WILLAMETTE FALLS
PINNIPED MONITORING PROJECT, 2018

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Oregon Department of Fish and Wildlife

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INTRODUCTION

The Marine Mammal Protection Act (MMPA) of 1972 provided protection for all marine mammals in U.S. waters. As one result, 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, thus meeting the conservation objective of the MMPA (Laake et al. 2018). Over this same period, many salmon and steelhead (*Onchorynchus* spp.) populations in the Pacific Northwest experienced significant declines in abundance and were subsequently listed as threatened or endangered under the Endangered Species Act (ESA). While pinniped predation was not the cause of these declines, in areas where salmonid abundance is low and California sea lion numbers are now high, increased predation levels can result in serious negative impacts to the survival and recovery of individual salmonid populations.

One such area 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sea lions foraging there for winter steelhead and spring Chinook salmon (Oregon Department of Fish and Wildlife [ODFW], unpublished data).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 (*Oncorhynchus 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. 2018). 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 had 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. 2017). Monitoring from 2014-2017 showed that California sea lion abundance had increased from the late 1990s and early 2000s and was continuing to increase annually. In addition, California sea lion predation had increased and had become particularly acute for threatened winter steelhead populations. Steller sea lions (*Eumatopias jubatus*) also began showing notable increases in abundance and residency duration starting in 2017. This report summarizes the continuation of these monitoring efforts in 2018.

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 species of pinnipeds are known to occur seasonally at Willamette Falls: California sea lions, Steller sea lions, and Pacific harbor seals (*Phoca vitualina*).

California sea lions—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). The stock is not listed as "endangered" or "threatened" under the ESA, nor as "depleted" or "strategic" under the MMPA (Caretta et al. 2017). California sea lions in the Pacific Northwest are seasonal migrants that arrive in August and depart in June of each year on way their 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, Laake et al. 2018, ODFW unpublished data; but see Maniscalco et al. 2004).

Steller sea lions— 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).

Harbor seals—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 (2013) of the total stock was 16,165 animals (Caretta et al. 2014). The stock is not listed as "endangered" or "threatened" under the ESA nor as "depleted" or "strategic" under the MMPA (Caretta et al. 2014).

Fish species accounts

Fish species preyed upon by pinnipeds at Willamette Falls include winter and summer steelhead, marked and unmarked spring Chinook salmon (*Oncorhynchus 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 Calapoolia 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 which 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 to run (e.g., winter/summer, unmarked/marked) based on passage date and the presence or absence of a hatchery fin clip.

Sampling design

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 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 with 10 x 42 binoculars. For each event, 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 2016-2017 studies but in contrast to the 2014-2015 studies which had sites spread over two strata (Figure 2). The reduction in spatial coverage was due to funding constraints which reduced staffing from four to two observers. 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 8 to 0600-1900 (13 hours) on June 3 (Figure 2).

There were 1,337 half-hour observation units (i.e., elements) in the sample out of a sampling frame of 19,842 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.

Assignment of salmonid predation events to run

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 (e.g., see Keefer et al. 2004).

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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 1000 times and the means were computed for run-specific total predation and associated measures of uncertainty. Predation relative to potential escapement was calculated for passage through October 31, 2018, which captures total escapement for all the runs. Rates were calculated as the estimated predation total divided by the sum of escapement and estimated predation.

Pinniped abundance estimation

It is generally not possible to obtain unbiased estimates of local pinniped population size due to sampling and detectability issues. We therefore estimated an index of abundance as follows. First, observers recorded the number and species of pinnipeds in their viewing area during their shift. Second, pictures of pinnipeds hauled out downriver 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. 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 could be highly variable.

Scat and spew analysis

We collected scat (fecal) and spew (vomitus) samples opportunistically prior to and throughout the study period from the haul out area at Sportcraft Landing (Figure 1). Samples were collected and processed following methodology described in Lance et al. (2001). Recovered hard parts were identified to lowest possible taxonomic level by comparing all identifiable prey remains (e.g., bones, otoliths, cartilaginous parts, lenses, teeth and cephalopod beaks) to a comparative reference collection.

Additional activities

The sampling design in 2018 was implemented using a crew of two staff, working eight hours a day, five days a week. 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 (e.g., data entry), conducting anecdotal observations (e.g., targeting sites with high predation rates or potential for interactions with the fishery), conducting haul-out counts, collecting scat, and photographing brands.

