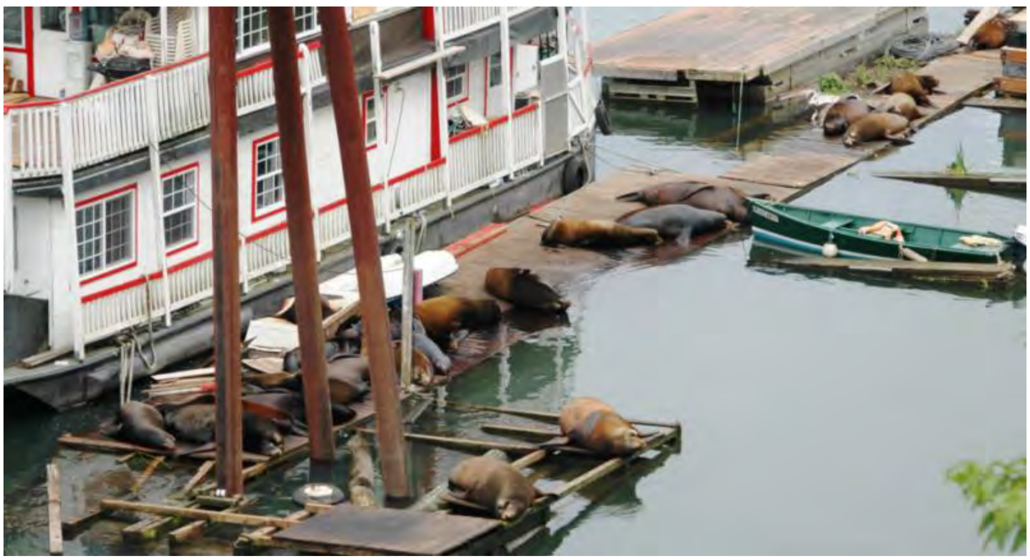
WILLAMETTE FALLS PINNIPED MONITORING PROJECT, 2016

October 20, 2016



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INTRODUCTION

California sea lions (*Zalophus californianus*) are seasonal migrants to the Pacific Northwest, generally arriving around August and departing by the following June. The majority of California sea lions in the Pacific Northwest are juvenile and adult males, while females and young generally stay in the breeding range in California and Mexico (Odell 1981). A small fraction of the population congregates at upriver sites such as Bonneville Dam and Willamette Falls each spring, typically peaking in late April and early May (Wright et al. 2010, Wright et al. 2014, Stansell et al. 2013, van der Leeuw 2015).

While archaeological evidence indicates that California sea lions were present along the Oregon coast during at least the last 3,000 years (Lyman 1988), there is no similar evidence of their presence in the lower Columbia River or its tributaries (Lyman et al. 2002). In contrast, there is abundant evidence of harbor seals (*Phoca vitulina*) in the lower Columbia River dating back 10,000 years. Until recent decades, Steller sea lions (*Eumetopias jubatus*) were the most common sea lion species in the Pacific Northwest and harbor seals were the most commonly observed pinniped in the lower Columbia River (Pearson and Verts 1970). Prior to enactment of the Marine Mammal Protection Act (MMPA) in 1972, Oregon and Washington had bounties in place in an effort to keep pinniped populations low, and a seal hunter was employed to drive pinnipeds out of the Columbia River until 1970 (Pearson and Verts 1970). By the mid-1970s, however, observations of California sea lions in the Pacific Northwest began to increase though they were still relatively uncommon in the lower Columbia River until the mid- to late-1980s (Beach et al. 1985).

By the early 1990s, several hundred California sea lions were regularly found around Astoria, Oregon, hauling out on jetties, floats, and navigation markers (Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), unpublished data). At that time, sea lions were foraging in the lower Columbia River to near Wallace Island (river mile 48), often targeting salmonids (*Oncorhynchus* spp.) caught in nets during commercial gillnet fishing seasons. These sea lions also began to forage farther upriver in search of prey, including anadromous smelt or eulachon (*Thaleichthys pacificus*) that returned to tributaries such as the Cowlitz River (river mile 70).

In the mid-1990s observations of California sea lions in the Willamette River began to increase where they often foraged for winter steelhead and spring Chinook salmon below the fishways at Willamette Falls (128 miles upstream from the ocean). Concerned that this would result in 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 monitoring sea lion occurrence and predation on salmonids at the falls beginning spring 1995. Continuing through 2003, results from these observations showed that sea lions at the falls generally numbered a dozen or fewer animals each year, and predation losses were generally a few hundred fish or less. In addition, the trend in predation activity appeared to be flat or declining whereas winter steelhead runs were increasing. Monitoring at the falls was discontinued after 2003 due to a shift in limited resources to Bonneville Dam on the Columbia River, where, in contrast, newly occurring sea lion predation on salmonids was increasing and beginning to number in the thousands annually (Naughton et al. 2011, Keefer et al. 2012, Stansell et al. 2013).

While not subject to monitoring from 2004-2008, anecdotal reports from Willamette Falls continued of sea lions predating on salmonids there each spring. Beginning in 2009, students from Portland State University (PSU) began conducting observations at the falls as part of a field studies class. It was soon clear from PSU's observations that an increase in predation activity by California sea lions was occurring below the falls. This increase brought with it increased damage to docks where sea lions hauled out and increased risk to both anglers and sea lions from depredation of fish caught in the recreational fishery below the falls.

Low winter steelhead passage above the falls in 2008 and 2009, coupled with the increase in sea lion activity, led ODFW to test non-lethal hazing techniques in 2010, and implement hazing projects in 2011 and 2013 in an attempt to deter sea lions from consuming threatened winter steelhead near the fish ladder entrances at Willamette Falls. While hazing was effective at moving California sea lions downstream away from the fish ladder entrances, sea lions would return and predation activity would resume as soon as hazing ceased for the day. In addition, it was speculated that displacing sea lions from the ladder entrances may have increased their interactions with the recreational fishery downriver. Thus, at least some predation that would have occurred at the ladder entrances may have instead occurred within the fishery area as sea lions preyed upon salmon and steelhead as they were being landed by fishers.

