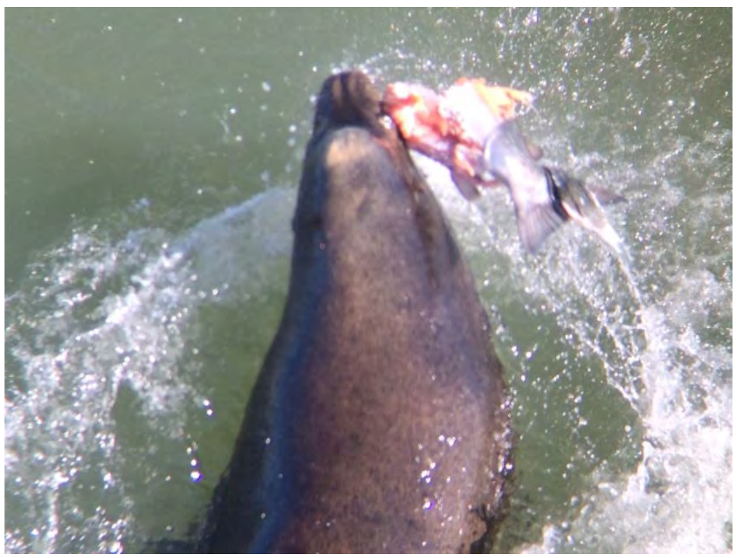
WILLAMETTE FALLS PINNIPED MONITORING PROJECT, 2015

September 15, 2015



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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). California sea lions typically congregate at upriver sites such as Bonneville Dam and Willamette Falls each spring, peaking in April and May (Wright et al. 2010, Wright et al. 2014, Stansell et al. 2013).

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 but 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navigation markers (Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), unpublished data).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 focused on obtaining rigorous estimates of predation. In contrast to previous monitoring efforts, the 2014 program was based on a probabilistic sampling design which covered not only Willamette Falls, but also the stretch of river from the falls downstream to the mouth of the Clackamas River. This report summarizes the continuation of that effort in 2015.

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). Willamette Falls is located 26 miles upriver from the confluence with the Columbia River and 128 miles from the ocean. It is the largest waterfall in the Pacific Northwest by volume and the 17th widest in the world.

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. 2013). The population has been growing at 5.4% per year and 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 (Allen and Angliss 2015). 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 principally 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). 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. Hatchery origin summer steelhead in the Willamette are not ESA listed, and support popular recreational fisheries that occur 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). These fish pass Willamette Falls from about April to August and co-occur with a more abundant run of hatchery-origin spring Chinook salmon. The hatchery-produced spring Chinook salmon are encountered to a moderate degree in ocean fisheries off Canada and Southeast Alaska, and 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, 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 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 Appendix 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 sixteen sites divided into two strata (Figure 1). Sites 1-6 (stratum 1) were each approximately 0.9 ha in area and occurred immediately below the falls where predation activity is typically greatest. Sites 7-16 (stratum 2) were each approximately 3.5 ha in area and occurred from the falls to the mouth of the Clackamas River. The total area covered in 2015 was approximately 41.7 ha. The temporal component of the sampling frame consisted of a subset of daylight hours, ranging from 0730-1730 (10 hours) in February to 0600-1800 (12 hours) in May (Figure 2). The sampling frame spanned 16 weeks (February 9-May 31) for stratum 1 and 15 weeks (February 9-May 24) for stratum 2.

There were 2,223 half-hour observation units (i.e., elements) in the sample out of a sampling frame of 37,968 units, resulting in an element-wise sampling fraction of 5.8%; the cluster-wise sampling fraction was 5.9% (240 clusters out of 4032; see Appendix B). Sampling weights in stratum one and two were 13.06 and 20.53, respectively, meaning that each observed predation or depredation event was multiplied by its sampling weight and then summed to arrive at population estimates. Based on extensive 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 less than 10%. As a "rule-of-thumb", estimates with CVs over 33% are considered unreliable.

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 field identification of salmonids to species (steelhead, Chinook salmon) or we treated all salmonid prey as unknown. In the second step, we assumed prey availability was proportional to window count composition which we computed based on pooled fishway counts over 1, 7, or 14 days subsequent to an observed event. This approach resulted in a total of six different predation estimates, one of which was our default model and the other five constituted a sensitivity analysis for that model.

Our default or preferred model was to use field observer identification when available and to assume the prey availability was proportional to run composition in the fish window on the day after an observed event. We believed that this was the most reasonable approach because 1) observers only identified prey to species when they were confident in doing so, and 2) Keefer et al (2004) found that most tagged salmonids in the Columbia and Snake Rivers passed dams in less than two days. As an example, under this approach 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.