In addition, we installed two sea lion traps at the haul-out area at Sportcraft Landing which replaced a single small trap that had been tested the prior season. The objective of trapping during the 2018 season was to conduct feasibility tests to see if animals would use the traps and, if so, to capture, mark if necessary, and relocate them to the coast. In the event we captured animals that were authorized for permanent removal under the state's MMPA Section 120 from Bonneville Dam (see NMFS 2016b) those animals would be transferred for euthanizing or placement in permanent captivity. Trapping activities were independent of the monitoring activity but are presented here for completeness.

RESULTS

Salmonid abundance and river conditions

Salmonid passage and run composition over Willamette Falls is summarized in Figures 3 and 4, respectively. All four runs were relatively low compared with the previous four years of monitoring. River height and temperature near Willamette Falls is summarized in Figure 5. River height and temperature were variable but tended to be at or below-average for much of the season relative to the previous four years.

Pinniped abundance

While formal monitoring didn't start until early January 2018, California sea lions were observed returning to Willamette Falls following their fall migration starting as early as 8/24/2017. During the January-June monitoring period the single-day maximum count of California sea lions and Steller sea lions was 35 (on 5/15/2018) and 11 (on 2/26/2018), respectively (Figure 6).

A total of 36 identifiable California sea lions were documented at Willamette Falls in 2018, bringing the 5-year total to 60 identifiable California sea lions (55 branded, 4 flipper-tagged, 1 natural mark) (Figure 7). In addition, four branded Steller sea lions were observed this year, bringing the 5-year total to five, along with an unknown number of unmarked individuals of both species. Over half of all brands seen at Willamette Falls are of animals either branded at Bonneville Dam or observed there at least once.

Predation

Observers documented a total of 972 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 (79%), followed by lamprey (12%), sturgeon (8%), and unknown or other fish (1%). California sea lions accounted for 89% of the total observed predation events but Steller sea lions accounted for 100% of the observed sturgeon kills.

An estimated 3,435 salmonids were consumed by California sea lions within the sampling frame from January 8 to June 3, 2018 (Table 2). The only other prey for which sufficient observations were made for reliable estimation was lamprey, of which California sea lions consumed an

estimated 687 individuals within the sampling frame. Since these estimates only apply to the sampling frame depicted in Figure 2, they are minimum estimates due to spatial and temporal undercoverage 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: 1,950 marked spring Chinook salmon (9% of potential escapement above falls), 466 unmarked spring Chinook salmon (9% of potential escapement), 516 summer steelhead (6% of potential escapement), and 503 winter steelhead (22% of potential escapement). For comparison, run-specific estimates for 2014-2017 are included in Appendices C-F. 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 and GI tract analysis

We collected a total of seven scat and one GI tract from the Sportcraft Landing haul out area from 11/15/2017 to 3/8/2018 (Table 4). Prey remains recovered from these samples largely matched the results of the surface feeding observations. However, because both Steller sea lions and California sea lions used the haul-out throughout the season it was not possible to assign scat to a particular sea lion species.

Trapping

We captured 11 California sea lions from 2/7/2018 to 3/14/2018, although one animal was caught twice bringing the total to 12 capture events (Appendix G). With the exception of U605, all animals were transported and released within 24 hours at Lost Creek State Recreation Site on the Oregon coast (U605 was euthanized under our Bonneville Dam Section 120 authority). Four of the five animals that were unmarked at time of capture received uniquely numbered flipper tags whereas the fifth animal was released unmarked in order to reduce handling stress for that individual. All relocated sea lions returned to Willamette Falls in 3.4 to 30.2 days, although the latter is likely biased high due to the low detectability of flipper-tagged animals. The approximate "swim-distance" from the relocation site to Willamette Falls was 370 km (230 mi).

DISCUSSION

Design-based predation estimates (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. 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.).

The results of the past five years of pinniped abundance and predation monitoring at Willamette Falls shows that California sea lion predation on listed salmonids below the falls is significant. This conclusion was also recently reached by the Willamette Falls Pinniped-Fishery Interaction Task Force and NMFS in their consideration of the State of Oregon's MMPA Section 120 application for lethal removal of California sea lions at Willamette Falls (NMFS 2018). Continued monitoring during the implementation of that authority over the next five years will help determine whether removals are successful in reducing predation, thereby increasing the probability of survival for listed Willamette River salmonids.

