

ANNUAL REPORT:  
PINNIPED MONITORING AT WILLAMETTE FALLS, 2021-2022

November 1, 2022



*Steller sea lion predation on white sturgeon, February 8, 2022 (credit: C. Owen, ODFW)*



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## INTRODUCTION

The Marine Mammal Protection Act (MMPA) of 1972 provides federal protection to all marine mammal species in U.S. waters. As one result of this legislation, the U.S. stock of California sea lions (*Zalophus californianus*) and the eastern stock of Steller sea lions (*Eumatopias jubatus*) have increased to the point that they are now likely within their Optimum Sustainable Population ranges (Caretta et al. 2021, Muto et al 2021). Over this same period, many salmon and steelhead (*Oncorhynchus* spp.) populations in the Pacific Northwest experienced significant declines in their abundance and were subsequently listed as threatened or endangered under the Endangered Species Act (ESA). While pinniped predation was not the ultimate cause of these declines, in areas where salmonid abundance is low and pinniped numbers are high, increased predation can result in significant negative impacts to the survival and recovery of individual salmonid populations.

One such area of relatively low salmonid and high pinniped abundance is 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), it wasn't until the mid-1990s there were frequent observations of California sea lions foraging there for winter steelhead and spring Chinook salmon attempting to pass the Falls (Oregon Department of Fish and Wildlife [ODFW], unpublished data). Concerned that Willamette Falls would become another "Ballard Locks"—a site in Washington where California sea lions effectively extirpated a run of steelhead (*O. mykiss*) (Fraker and Mate 1999)—ODFW began a predation monitoring program at Willamette Falls in 1995, as well as a California sea lion marking program at Astoria in 1997 to identify and track California sea lions in the Columbia River Basin (Brown et. al 2020).

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. 2021). Attention soon returned to Willamette Falls, however, as winter steelhead passage decreased, and sea lion activity increased. This led ODFW to conduct non-lethal hazing at Willamette Falls in 2010, 2011, and 2013 in an attempt to deter sea lions from consuming threatened winter steelhead near the fish ladder entrances. However, as has been seen elsewhere (e.g., see review in Scordino 2010), non-lethal deterrents had only limited and short-term effects as pinnipeds eventually adapted to them.

Hazing was discontinued after 2013 in order to shift limited resources to a rigorous monitoring effort (e.g., see Wright et al. 2021). That effort showed that California sea lion abundance had increased from the late 1990s and early 2000s and that California sea lion predation had become particularly acute for threatened winter steelhead populations (e.g., see Appendix 2 of ODFW et al. 2019). In addition, Steller sea lions also began showing notable increases in abundance and residency starting in 2017. Based on the results of this monitoring, the state of Oregon requested lethal removal authority for California sea lions under Section 120 of the MMPA, which was subsequently granted on November 14, 2018 (NMFS 2018) and later expanded to include Steller sea lions on August 25, 2020 (NMFS 2020). This report summarizes the ninth consecutive year

of pinniped monitoring at Willamette Falls and partially fulfills reporting requirements under our management authorities.

## METHODS

### *Study area*

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

### *Pinniped species accounts*

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

California sea lions—California sea lions are currently the most common and abundant pinniped observed at Willamette Falls, although their numbers and duration of occurrence have been declining due to the success of recent management actions. California sea lions in Oregon belong to the U.S. stock for which the most recent (2014) estimate was approximately 257,606 animals (minimum population size estimate = 233,515 individuals) (Laake et al. 2018, Carretta et al. 2021). The stock is not listed as "endangered" or "threatened" under the ESA, nor as "depleted" or "strategic" under the MMPA (Carretta et al. 2021). California sea lions in the Pacific Northwest are seasonal migrants that begin arriving in Oregon in late July and have mostly departed by late June on their way back and forth from the breeding grounds in southern California and Mexico (Wright et al. 2010, Elorriaga-Verplancken et al. 2014, Brown et al. 2020). This seasonal population is comprised almost exclusively of  $\geq 3$ -year-old males (Mate 1975, Maniscalco et al. 2004, ODFW unpublished data), recently estimated to number approximately 50,000-75,000 animals (Laake et al. 2018).