The five alternative models included using field observer identification as above but pairing it with run composition pooled over window counts of 7 and 14 days, or by ignoring field observer identification (i.e., treating all salmonids as unknown) and pairing that with run composition pooled over 1, 7 and 14 days. 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 escapement (i.e., percent of the "run" impacted) was calculated for passage through August 15, 2015, which represents 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 the predation total.

Additional activities

The sampling design was implemented using a crew of four staff, working eight hours a day, five days a week. Training and orientation occurred during the first week of February with data collection beginning the following 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 data entry, conducting anecdotal observations (e.g., targeting sites with high predation rates or potential for interactions with the fishery), conducting haul-out counts, photographing brands, and cross-training.

RESULTS AND DISCUSSION

Observations

Maximum single-day observation totals for pinnipeds in the study area were: 32 California sea lions (April 27), two Steller sea lions (several dates in February), and one harbor seal (April 14). Six California sea lions and two Steller sea lions were already present on the first day of formal observations (February 9) but only a single California sea lion remained on the last day of observations (May 28). Steller sea lions only occurred during February (with the exception of a single day in late April) whereas California sea lions were present during 100% of the observation days over the 16 week study.

A total of 22 uniquely branded California sea lions were confirmed to have occurred during the study based on photographs and/or multiple independent sightings (Table 1). An additional eight unbranded California sea lions were documented with distinguishable characteristics (e.g., size, scarring, instrumentation). These numbers, however, represent only a fraction of the true number of individual pinnipeds that occurred at the falls since it is not possible to keep track of all unmarked animals over the course of the study. The total number of individual California sea lions that occurred during the study was probably around 50 individuals (i.e., 30 identifiable sea lions plus periodic turnover of nondescript sea lions). Over three-quarters (17 of 22) of the branded sea lions at the falls in 2015 had been seen previously at the falls or at Bonneville Dam and six were on the list of animals authorized for permanent removal under Oregon's MMPA Section 120 Letter of Authorization from NMFS.

Observers documented a total of 1,390 predation events over the course of the project (Table 2). This includes predation events seen at pre-assigned, sample-based observation units, as well as anecdotal observations. Salmonids were the most frequently observed prey item (85%) followed by lamprey (12%), unknown or other fish (2%), and sturgeon (1%). California sea lions accounted for nearly all of the observed predation events (99%) as Steller sea lions were few in number and only occurred early in the season. Steller sea lions accounted for 12 of the 14 sturgeon killed (several of which were oversized), as well as two steelhead. California sea lions were observed to depredate 36 salmonids from bank and boat anglers.

Run timing and river conditions

Daily salmonid run counts and composition are presented in Figure 3. Winter steelhead were the majority run during the first half of the study, replaced by hatchery spring Chinook salmon during the latter. Summer steelhead were exceptional for their low numbers in 2015. River conditions were below average in flow and above average in temperature (Figure 4), reflecting the severe drought conditions of 2015.

Predation estimates

An estimated 5,775 salmonids were consumed by California sea lions in the study area from February 9 to May 31, 2015 (Table 3). The majority of predation occurred during April in stratum 1 (Figure 5). Partitioning this total between free-swimming fish and those depredated in the recreational fishery yielded estimates of 5,344 and 431 salmonids, respectively. The only other prey for which sufficient observations were made for reliable estimation was lamprey, of which California sea lions consumed an estimated 758 individuals. The estimated number of sturgeon killed by Steller sea lions was 34, but the large CV of 70% indicates that the estimate is unreliable.

Predation estimates by run

Estimates of salmonid predation by run (winter/summer steelhead, wild/hatchery Chinook salmon) based on the default model are presented in Table 4; results from the sensitivity analysis are presented in Appendix C. Estimated predation was approximately proportional to relative prey abundance, with most of the predation estimated to be hatchery spring Chinook salmon (4,179 fish or 9% of potential escapement), followed by wild spring Chinook salmon (950 fish or 10% of potential escapement), winter steelhead (501 fish or 10% of potential escapement), and lastly summer steelhead (146 fish or 5% of potential escapement). Sensitivity analysis suggested that using observer information and varying the number of pooling days only had modest effects on the results.

Non-sampling errors

Design-based predation estimates were based solely on sampling units from the stratified, three-stage cluster sampling design and do not include anecdotal observations. The 95% confidence intervals in Table 3 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 and 2). Pinniped predation on salmonids occurring outside the sampling frame (e.g., downriver, during January, at dawn or dusk) would result in predation estimates being too low. While this most likely occurred, it is difficult to quantify without further expansion of the sampling frame to better match the target population.