ACKNOWLEDGMENTS

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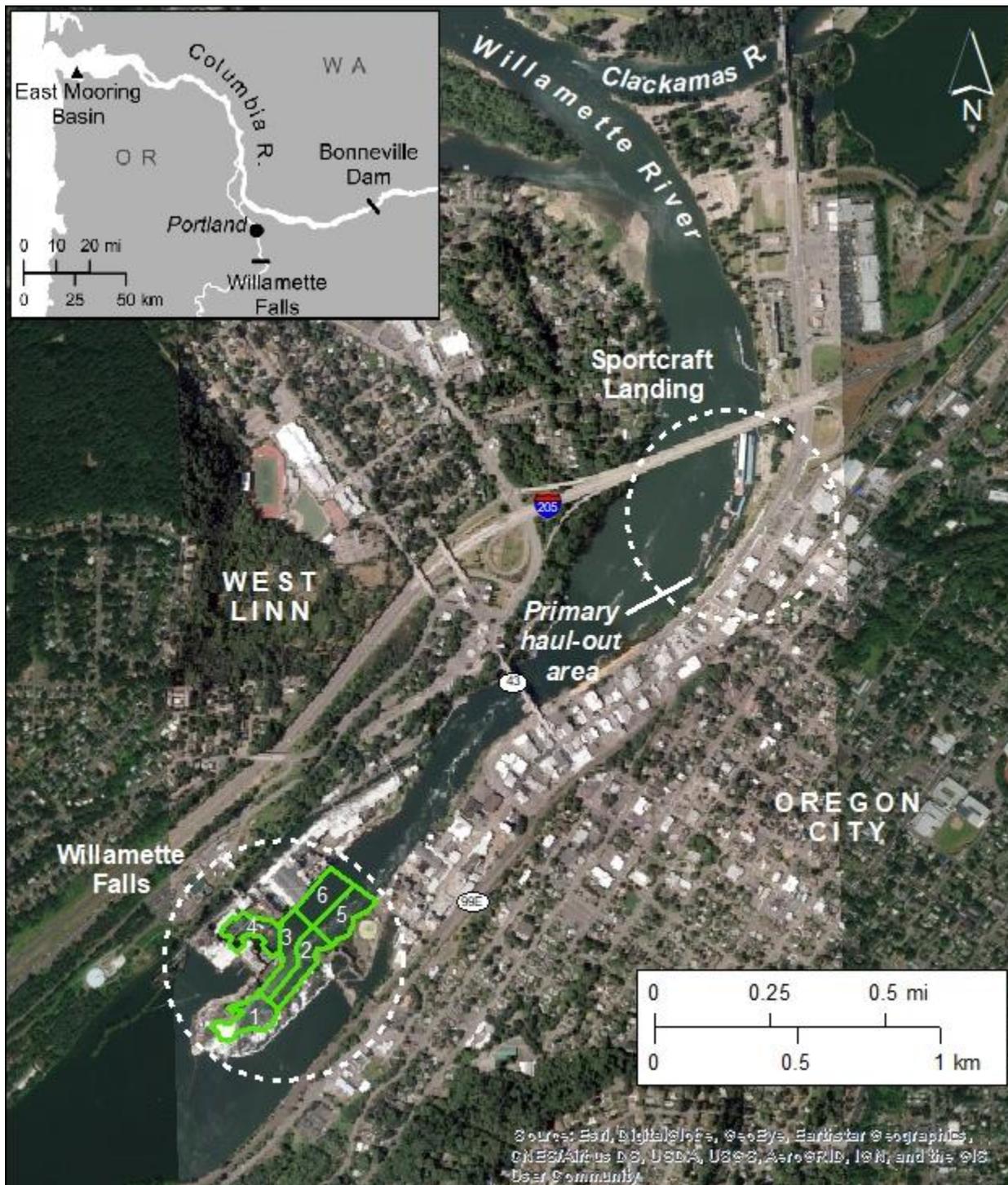
Figure 1. Illustration of the spatial component of the sampling frame for 2016-2018. Sites 1-6 ("Falls" stratum) were each approximately 0.9-ha in area.