Hazing was discontinued after 2013 in order to shift the agency's limited resources to a new monitoring effort in 2014 (Wright et al. 2014) and 2015 (Wright et al. 2015). This report summarizes the continuation of that effort in 2016 and provides three-year summaries of several project findings to date.

METHODS

Study area

The study area was located from Willamette Falls on the Willamette River, downstream to the mouth of the Clackamas River (Figure 1). Unlike in previous years, formal observations were only conducted in the immediate vicinity of the falls (i.e., sites 1-6). The falls are located 26 miles upriver from the confluence with the Columbia River and 128 miles 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. The U.S. stock of California sea lions is not listed as "threatened" or "endangered" under the Federal Endangered Species Act (ESA), nor as "depleted" or "strategic" under the MMPA (Carretta et al. 2016). The population is estimated to number approximately 300,000 animals. Steller sea lions have been observed sporadically at the falls over the last decade, albeit more consistently in recent years. Steller sea lions in Oregon belong to the eastern Distinct Population Segment (DPS). The eastern DPS was delisted from

ESA "threatened" status in 2013 but it remains classified as "depleted" under the MMPA and is therefore a "strategic" stock (Muto et al. 2016). Pacific harbor seals, while abundant throughout coastal Oregon and the lower Columbia River, are relatively rare and inconspicuous visitors to upriver sites such as Willamette Falls.

Fish species accounts

Fish species preyed upon by pinnipeds at Willamette Falls include winter and summer steelhead, hatchery and wild 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—naturally spawning wild winter steelhead and wild spring Chinook salmon—are listed as "threatened" under the ESA.

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 (ODFW and National Marine Fisheries Service (NMFS) 2011, NMFS 2016). These fish pass Willamette Falls from November through May, co-occurring, to some extent, with introduced hatchery 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.

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) (ODFW and NMFS 2011, 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. Illegal take of unmarked fish is thought to be low and hooking mortalities are generally estimated to be 10 percent (NMFS 2016).

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, wild/hatchery) 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 stratified, three-stage cluster sampling design, with repeated systematic samples at each stage (see Figures 1-3 and Appendices A and B for descriptions of the design; see Lohr 1999 and Scheaffer et al. 1990 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 site 1). 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). 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 in contrast to the 2014 and 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 over previous years. 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 0800-1700 (9 hours) in February to 0600-1900 (13 hours) in May (Figure 3). The sampling frame spanned 17 weeks from February 1 to May 29.

There were 1,114 half-hour observation units (i.e., elements) in the sample out of a sampling frame of 16,668 units, resulting in an element-wise sampling fraction of 6.7%; the cluster-wise sampling fraction was 6.7% (120 clusters out of 1792; see Appendix A). The sampling weight was 14.93, meaning that each observed predation or depredation event represented itself and 13.93 additional unobserved events. Based on 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 and 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, wild/hatchery spring Chinook salmon) based on a combination of field observations, fishway window counts, and Monte Carlo methods. We did this using a two-step conceptual model. In the first step, we either used observer identification of salmonids to species (if applicable) 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.

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% hatchery spring Chinook salmon, and 1% wild 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 August 15, 2016, which captures total escapement for all the runs except summer steelhead, which continue until October 31st. 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 abundance estimates of pinnipeds since they do not all haul out together at the same time and they are often not uniquely identifiable. They also are capable of moving over a 100 km/d so local populations cannot be considered 'closed' for mark-recapture methods. Pinniped abundance was therefore estimated using an approach similar to the area-under-the-curve (AUC) method used to estimate salmonid escapement (e.g., see Parsons and Skalski 2010). In the AUC approach, the total number of individuals is estimated by dividing an estimate of total 'animal-days' by an estimate of average 'animal residency'.

We estimated 'CSL-days' as follows. First, observers recorded the number and species of pinnipeds in their viewing area at every half-hour during their shift. Second, pictures of pinnipeds hauled out downriver near Sportcraft Marina were taken every half-hour using automated cameras and from which pinnipeds were later counted. Both counts were then added together to obtain estimates for each half hour from which the 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. Lastly, a loess model was fit to the weekly maximums to obtain daily estimates of abundance for the entire study period.

We estimated average daily 'CSL residency' based on observations of branded CSLs. Given that observer effort varied each day (and was mostly absent on weekends) we could not estimate daily occurrence. We therefore estimated weekly occurrence which we then multiplied by 7 to obtain an estimate of daily occurrence. In order for a branded CSL to be considered resident for a given week, we required it to be observed on three or more days. More than three days (out of a typical 5-day work week) would likely be too restrictive given that detectability is less than one, and less than three days might risk including transient animals that were only in the area briefly and wouldn't be contributing significantly to the overall salmonid take.

Additional activities

The sampling design in 2016 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, and photographing brands. Conduct of anecdotal observations changed in 2016 from previous years in that observers were not required to observe specific sites for extending periods of time regardless of predation activity but rather to actively seek predation "hot-spots" in order to maximize anecdotal observations of predation.

RESULTS

Salmonid abundance and river conditions

Daily salmonid run counts and composition for 2016, as well as the previous two years, are presented in Figures 4 and 5, respectively. River temperature and height for the past three study periods are presented in Figure 6.

Pinniped abundance

California sea lion abundance increased each week of the study, peaked in late April and early May, and declined rapidly thereafter (Figure 7). At least six California sea lions and one Steller sea lion were present when the study began the first week of February. Maximum single-day observation totals were 35 California sea lions (April 22) and one Steller sea lion (many dates from February 4 to April 16); no harbor seals were observed in 2016. At least three California sea lions were still present on the last day of observations (May 27).

A total of 26 branded California sea lions were detected on at least three or more days during 2016 (Figure 8). Nearly two-thirds (16 of 26) of the branded sea lions in 2016 had been seen previously at the falls, although many of the remainder may have occurred there before but were unidentifiable since they were not yet branded.

The total number California sea lion days was 2247 (i.e., sum of fitted line in Figure 7). The estimated mean residency was 47 days (calculated from residency data in Figure 8). Dividing total CSL-days by average residency yielded an estimate of 48 individual CSLs in the study area during the study period (26 branded, 22 unbranded).