Another example of undercoverage in this study came from at least one California sea lion (U278) that defeated a sea lion excluder device and entered ladder leg two to forage for prey in the fish ladder. U278 was observed foraging for fish in the ladder on at least six days during March and April (3/2, 3/12, 3/26, 4/2, 4/6, 4/22). Modification of the excluder is scheduled to be completed before next season in order to prevent a repeat of this occurrence.

Lastly, non-sampling errors in the form of missing data occurred on several days encompassing 53 sampling elements. Forty of these were due to holidays (President's Day, Memorial Day) and the remainder due to missed assignments (e.g., locked gate, scheduling errors). Surface-feeding events in these elements were imputed as zeros.

Conclusions and recommendations

Estimated California sea lion predation on salmonids below Willamette Falls in 2015 was notably higher than in 2014 and presumably higher than any year prior to that. It was also higher than that estimated in many previous years at Bonneville Dam, although 2015 also saw record high predation at that site (Leeuw et al. 2015). Depredation of catch in the recreational fishery below the falls was also notably higher than in 2014 when it was rarely observed. Part of the increase in predation totals at the falls may be explained by an increase in the sampling frame (e.g., three additional weeks and additional daylight hours) but much of it is likely due to an increase in sea lion abundance and residence times below the falls. Flows in the Willamette River in 2015 were also much lower and clearer than average, and, together with reduced turbulence, may have facilitated higher predation success.

Recommendations for future monitoring include starting earlier in the year and covering more of each day in order to account for these sources of undercoverage. Other recommendations include: trapping and marking sea lions caught at Willamette Falls; improving estimates of sea lion abundance and residency rates; monitoring depredation in the fishery through creel surveys; and reducing or eliminating haul-out opportunities near the falls.

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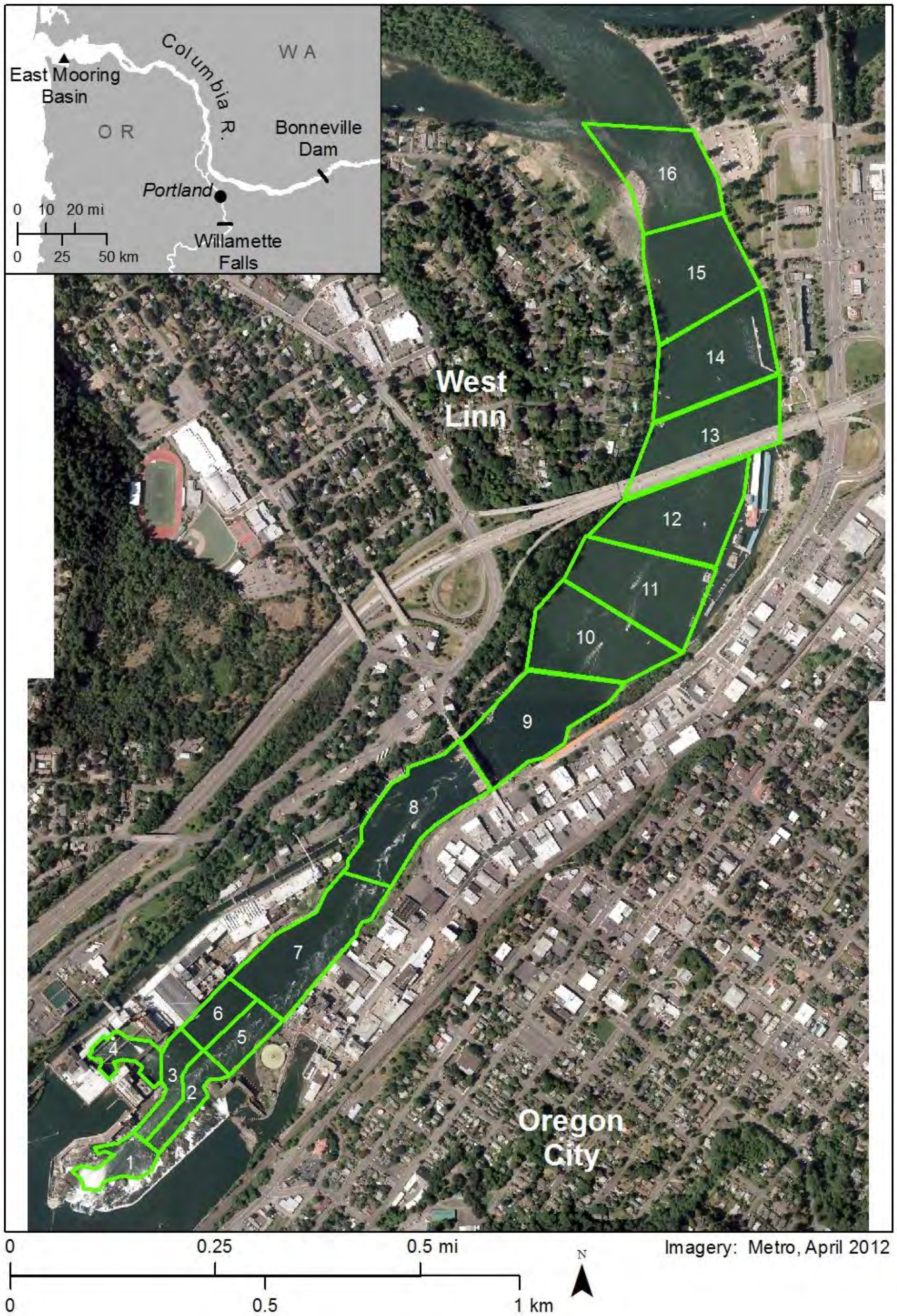