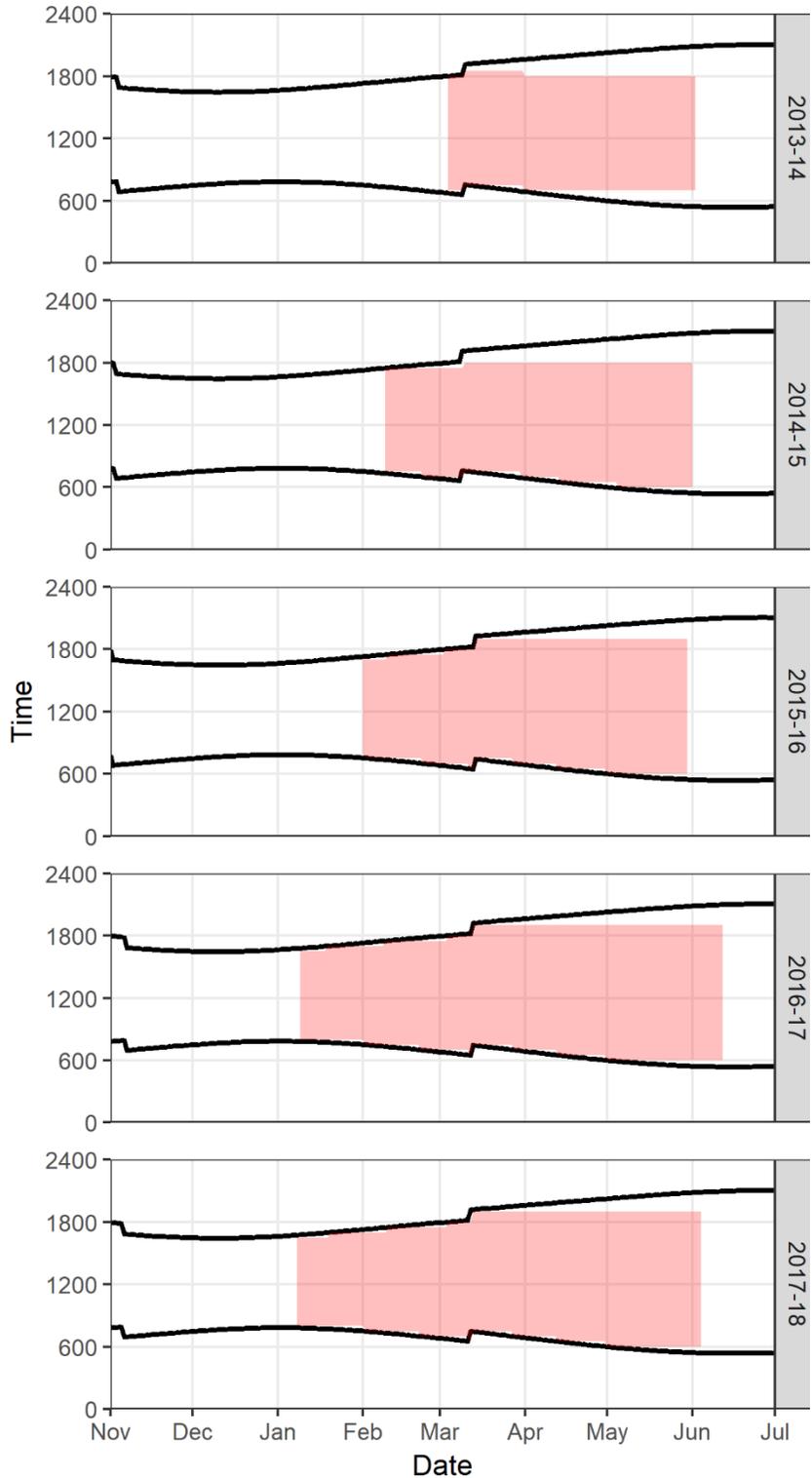
Figure 2. Illustration of spatial (left) and temporal (right) coverage of sampling frame by year. Red shaded areas depict time and area included in frame; dark black lines on the graph at right indicate sunrise and sunset, adjusted for daylight savings.