Steller sea lions—Steller sea lions have been observed sporadically at Willamette Falls over the last decade, albeit more consistently and in increasing numbers in recent years. Steller sea lions in Oregon belong to the eastern Distinct Population Segment (DPS). Not accounting for animals at sea, the most recent (2017) estimate of the eastern DPS was 18,450 (95% credible interval of 15,030-22,253) pups and 58,699 (95% credible interval of 50,312-68,052) non-pups (Muto et al. 2021); these estimates cannot be used to represent a total population abundance estimate, however, as they do not account for animals at sea. The stock is not listed as "endangered" or "threatened" under the ESA, nor as "depleted" or "strategic" under the MMPA (Muto et al. 2021).

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 (1999) estimate of

the total stock was 24,732 animals (Carretta et al. 2021). However, since this estimate is out of date the current population abundance and trend for this stock is unknown. The stock is not listed as "endangered" or "threatened" under the ESA nor as "depleted" or "strategic" under the MMPA (Carretta et al. 2021).

### *Fish species accounts*

Fish species primarily preyed upon by pinnipeds at Willamette Falls are winter and summer steelhead, marked (hatchery) and unmarked (wild) spring Chinook salmon (*O. tshawytscha*), Pacific lamprey (*Entosphenus tridentatus*), and white sturgeon (*Acipenser transmontanus*). All of these species are of conservation or management concern, and two—winter steelhead and wild spring Chinook salmon—are listed as "threatened" under the ESA.

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

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

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

### *Pinniped counts*

We estimated pinniped abundance in the study area based on a combination of direct observations as well as imagery from automated time-lapse cameras at the Sportcraft Landing haulout area (Figure 1). Counts at Willamette Falls (i.e., sites 1-6, Figure 1) were conducted hourly during weekday, daytime observation shifts whereas camera counts were based on hourly images of the trap decks taken 24 hrs a day, 7 days a week. Both types of counts were then added together to obtain total hourly counts from which a maximum count was retained to represent the minimum abundance for that day. Alternatively, if the tally of individual animals observed over a given calendar day was greater than the maximum hourly count, then that number was used for

that day. For the fall and early winter period before formal observations began we only used camera counts and anecdotal observations to obtain daily maximum counts. The maximum daily count for a given week was used as an estimate of the minimum number of individuals to be present in the study area for that week.

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

### *Pinniped predation estimation*

While pinnipeds can consume small prey underwater, they usually must surface to manipulate and consume larger prey such as an adult salmonid (Roffe and Mate 1984). We utilized this aspect of their foraging behavior (i.e., surface-feeding), in conjunction with statistical sampling methods (e.g., Lohr 1999, Hankin et al. 2019) to estimate the total number of adult salmonids consumed by sea lions over a spatio-temporal sampling frame. From 2014-2020 we estimated total surface predation of adult salmonids based on a (pseudo) probability sample generated from a three-stage cluster sampling design, with repeated systematic samples at each stage (e.g., Wright et al. 2020). In 2021, in order to mitigate COVID-19 risks and in anticipation of decreased sea lion activity, we experimented with a new sampling design based on spatially balanced sampling methods, specifically Halton iterative partitioning (HIP) (Robertson et al. 2018, Hankin et al. 2019). In 2022 we returned to using the three-stage cluster sampling design.

The variable of interest was the initiation of a surface-feeding event whereby a sea lion was observed to surface and begin prey consumption within a given spatio-temporal observation unit. Since prey handling and consumption for some prey species such as large sturgeon can last over an hour and drift over a kilometer downstream, we only formally recorded events that included observations of the initial surfacing immediately after prey capture; all other events were treated as anecdotal. We included both predation on free swimming fish as well as depredation of hooked fish in the recreational fishery (collectively referred to as "predation" hereafter unless specifically noted). We assumed that the probability of detecting an event, given that it occurred, was one. Surface-feeding observations were conducted from shore by visually scanning a given area with unaided vision and/or binoculars. For each event, trained observers recorded the time, site, sea lion species, prey species, and whether the fish may have been taken from an angler. If prey appeared to escape without mortal wounds then the event was noted but not included in the tally used for estimation.