Figure 1. Illustration of the spatial components of the sampling frame for 2015. Sites 1-6 (stratum 1) were each approximately 0.9-ha in area and Sites 7-16 (stratum 2) were each approximately 3.5-ha in area.

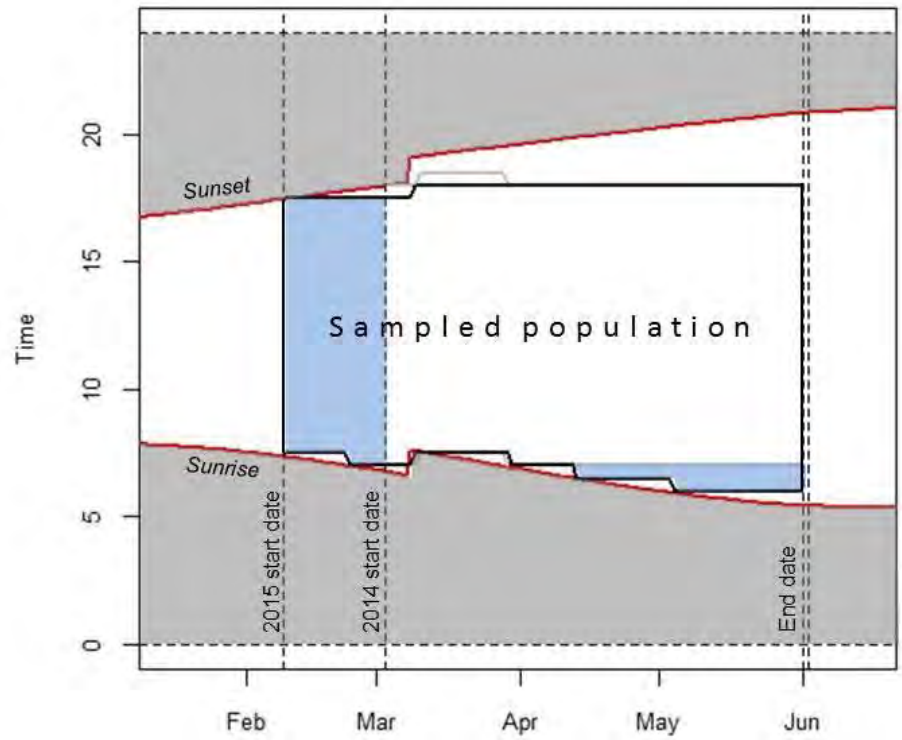

Figure 2. Illustration of the temporal components of the sampling frame for 2014 and 2015. Inferences are limited to the "sampled" population (black polygon) whereas predation likely occurred during all daylight hours (i.e., the "target" population defined by the red plolygon corresponding to sunrise and sunset). Differences between the target and sampled population are termed "undercoverage" and represent potential for underestimation of total predation. The sampled population in 2015 was increased over 2014 to include additional weeks early in the season and additional daylight hours near dawn later in the season (denoted in blue).