Predation

Observers documented a total of 1,211 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 anecdotal observations. Salmonids were the most frequently observed prey item (83%) followed by lamprey (15%), unknown or other fish (1%), and sturgeon (1%). California sea lions accounted for nearly all of the observed predation events (99%). Steller sea lions accounted for all 8 of the sturgeon killed as well as 9 salmonids.

An estimated 4,585 salmonids were consumed by California sea lions in the study area from February 1 to May 29, 2016 (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 1,254 individuals. These estimates only apply to the sampling frame for 2016 depicted in Figures 2 and 3 and are therefore minimum estimates due to spatial and temporal undercoverage of the target population (see Discussion below for "model-based" estimates of predation for the target population).

Salmonid predation by run

Estimates of salmonid predation by run (winter/summer steelhead, wild/hatchery Chinook salmon) are presented in Table 3. Averaging across the six run assignment models yielded run-specific estimates of: 2,252 hatchery spring Chinook salmon (9% of potential escapement above falls), 650 wild spring Chinook salmon (9% of potential escapement), 768 summer steelhead (4% of potential escapement through 8/15/2016), and 915 winter steelhead (14% of potential escapement). For comparison, run-specific estimates for 2014 and 2015 are included in Appendix C and D, respectively. As noted before, these estimates only apply to the sampling frames depicted in Figures 2 and 3 and are therefore minimum estimates due to spatial and temporal undercoverage of the target population.

DISCUSSION

Design-based predation estimates (i.e., Table 2) were based solely on sampling units from the stratified, 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 Figures 1-3 and Appendix A for design details). If pinniped predation on salmonids occurred outside the sampling frame (e.g., downriver, during January, at dawn or dusk) then our estimate of predation would be too low.

In 2016 the largest source of undercoverage was likely spatial since we did not have staffing to observe the river strata as in previous years. Adjusting for this undercoverage requires making assumptions about the relative amount of predation in the falls and river strata. If we use 2015 as the basis for such a comparison we see that predation in the falls strata in 2015 represented approximately 63% of the total estimated predation (Table 4). In 2014 the stratum boundaries were slightly different but if we adjust the estimates from that year to more closely match site boundaries in 2015-2016 then the falls strata in 2014 represented approximately 60% of the total estimated predation that year. If we assume that predation in the falls strata in 2016 represented the average percentage from the previous two years (61.5%), then the estimated total predation in the study area would be 7,455 salmonids (Table 4). Further adjustments to address temporal undercoverage (e.g., study duration, day length) would require additional assumptions and were not pursued here.

An alternate approach to estimating predation is to use a bioenergetic model to estimate prey requirements. We adapted the bioenergetic model of Winship et al. (2002) and Winship and Trites (2003) and applied it to our estimate of CSL-days in the study area (i.e., 2247). Modified parameter inputs included.: normally distributed CSL weight (mean = 275 kg, SD = 45 kg); an average salmonid weight of 5.1 kg; salmonids as primary prey, uniformly distributed from 85% to 100% of diet; and primary and secondary prey energetic density uniformly distributed 5-9 kJ/g wet mass and 3-11 kJ/g wet mass, respectively. Simulation results yielded an average requirement of 11.7 kg/d which translated into a mean of 2.3 salmonids/d and a mean percent body weight of 4.3%. The total estimated number of salmonid required was 5,151 fish. This model-based estimate is of food requirements and not food consumption, however, and may be biased low since observed rates at Bonneville Dam have been much higher. The spatially-adjusted estimate of 7,455 salmonids above would require a mean predation rate of 3.3 fish/d.

While it's difficult to make a direct "apples-to-apples" comparison of predation across the three study years due to changes in the sampling frame (see Figures 1-3 and Appendix A), it appears that sea lion abundance and attendant predation increased each year. For example, comparing salmonid predation estimates from the 'falls' stratum between 2015 and 2016, where there was a relatively minor difference in temporal coverage, showed a 26% increase in predation. In addition, maximum single day CSL abundance increased each year from 27 (2014) to 32 (2015) to 35 (2016) individuals. The number of confirmed brands also increased from 19 (2014) to 23 (2015) to 26 (2016), although the branded population also increased each year (Figure 8).

Over the three-year study a total of 39 branded sea lions have been observed at the falls. Of these, over one-half (20 of 39) had also been observed at least once at Bonneville Dam, and one-quarter (10 of 39) were on the list for removal (or had been removed) under the States' MMPA Section 120 authority at Bonneville Dam.

In conclusion, the results of the past three years of pinniped abundance and predation monitoring at Willamette Falls suggests that the problem of California sea lions taking listed salmonids below the falls is significant. Recommendations for future work include an earlier start (i.e., January), installation of a trap to begin marking unbranded sea lions, and continued improvements to the behavioral observations and abundance monitoring.