Observers followed a schedule of when and where to observe based on a probability sample generated from a three-stage cluster sampling design, with repeated systematic samples at each stage (see Figures 1 and 2, and Appendix A, for descriptions of the design; see Lohr 1999 for

background on sampling; see Wright et al. 2007 for implementation of this design elsewhere). The first stage or primary sampling units (PSUs) were "days of the week" (i.e., Sunday, Monday, etc.). The second stage or secondary sampling units (SSUs) were "site-shifts" within a day of the week (e.g., 0700-1530 at specified site(s)). The third stage or tertiary sampling units (TSUs) were 30-min observation bouts within a site-shift (i.e., three out of every four 30-min periods at a given site). Due to constraints imposed by work schedules (e.g., lunch breaks, days off), some deviations from a truly randomized design were unavoidable. However, since there is no reason to believe that sea lion foraging behavior should vary systematically with observer breaks or weekends/holidays, then imposing some restrictions on randomization is unlikely to introduce bias into estimation.

The spatial component of the sampling frame consisted of six sites in a single stratum (Figure 1). This is identical to the 2016-2019 studies but in contrast to the 2014-2015 studies that had sites spread over two strata (Figure 2). Sites 1-6 were each approximately 0.9 ha in area and occurred immediately below the falls where predation activity is typically greatest. The temporal component of the sampling frame consisted of a subset of daylight hours, ranging from 0800-1630 PST (8.5 hours) in January to 0600-1900 PDT (13 hours) in May (Figure 2).

There were 1,388 half-hour observation units (i.e., elements) in the sample out of a sampling frame of 20,658 units, resulting in an element-wise sampling fraction of 6.7%; the cluster-wise sampling fraction was also 6.7% (120 clusters out of 1792; see Appendix A). The sampling weight was 14.93, meaning that each observed predation event represented itself and 13.93 additional unobserved events. Based on previous pilot testing of the design against simulated data it was anticipated that the total salmonid predation estimate would have a coefficient of variation (CV) of 10% or less (estimates with CVs over 33% are generally considered unreliable). Missing elements (e.g., due to holidays, missed assignments, etc.) were assumed to be missing-completely-at-random but were imputed as zeros, which likely contributed to small negative bias in the predation estimates.

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

As an example, if a steelhead was killed on Monday and the window count composition for steelhead on Tuesday was 50% winter steelhead and 50% summer steelhead, then the observed kill would be assigned to a run based on a metaphorical coin toss. For the case of "unknown" salmonids, if a salmonid was killed on Monday and the window count composition on Tuesday was 90% winter steelhead, 5% summer steelhead, 4% marked spring Chinook salmon, and 1% unmarked spring Chinook salmon, then the observed kill would be assigned to a run based on a metaphorical toss of a 100-sided die where 90 sides were winter steelhead, 5 were summer steelhead, etc.

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

#### *Additional activities*

The predation monitoring design in 2022 was implemented using a single, full-time staff member who was assisted when needed by additional staff. Due to the nature of random sampling, as well as limits on how long one can sustain intense concentration, not all hours of every day were devoted to conducting sample-based observations. Any time not needed for sample-based observations was used for administrative tasks, conducting anecdotal predation observations, haul-out counts, and photographing brands.

## RESULTS

#### *River conditions*

River height and temperature near Willamette Falls are summarized in Figure 3. The most notable hydrologic events during the study included below-average water levels in the late winter months followed by above-average water levels and below-average temperatures in the early summer months.

#### *Salmonid fishway passage*

Salmonid passage and run composition over Willamette Falls are summarized in Figures 4 and 5, respectively. Passage of ESA-listed winter steelhead and spring Chinook salmon both increased in 2022 relative to the previous year but were both below their respective averages since predation observations began in 2014.