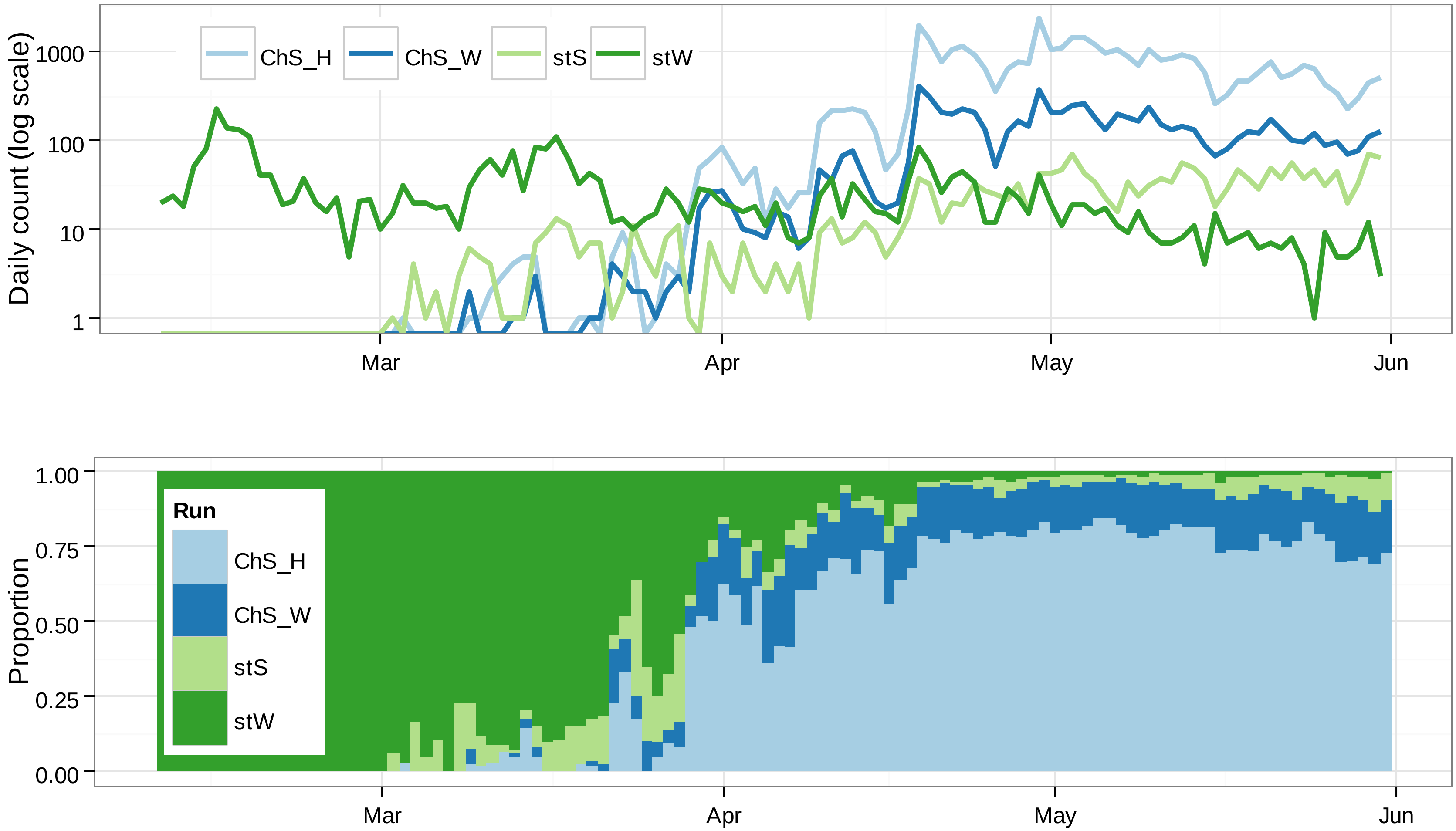

Figure 3. Summary of daily run count and composition passing Willamette Falls from February-June, 2015 (stW = winter steelhead, stS = summer steelhead, ChS_W = wild spring Chinook salmon, ChS_H = hatchery spring Chinook salmon).