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

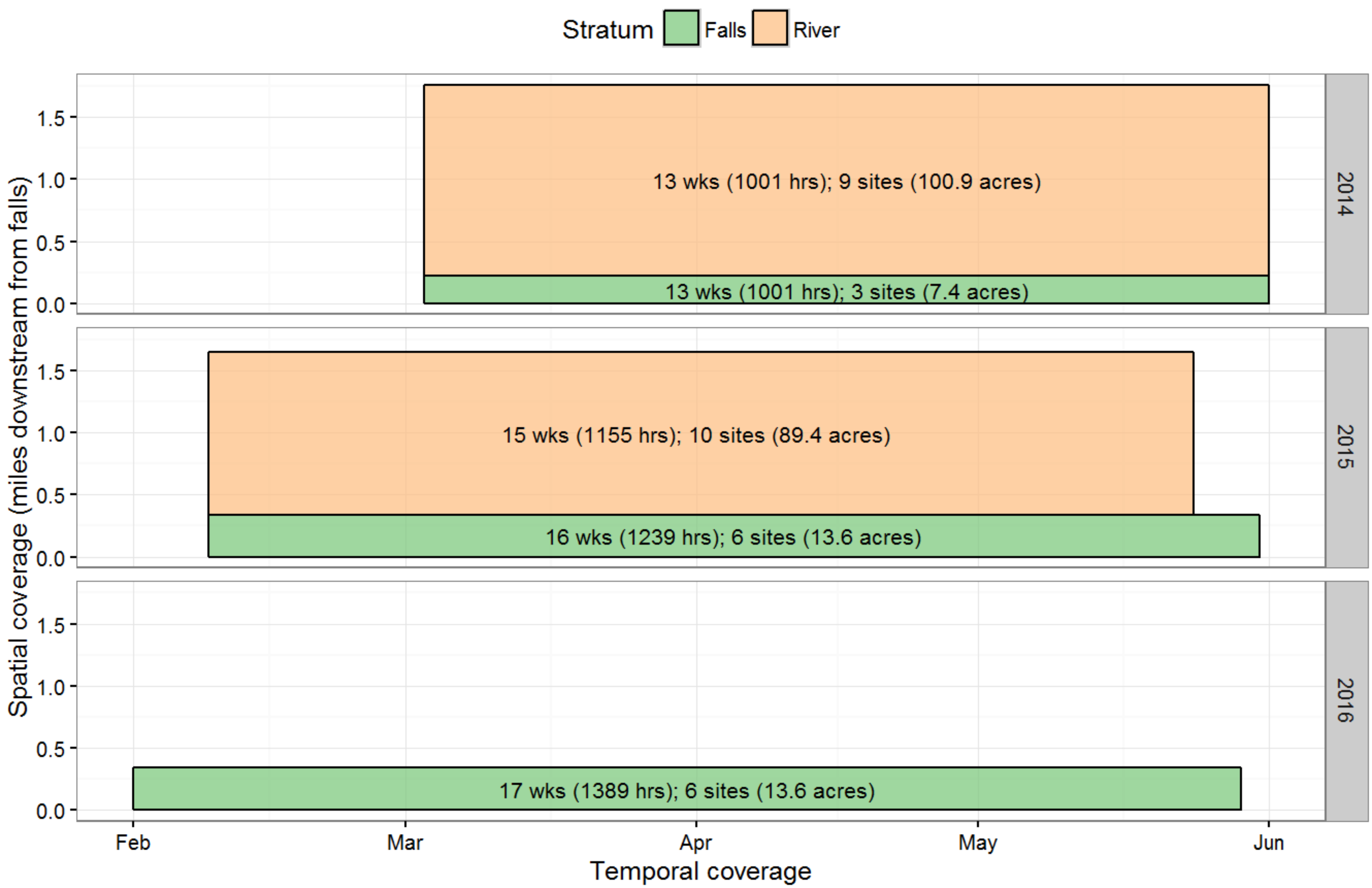

Figure 2. Illustration of approximate temporal and spatial coverage of sampling frame by year and strata.

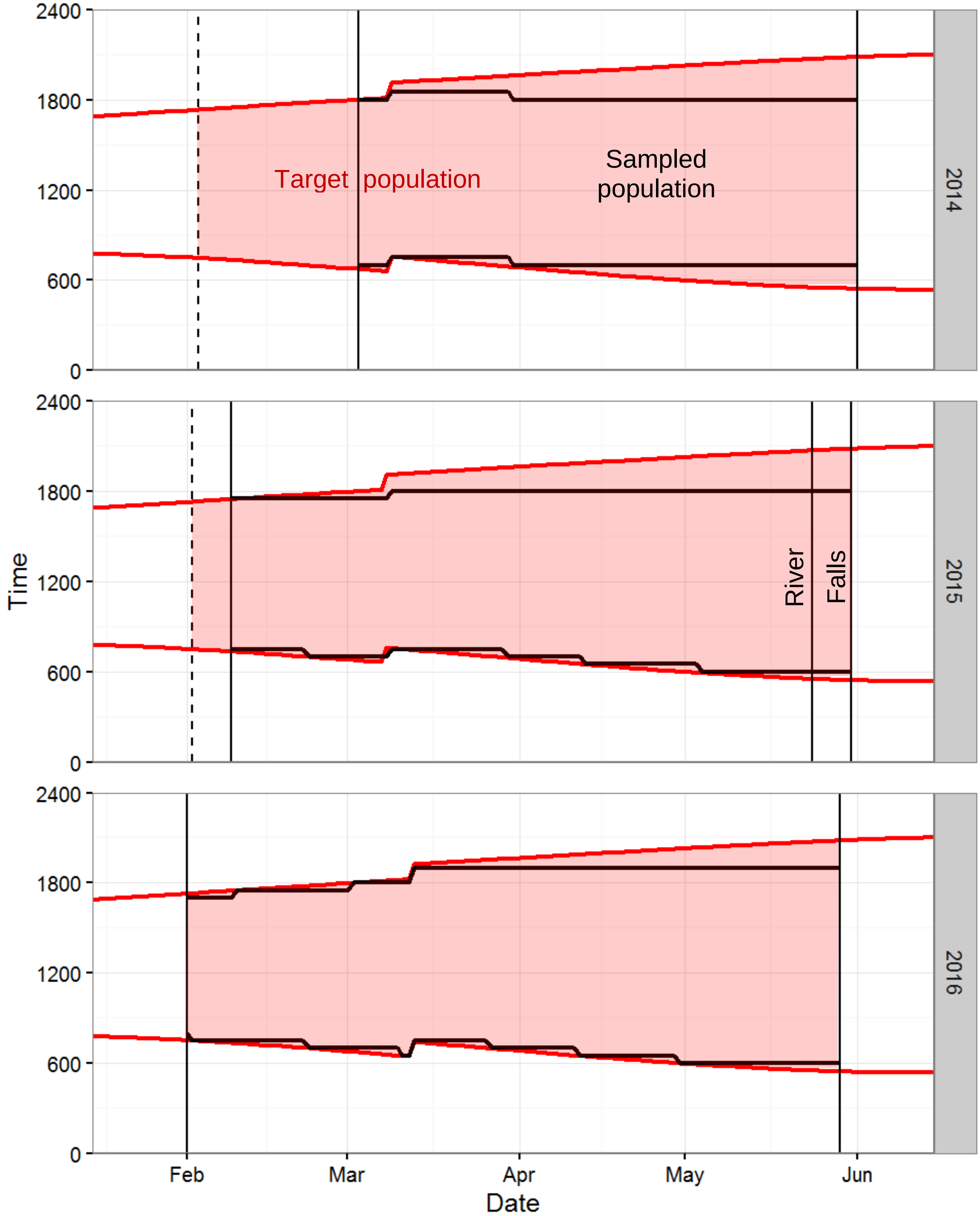

Figure 3. Illustration of temporal coverage of sampling frame by year showing sampled (frame) population outlined in black and target population shaded in red.