#### *Pinniped counts*

Pinniped counts based on automated cameras and incidental observations by staff at the Sportcraft haulout area began July 2021 before sea lions migrated into the study area and continued through June 2022 when sea lions had migrated out of the study area. Counts based on formal observations at Willamette Falls began in early January 2022 and continued through early June 2022. Boat-based river surveys began late August 2021 and continued through early June 2022.

California sea lions—There were no sightings of California sea lions in the study area during the last half of 2021 (Figure 6). The first individuals to occur at the falls were a pair of animals that were seen on a single day in late February (2/22/22), followed one month later by a single animal on 3/21/22 which marked the return of the “spring cohort” of California sea lions to the falls. Thereafter, numbers gradually increased until reaching a seasonal maximum of six individuals observed on 4/28/2022. The last sighting in the study area occurred on 6/10/2022. Boat surveys

of the Willamette River from the falls to the confluence with the Columbia River showed a similar phenology and relative abundance (Figure 7). Two individually identifiable California sea lions were documented at Willamette Falls in 2022 (R07 and X520). Both of which occurred in the study area in one or more previous years, and both were captured and removed in May along with one unidentified animal (Figure 6).

Steller sea lions— There were no sightings of Steller sea lions in the study area during the last half of 2021 (Figure 6). The first individual to occur at the falls was in early January (1/11/22), followed by an intermittent increase in until reaching a seasonal maximum of five individuals on 2/15/22. The “winter cohort” of Steller sea lions departed 2/28/22 and only a single, highly habituated individual occurred at the falls during the spring months (3/25-4/29/22). Boat surveys of the Willamette River from the falls to the confluence with the Columbia River showed a similar phenology but substantially greater abundance and distribution throughout the river (Figure 7). Based on natural markings, only one individually identifiable Steller sea lion was documented at the Falls in 2022. No Stellers sea lions were removed this season since they did not use the traps.

### *Predation*

California sea lions—A total of 178 predation events by California sea lions were documented during the 2022 field season (Table 1). This includes predation events seen at pre-assigned, probability-based sample units, as well as all anecdotal observations. Salmonids were the most frequently observed prey item (85%), followed by lamprey (13%), and other or unknown prey (2%). Based on the subset of these observations that occurred during probability sampling, we estimated that a total of 597 salmonids were consumed by California sea lions across the sampling frame (Table 2). Partitioning this total to run based on Monte Carlo modeling, we estimated that California sea lions consumed 50 winter steelhead (1.8% of potential escapement), 109 summer steelhead (1.9% of potential escapement), 90 unmarked spring Chinook salmon (1.4% of potential escapement above falls), and 348 marked spring Chinook salmon (1.1% of potential escapement) (Table 3).

Steller sea lions—Observers documented 68 predation events by Steller sea lions during the 2022 field season (Table 1). This includes predation events seen at pre-assigned, probability-based sample units, as well as all anecdotal observations. White sturgeon was the most frequently observed prey item (65%), followed by salmonids (16%), other or unknown prey (12%), and lamprey (7%). Based on the subset of these observations that occurred during probability sampling, we estimated that a total of 45 salmonids were consumed by Steller sea lions across the sampling frame (Table 2). This estimate was highly uncertain, however, due to the low number of observed events in the frame and we therefore did not further partition the total into run-specific estimates.

## DISCUSSION

The predation estimates presented in this report (i.e., Tables 2 and 3) are based solely on probability samples 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).

As in previous years, spatial and temporal undercoverage in our sampling frame likely resulted in our estimates of predation being biased low. Spatial undercoverage occurred because we only sample the "falls" strata whereas we know predation occurs in the "river" strata and, in some years, the nearby Clackamas River. Temporal undercoverage also occurred because, as in prior years, some sea lions likely foraged outside of our daily sampling times (i.e., before sunrise and after 7 p.m.).

Despite the undercoverage issues noted above, and setbacks due to COVID-19 in 2020, it was nonetheless clear that sea lion removals have resulted in substantial and sustained decreases in predator abundance (Figure 6) and associated predation compared to pre-management years, particularly for listed winter steelhead (Table 3). The main obstacle to removing the remaining sea lions at Willamette Falls is their lack of use of the traps. Changes to capture protocols (e.g., relocating traps, darting animals in the water) will likely have to be made to completely eliminate this remaining source of salmonid mortality.