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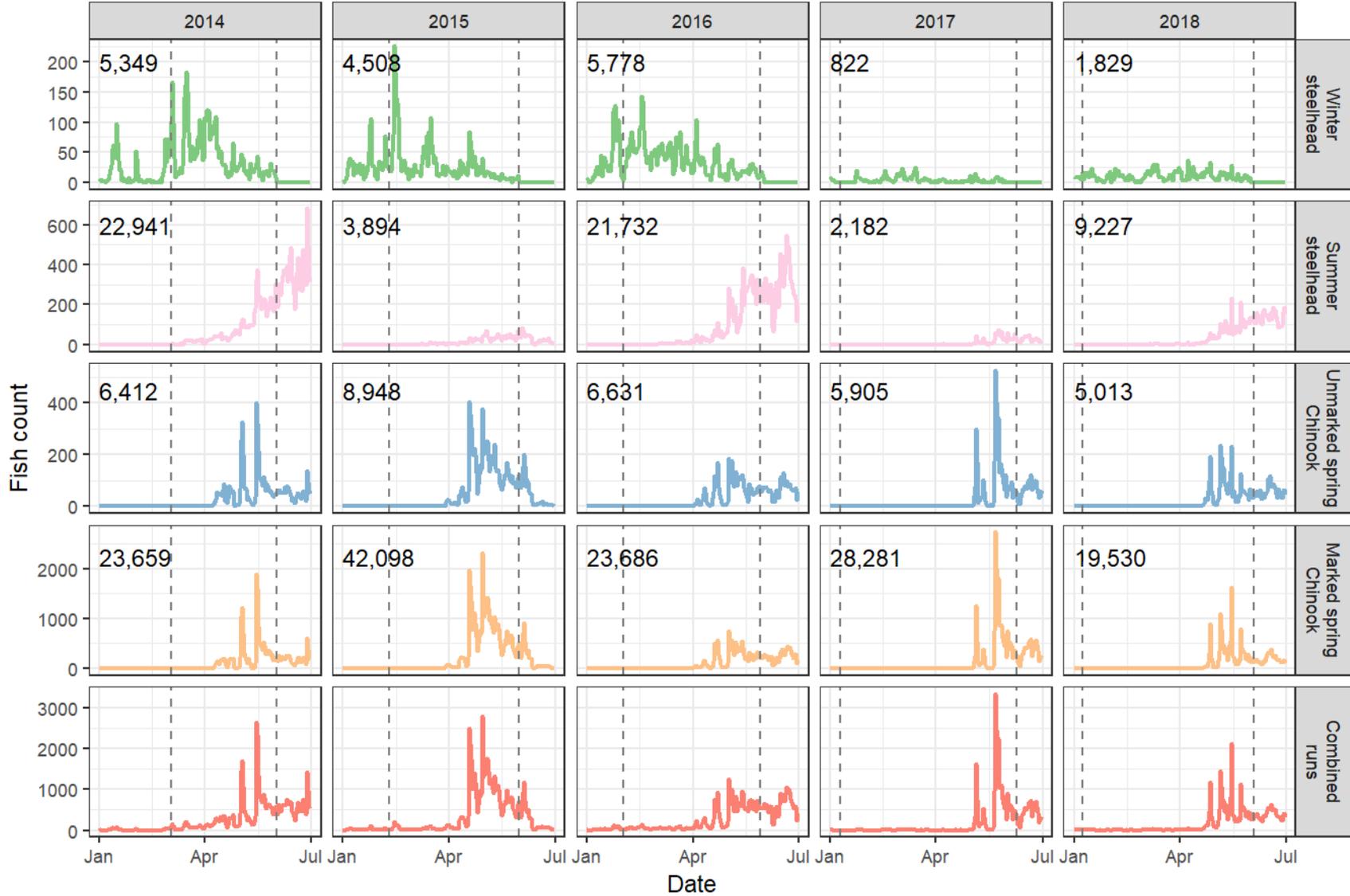
Figure 3. Daily fish counts at Willamette Falls by run and year. Vertical lines indicate study start and end dates; final run size is inset upper left of each graph.