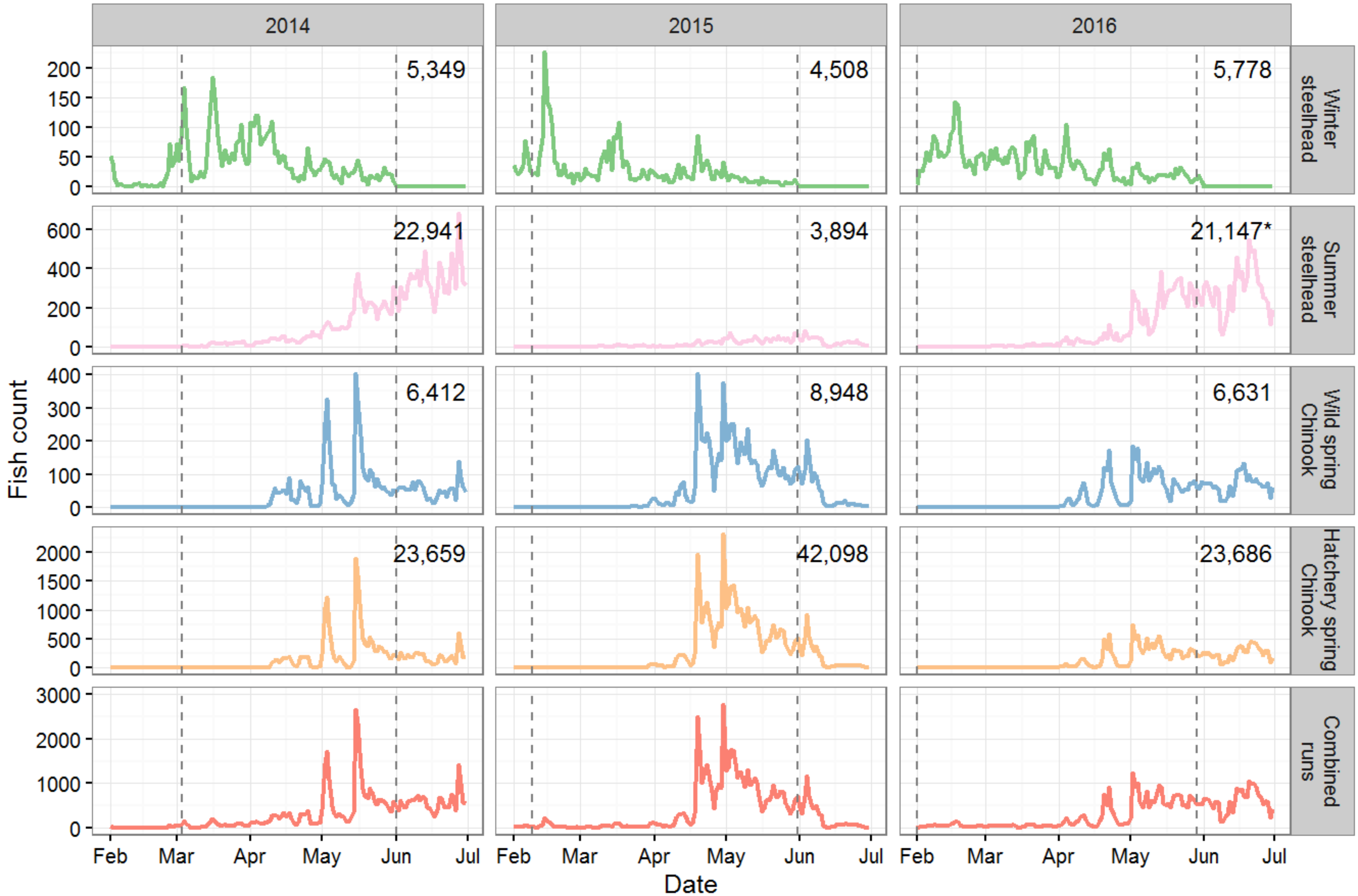

Figure 4. Daily fish counts at Willamette Falls by run and year. Vertical lines indicate study start and end dates; final run size inset upper right (*2016 summer steelhead through 8/15/2016).

