-392)	24.7% (15.3%-32.3%)	180 (68-291)	7.6% (3%-11.8%)	397 (196-599)	6.3% (3.2%-9.2%)	1826 (1064-2588)	6.1% (3.6%-8.4%)
2018	503 (351-655)	21.6% (16.1%-26.4%)	517 (341-694)	5.3% (3.5%-7%)	467 (308-627)	8.5% (5.8%-11.1%)	1947 (1589-2304)	9.1% (7.5%-10.6%)
2019	280 (156-405)	8% (4.6%-11.2%)	109 (32-186)	2% (0.6%-3.3%)	254 (149-358)	3.7% (2.2%-5.2%)	477 (345-608)	3.7% (2.7%-4.7%)
2020	22 (0-51)	0.4% (0%-0.9%)	34 (0-73)	0.7%* (0%-1.4%)*	151 (60-242)	1.7% (0.7%-2.7%)	495 (318-671)	1.9% (1.2%-2.6%)

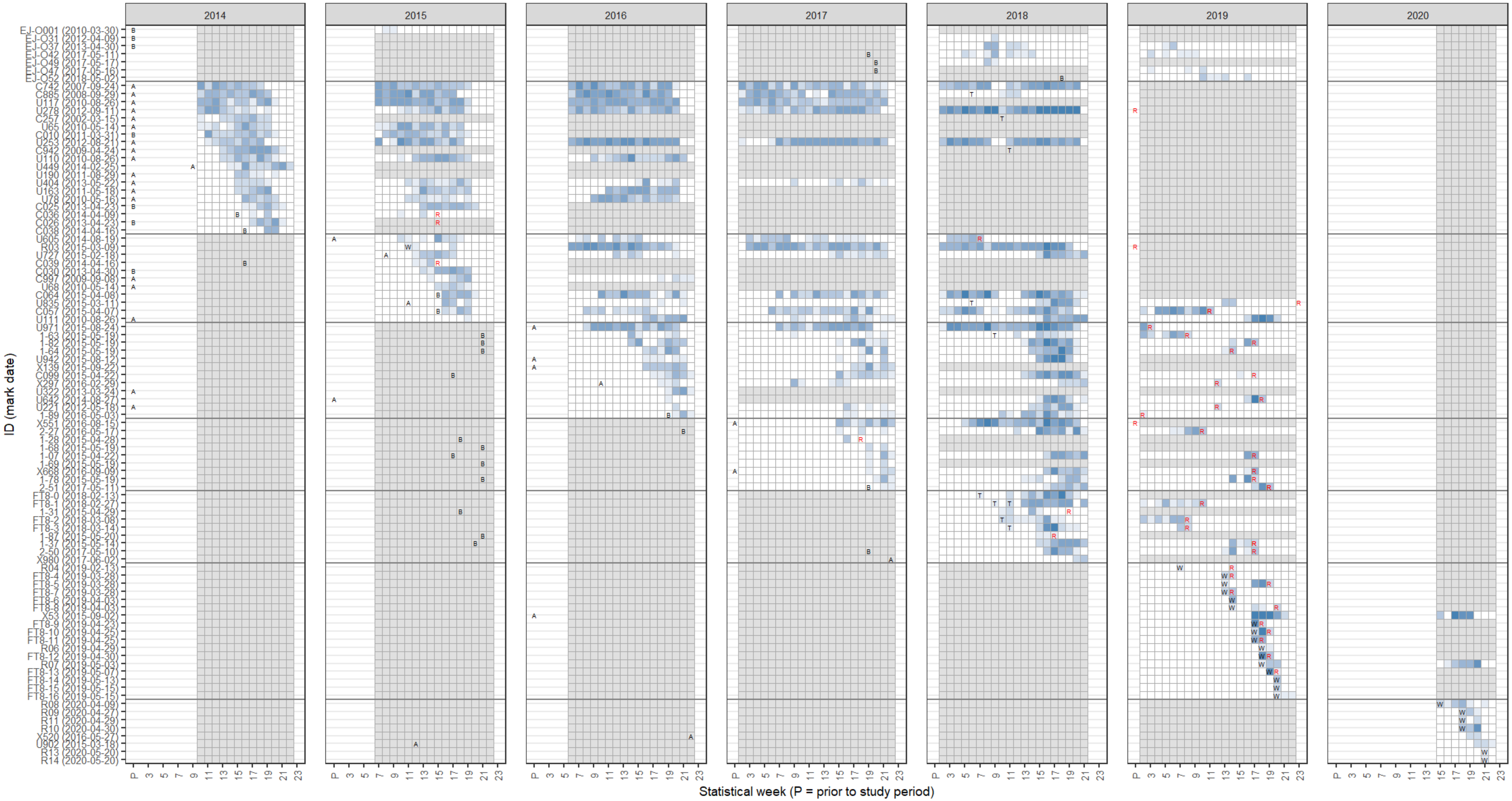
*Summer steelhead escapement through 9/27/2020.

Appendix A. Sampling design metadata describing the Willamette Falls sea lion monitoring program, 2014-2020.

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
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
		12	4							3,024				240	7.9%		24,024	1,895	
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
		16	4							4,032				240	6.0%		37,968	2,223	
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
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
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
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
2020	F	6	2	Jan 6 – May 31	21	1,642.5	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,710	1,329	11.08

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. Weekly occurrence of identifiable Steller sea lions and California sea lions at Willamette Falls. Data area sorted by year (column) and week of first detection (row). Steller sea lions are indicated by prefix 'EJ'. Cell color indicates relative frequency of detection (darker hue = more days detected). Cell letters indicate location where it was marked or otherwise first identified ('A'=Astoria, 'B'=Bonneville Dam, 'W'=Willamette Falls), whether it was permanently removed ('R'), and/or translocated ('T') to the coast.