Figure 4. Daily run composition at Willamette Falls by year. Dashed lines indicate study dates. (Leap day 2/29/2016 not shown).
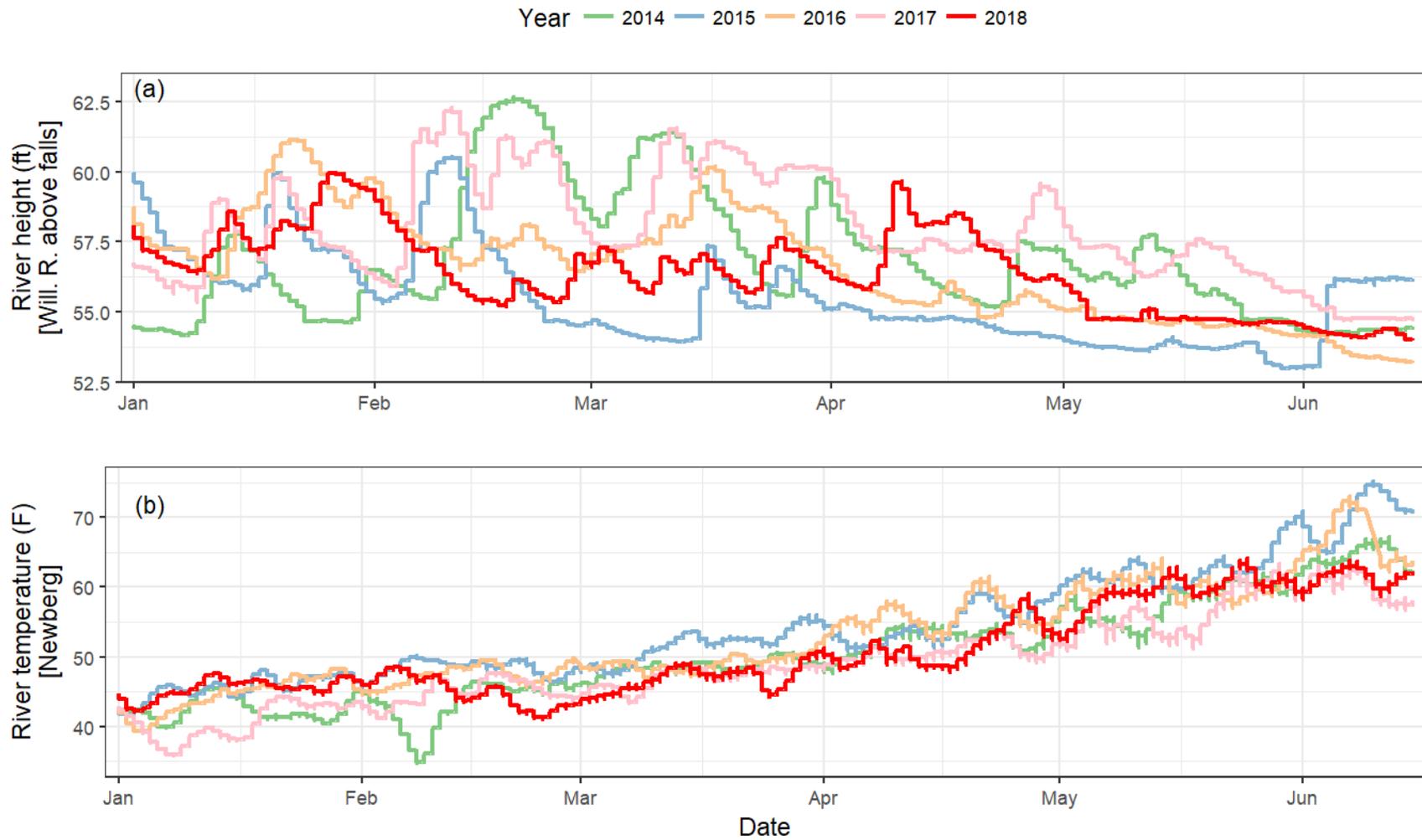
Figure 5. Willamette River height (a) and temperature (b) by date and year.
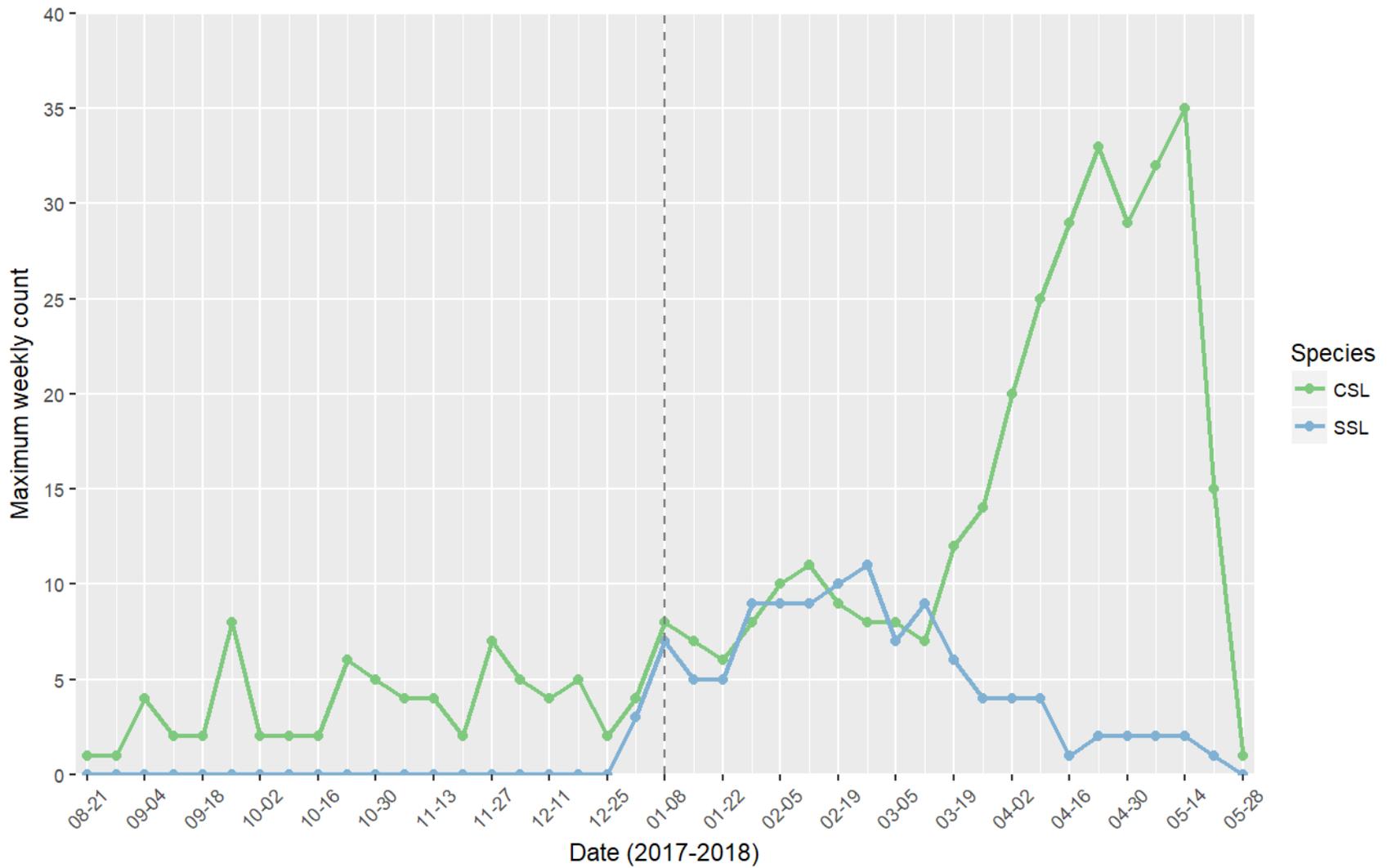
Figure 6. Maximum weekly counts of California sea lions (CSL) and Steller sea lions (SSL) below Willamette Falls, 2017-2018. Counts were plotted on the first day of each statistical week; dashed vertical line denotes start of the predation monitoring project.