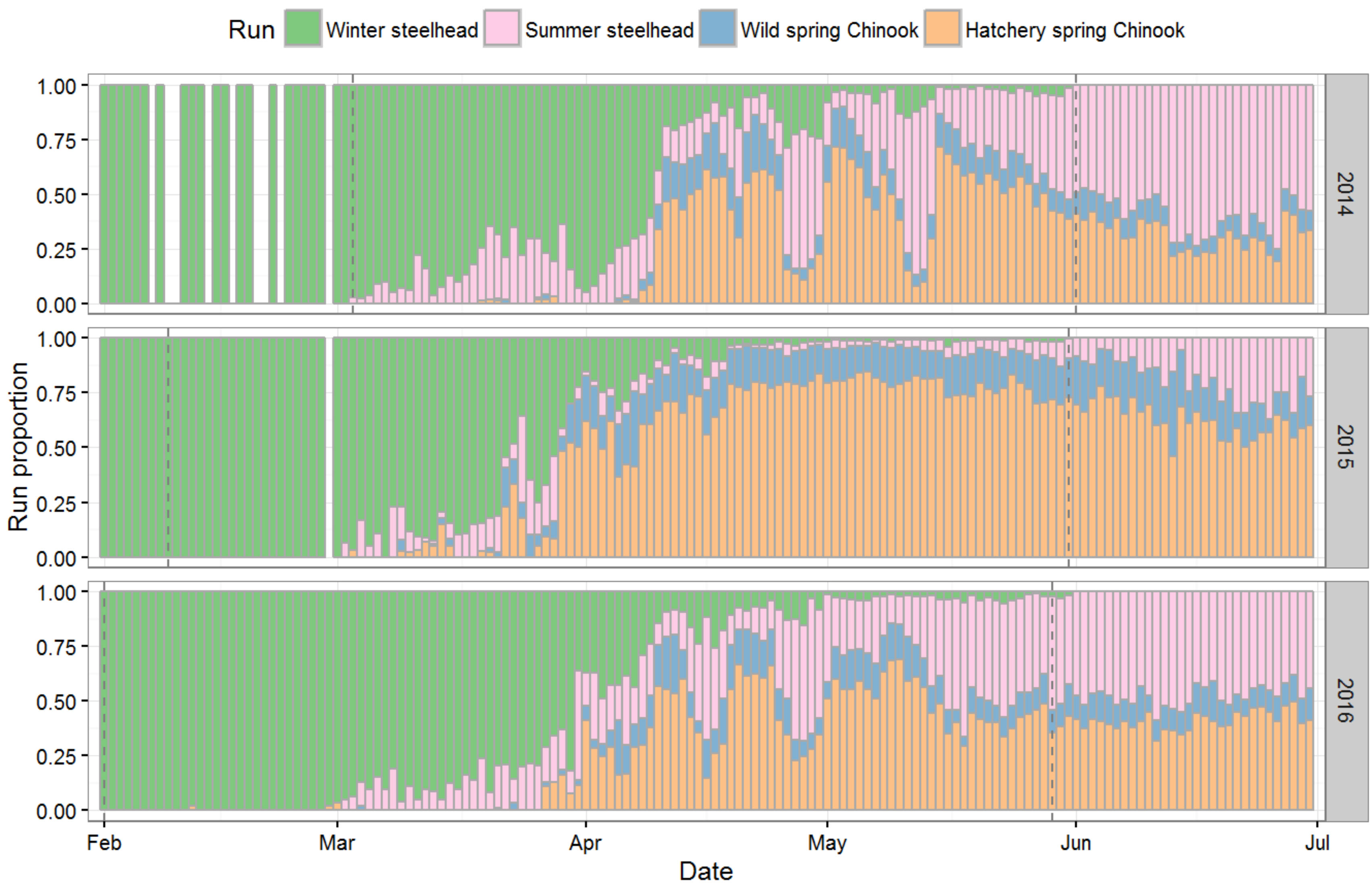

Figure 5. Daily run composition at Willamette Falls by year. Vertical dashed lines indicate study start and end dates.

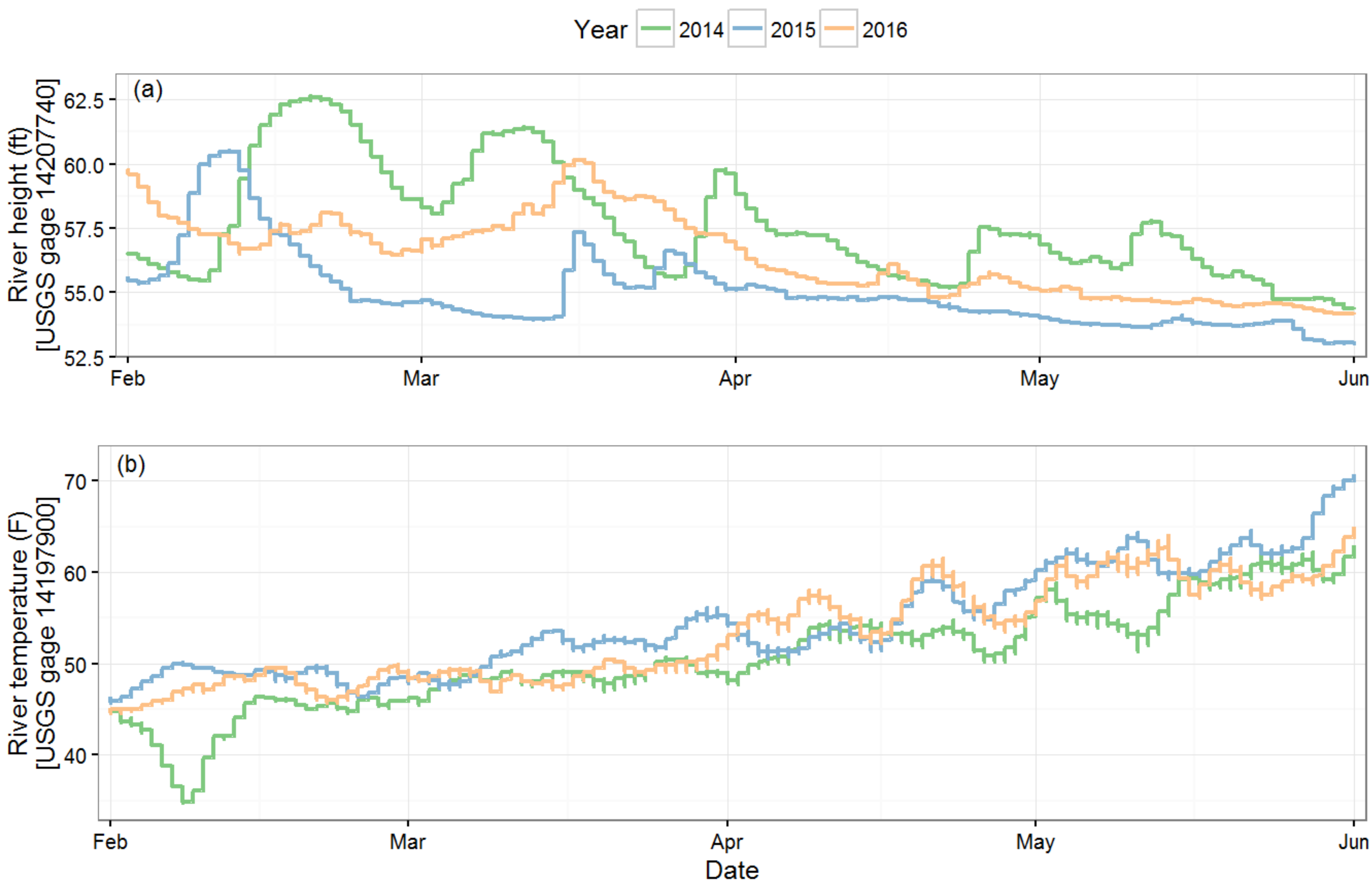

Figure 6. Willamette River height (a) and temperature (b) by year.