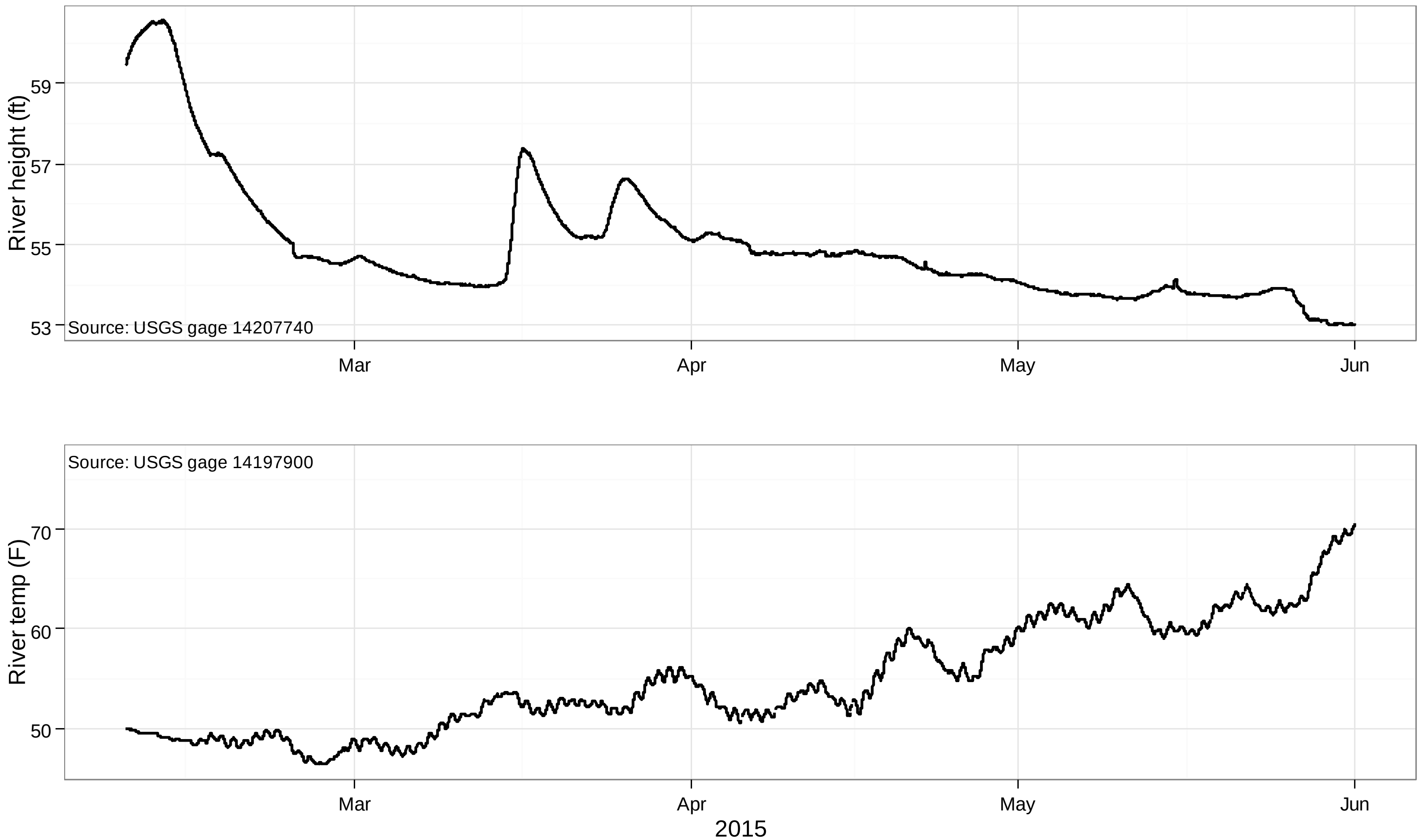

Figure 4. Summary of daily river height and temperature from February-June, 2015, as measured at USGS gages located above the falls at Oregon City (gage 14207740) and at Newberg (gage 14197900), respectively.