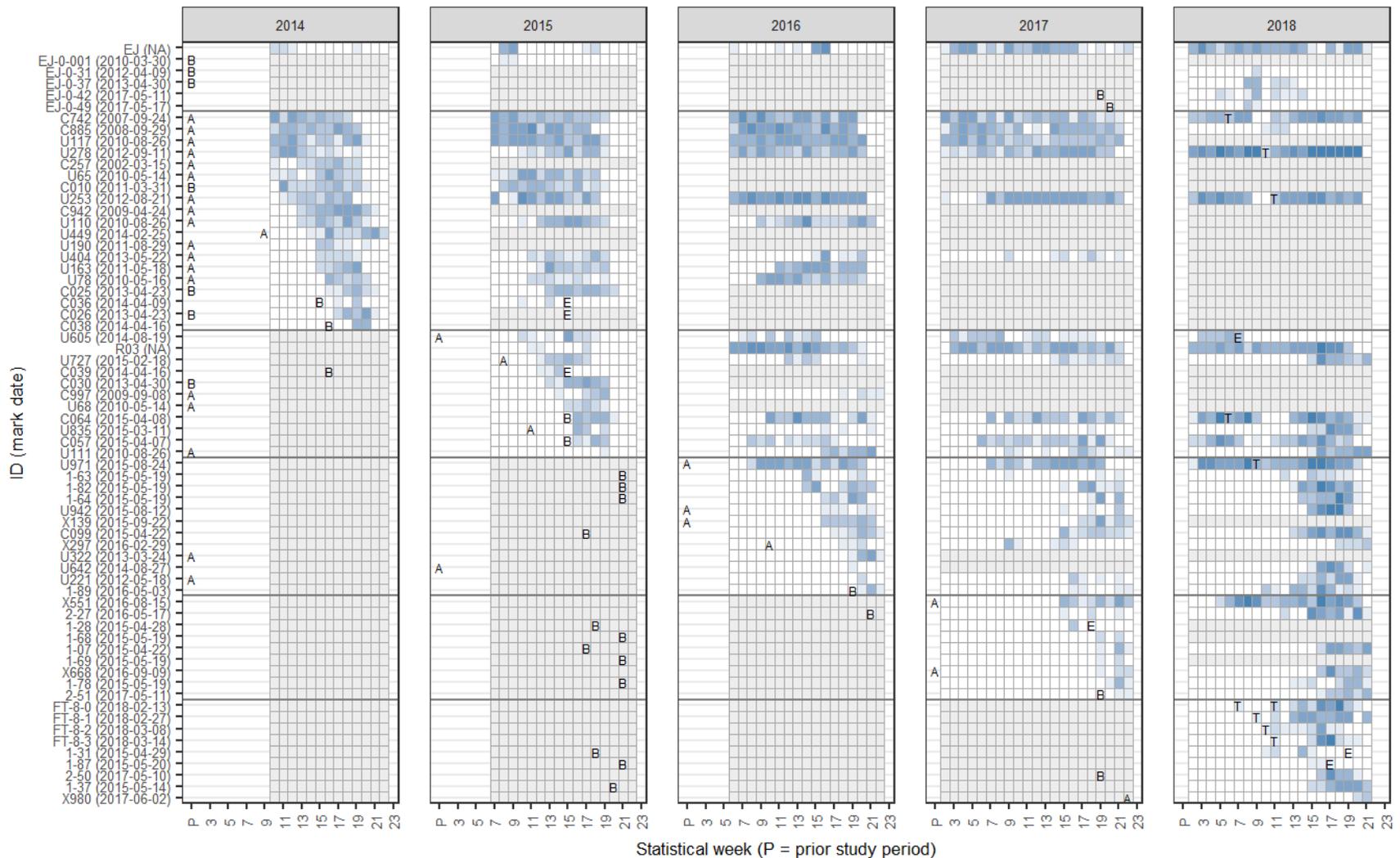
Figure 7. Weekly residency of Steller sea lions and California sea lions at Willamette Falls sorted by year (column) and week of first detection (row). Steller sea lions are indicated by prefix 'EJ' (with first row indicating presence only). Cell color indicates relative frequency of detection (darker hue = more days detected). Cell letters indicate location where it was branded ('A'=Astoria, 'B'=Bonneville), whether it was euthanized ('E') at Bonneville Dam, and/or whether it was translocated ('T') to the coast.