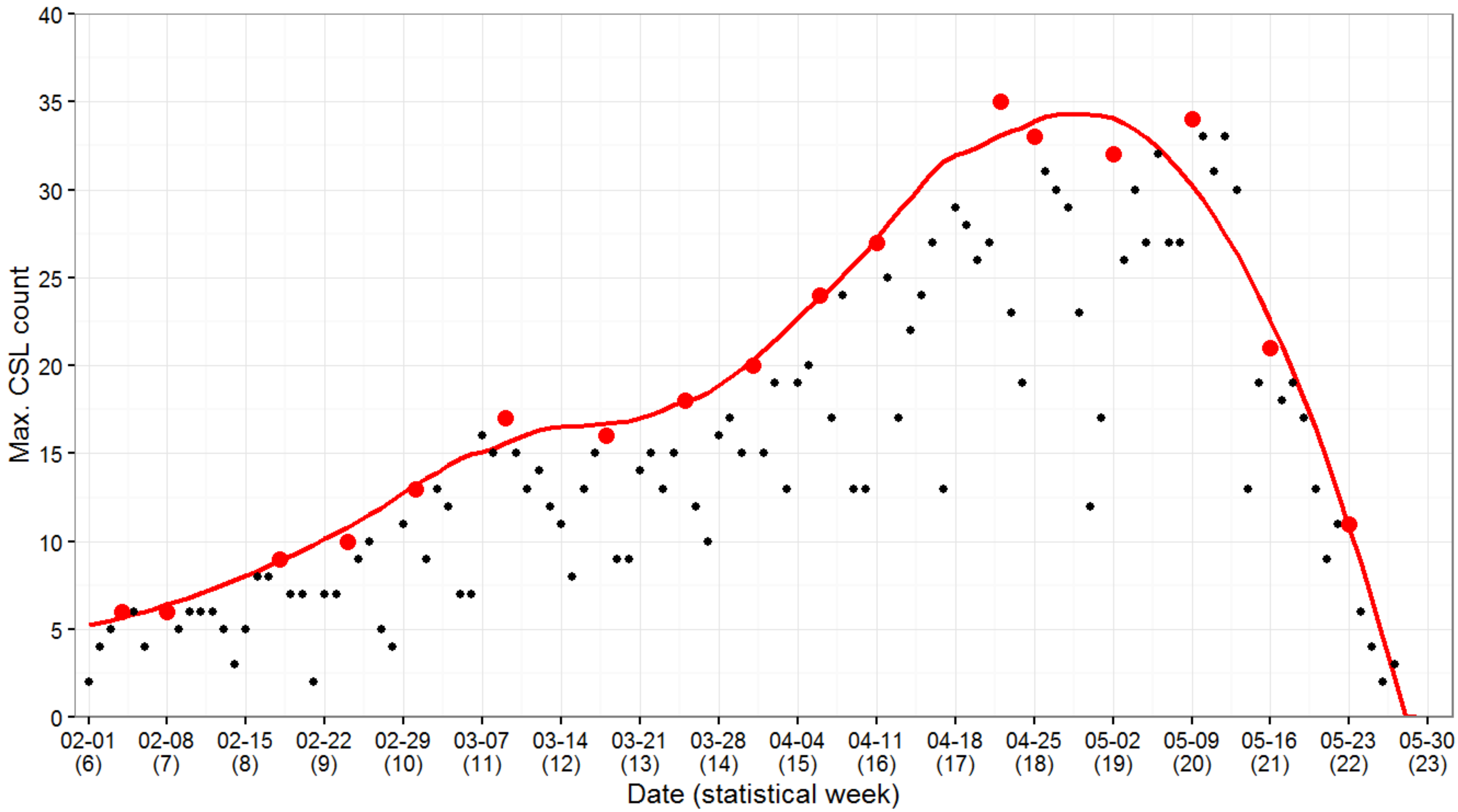

Figure 7. Maximum daily (black dots) and weekly (red dots) counts of CSLs below Willamette Falls, 2016. Red line equals loess fit (span = 0.5) of weekly counts.