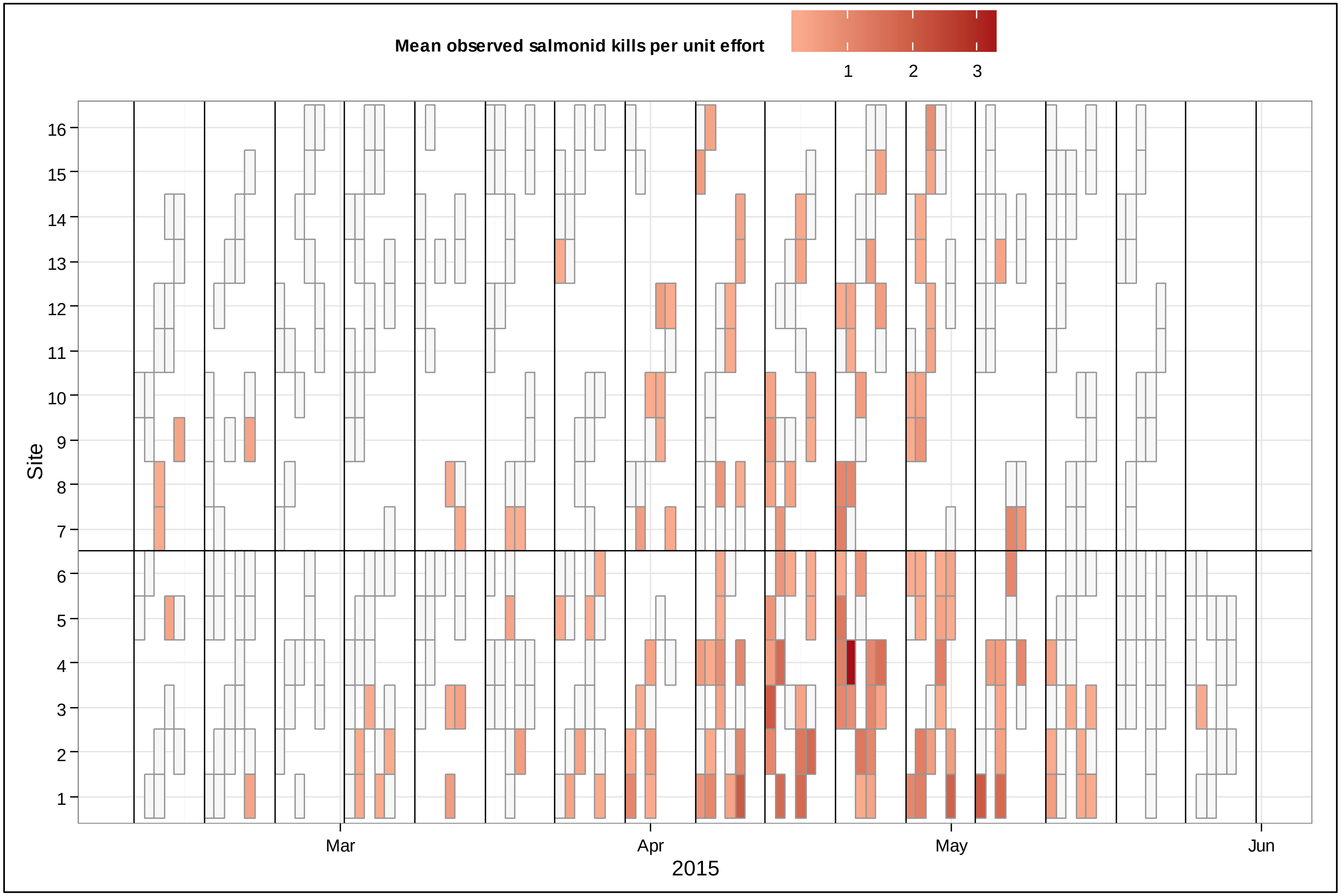

Figure 5. Mean number of observed salmonid predation events (including depredation) per element by site and date.

Table 1. Summary of confirmed observations of 22 branded California sea lions at Willamette Falls, 2015.

Brand	First seen (m/d)	Last seen (m/d)	Potential duration (d)	Seen previously at			On Section 120 removal list
				Will. Falls in 2014	Will. Falls in 2013 or earlier	Bonneville Dam	
U117	2/03	5/08	94	YES	YES	YES	
C742	2/03	5/06	92	YES	YES		
U65	2/03	5/01	87	YES	YES	YES	
U253	2/05	4/30	84	YES	YES		
C885	2/06	4/23	76	YES	YES		
C010	2/18	5/04	75	YES	YES	YES	YES
U278	3/02	5/07	66	YES	YES		
U605	3/02	4/27	56				
U110	3/08	5/08	61	YES		YES	
C036	3/08	3/26	18	YES		YES	YES
U78	3/10	5/06	57	YES			
U404	3/11	5/08	58	YES			
U727	3/17	4/24	38				
U163	3/19	5/08	50	YES			
C039	3/21	4/06	16			YES	YES
C025	3/24	5/13	50	YES	YES	YES	
C030	3/26	5/08	43			YES	YES
C997	4/01	5/08	37				
U68	4/08	5/08	30				YES
C064	4/13	5/14	31			YES	
U835	4/13	5/08	25				
C057	4/17	5/08	21			YES	YES

Table 2. Summary of all predation and depredation events observed below Willamette Falls from February 3 to May 28, 2015. Includes events from anecdotal observations as well as those seen during probability-based sampling assignments.