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Table 1. Summary of all predation events observed below Willamette Falls from January 8 to June 3, 2018. 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	394	10	404
Unknown salmonid	206*	8	214
Steelhead	149	1	150
Lamprey	108	4	112
Sturgeon	0	79	79
Unknown/other fish	11	2	13
Total	868	104	972

*Includes two anecdotal angler depredation events.

Table 2. Summary of estimated predation by California sea lions below Willamette Falls from January 8 to June 3, 2018 based on the three-stage cluster sampling design. 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.

Prey	Observed total	Estimated total	Standard error	Coefficient of variation	95% confidence interval	
					Lower bound	Upper bound
Salmonids	230	3435	212	0.06	3019	3851
Lamprey	6	687	88	0.13	515	859

Table 3. 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

Table 4. Dietary analysis of seven unknown sea lion scat samples and one California sea lion gastrointestinal (GI) tract sample collected at Sportcraft Landing from 11/15/2017-3/8/2018.

Date	Sample	Salmonid, adult	Salmonid, juvenile	Sturgeon	Pacific lamprey	Clupeidae	Cyprinidae
11/15/2017	1 scat	1					
11/29/2017	1 scat	1				1	
1/9/2018	1 scat	1	1				
1/30/2018	2 scat			2			
2/14/2018	1 GI*	1	2				
2/27/2018	1 scat		1	1			1
3/8/2018	1 scat	1			1		

* CSL U605 was captured at Sportcraft Landing but euthanized under MMPA Section 120 authority at Bonneville Dam.

Appendix A. Design data describing the Willamette Falls sea lion monitoring program, 2014-2018.

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	1653.5	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,842	1,337	11.14	NA

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, confidence interval, 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	SE	CV
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	SE	CV
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	SE	CV
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	SE	CV
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. Summary of California sea lion capture events from Willamette Falls, 2018. With the exception of U605, all animals were released at Lost Creek State Recreation Site on the Oregon coast, approximately 370 km (230 mi) from Willamette Falls; U605 was euthanized under MMPA Section 120 authority at Bonneville Dam.

Capture date	CSL ID*	Return time (days)	Note
2018-02-07	C742	3.4	
2018-02-08	C064	5.0	
2018-02-13	NA → FT 8-0	28.3**	
2018-02-14	U605	-	Euthanized
2018-02-27	NA → FT 8-1	11.9**	
2018-02-28	U971	5.0	
2018-03-05	U278	6.0	
2018-03-06	NA → FT 8-2	4.9**	
2018-03-08	NA → NA	NA	Did not mark
2018-03-13	U253	5.0	
2018-03-13	FT 8-0	15.1**	
2018-03-14	NA → FT 8-3	30.2**	

*Brand or flipper-tag (FT). NA denotes that the animal was unmarked at time of capture and/or release.

**Return times for flipper-tagged animals likely biased high due to low detectability of flipper tags relative to brands.