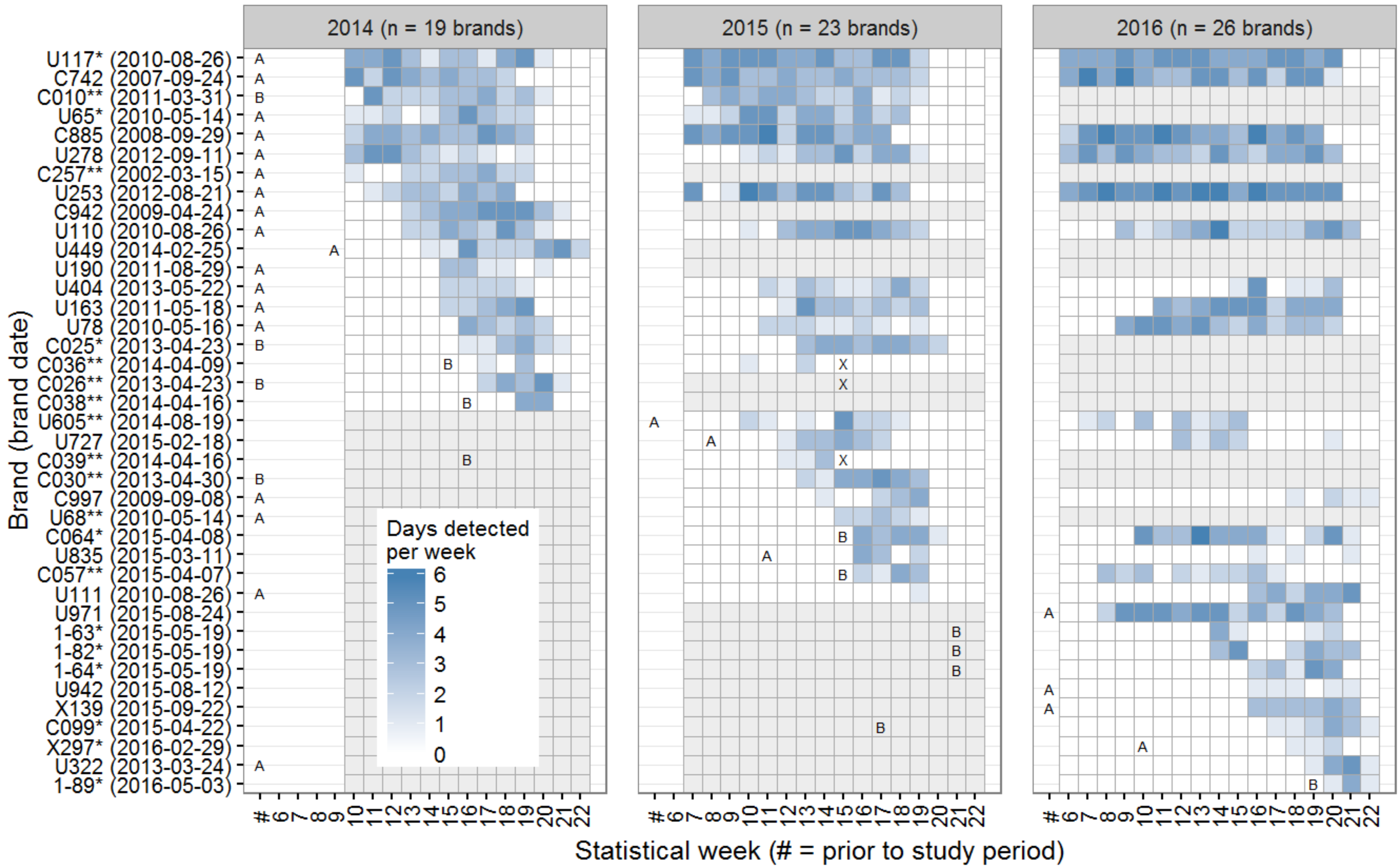

Figure 8. Weekly residency of branded California sea lions (n = 39) at Willamette Falls sorted by year and week of first detection. Capture location at branding denoted by 'A' (Astoria) or 'B' (Bonneville Dam); X denotes animal was removed under MMPA Section 120; * indicates animal documented at Bonneville Dam; ** indicates animal on MMPA Section 120 list for removal. Brands recorded less than three days per year were considered unconfirmed and are not included unless photographed.

Table 1. Summary of all predation events observed below Willamette Falls from February 1 to May 29, 2016. 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	434	2	436
Unknown salmonid	378	7	385
Steelhead	189	0	189
Lamprey	182	0	182
Unknown/other fish	11	0	11
Sturgeon	0	8	8
Total	1,194	17	1,211

Table 2. Summary of estimated predation by California sea lions below Willamette Falls from February 1 to May 29, 2016 based on stratified, three-stage cluster sampling design.

Prey*	Observed total	Estimated total	Standard error	Coefficient of variation	95% confidence interval	
					Lower bound	Upper bound
Salmonids	307	4,585	461.8	0.10	3,680	5,490
Lamprey	84	1,254	285	0.22	696	1,813
Sturgeon	1	15	14	0.97	8**	43

*All prey except sturgeon were taken by California sea lions.

**Lower bound for sturgeon was negative and was therefore replaced with the observed number killed from Table 2.

Table 3. 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 Figures 2 and 3 and therefore are likely minimum estimates due to undercoverage of the target population.

Run (escapement)	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
Hatchery 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%)
Wild 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 (21,147*)	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%*	(4%*	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)	4%*	(3%*	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%)

*Through 8/15/2016 (run ends 10/31/2016).

Table 4. Summary of California sea lion predation on salmonids extrapolated to river strata in 2016 based on relative amounts of predation observed between the two strata in 2014-2015. Note, however, that the 2014-2015 estimates themselves represent less temporal coverage than 2016 (see Figures 1-3 and Appendix A).

Year	Stratum	Estimated CSL salmonid take	% CSL salmonid take	Site-adjusted % CSL salmonid take
2014	Falls	1,842	50%	60%
	River	1,848	50%	40%
		3,690	100%	100%
2015	Falls	3,620	63%	
	River	2,156	37%	
		5,775	100%	
2016	Falls	4,585		
	River	*2,870**		
		*7,455**		

*Extrapolations based on 2014 and 2015 estimates.

Appendix A. Design data describing the Willamette Falls sea lion monitoring program, 2014-2016.

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	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	
	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	
			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	
	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	
			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	45

Appendix B. Simplified example illustrating three-stage cluster sampling design. Each observed cell has a sampling weight of 3.38 or equivalently an inclusion probability of 0.30. 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
1		1st stage				2nd stage				3rd stage							
2		Primary sampling units (PSUs)				Secondary sampling units (SSUs)				Tertiary sampling units (TSUs)				Observed samples - y			
3		0	0	0		0	0	0		0	0	0		0		0	
4		0	0	1		0	0	1									
5		3	3	0		3	3	0		3	3	0		3	3		
6																	
7		1	1	2		1	1	2		1	1	2			1	2	
8		1	1	3		1	1	3		1	1	3		1		3	
9		3	3	3		3	3	3									
10										Cells within rows							
11		2	3	0		Rows within tables				K	3						
12		1	2	3		M	3			k	2						
13		0	1	2		m	2							SUM(N3:P8)	13	sum y	
14														(C15/C16)*(G11/G12)*(K10/K11)	3.38	sampling weight	
15		Tables												1/O14	0.30	inclusoin probability	
16		N	3														
17		n	2											O13*O14	43.9	population total estimate	
18														SUM(B3:D13)	39	true population total	
19														O17-O18	4.9	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 Figures 2 and 3 and therefore are likely minimum estimates due to undercoverage of the target population.

Run (escapement)	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
Hatchery 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%)
Wild 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%)

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 Figures 2 and 3 and therefore are likely minimum estimates due to undercoverage of the target population.

Run (escapement)	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
Hatchery 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%)
Wild 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%)