Prey	California sea lion - predation	California sea lion - depredation	Steller sea lion - predation	Total
Chinook salmon	665	31		696
Unknown salmonid	358	5		371
Steelhead	108		2	110
Lamprey	175			175
Unknown/other fish	21	3		24
Sturgeon	2		12	14
Total	1,337	39	14	1,390

Table 3. Summary of estimated predation (including depredation) below Willamette Falls from February 9 to May 31, 2015 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	382	5,775	346	0.06	5,096	6,455
-predation	361	5,344	349	0.07	4,661	6,028
-depredation	21	431	101	0.23	234	628
Lamprey	58	758	116	0.15	531	984
Sturgeon	2	34	24	0.70	14**	80

*All prey were taken by California sea lions except sturgeon

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

Table 4. Summary of total salmonid predation (including depredation) and predation as percent of potential escapement by run based on default run assignment model. Means for total, percent coefficient of variation (CV), and lower and upper bounds (LB, UB) from 95% confidence intervals (95CI) are presented from 1000 runs of the model.

	Predation				Predation as percent of potential escapement		
Salmonid run (escapement)	Total	CV	95CI LB	95CI UB	Total	95CI LB	95CI UB
Hatchery spring Chinook salmon (42,098)	4,179	0.07	3,633	4,726	9%	8%	10%
Wild spring Chinook salmon (8,948)	950	0.13	706	1,194	10%	7%	12%
Winter steelhead (4,503)	501	0.20	307	694	10%	6%	13%
Summer steelhead (2,747*)	146	0.33	54	237	5%	2%	8%

*Through August 15, 2015.

Appendix A. 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 B. Summary of stratified, three-stage cluster sampling design used in 2015.

Stratum	Stage	Sampling unit	Population size	Sample size	Mean elements per cluster	Sample selection
1 (six 0.9-ha sites, 16 weeks)	1	Day (PSU)	N = 7	n = 5		Non-random
	2	Site-shift (SSU)	M = 14	m = 2		Random
	3	Bout (TSU)	K = 16	k = 12		Non-random
		Total clusters	1568	120	9.5	
		Sampling weight:	1568 / 120 = 13.067			
2 (ten 3.5-ha sites, 15 weeks)	1	Day (PSU)	N = 7	n = 5		Non-random
	2	Site-shift (SSU)	M = 22	m = 2		Random
	3	Bout (TSU)	K = 16	k = 12		Non-random
		Total clusters	2464	120	9.4	
		Sampling weight:	2464 / 120 = 20.533			

Appendix C. Summary of total salmonid predation (including depredation), and predation as percent of potential escapement, by run. Means for total, percent coefficient of variation (CV), and lower and upper bounds (LB, UB) from 95% confidence intervals (95CI) are presented from 1000 runs of each of six run assignment models.

Salmonid run (escapement)	Run composition model	Days pooled	Predation				Predation as % of potential escapement		
			Total	CV	95CI LB	95CI UB	Total	95CI LB	95CI UB
Hatchery Chinook salmon (42,098)	Window count only	1	3,882	0.07	3,351	4,413	8%	7%	9%
		7	4,057	0.07	3,507	4,608	9%	8%	10%
		14	4,217	0.07	3,655	4,780	9%	8%	10%
	Field observation	1	4,179	0.07	3,633	4,726	9%	8%	10%
		7	4,242	0.07	3,695	4,788	9%	8%	10%
		14	4,321	0.07	3,769	4,874	9%	8%	10%
Wild Chinook salmon (8,948)	Window count only	1	876	0.14	643	1109	9%	7%	11%
		7	868	0.13	641	1095	9%	7%	11%
		14	866	0.13	641	1091	9%	7%	11%
	Field observation	1	950	0.13	706	1,194	10%	7%	12%
		7	935	0.13	703	1,168	9%	7%	12%
		14	896	0.13	664	1,128	9%	7%	11%
Winter steelhead (4,503)	Window count only	1	789	0.14	571	1,007	15%	11%	18%
		7	648	0.15	453	842	13%	9%	16%
		14	503	0.17	334	673	10%	7%	13%
	Field observation	1	501	0.20	307	694	10%	6%	13%
		7	470	0.21	279	661	9%	6%	13%
		14	423	0.22	240	606	9%	5%	12%
Summer steelhead (2,747)*	Window count only	1	229	0.26	117	342	8%	4%	11%
		7	202	0.28	96	309	7%	3%	10%
		14	189	0.28	88	290	6%	3%	10%
	Field observation	1	146	0.33	54	237	5%	2%	8%
		7	128	0.36	42	215	4%	2%	7%
		14	135	0.35	47	223	5%	2%	8%

*Through August 15, 2015.