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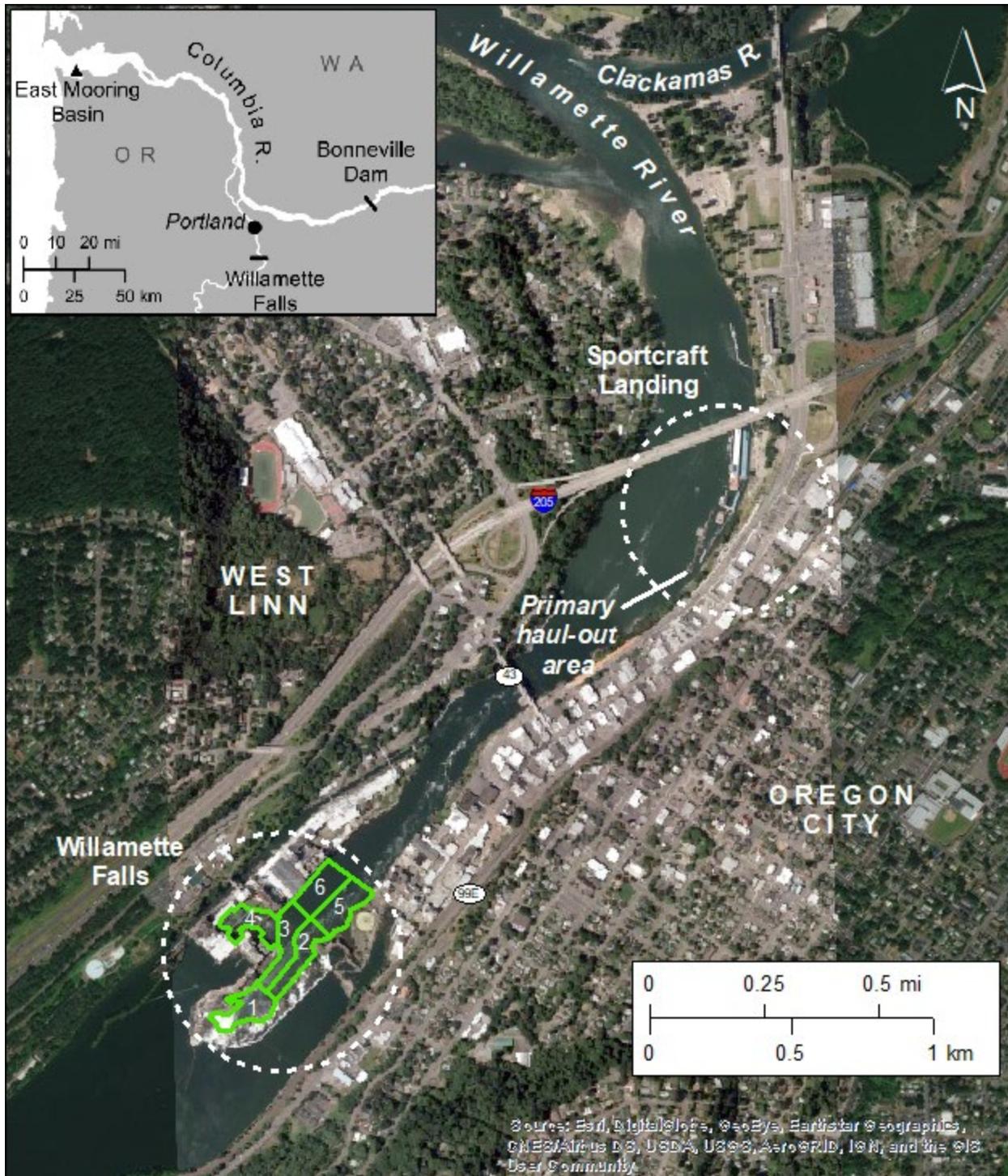


Figure 1. Illustration of the spatial component of the sampling frame for 2016-2022. Sites 1-6 ("Falls" stratum) were each approximately 0.9-ha in area.

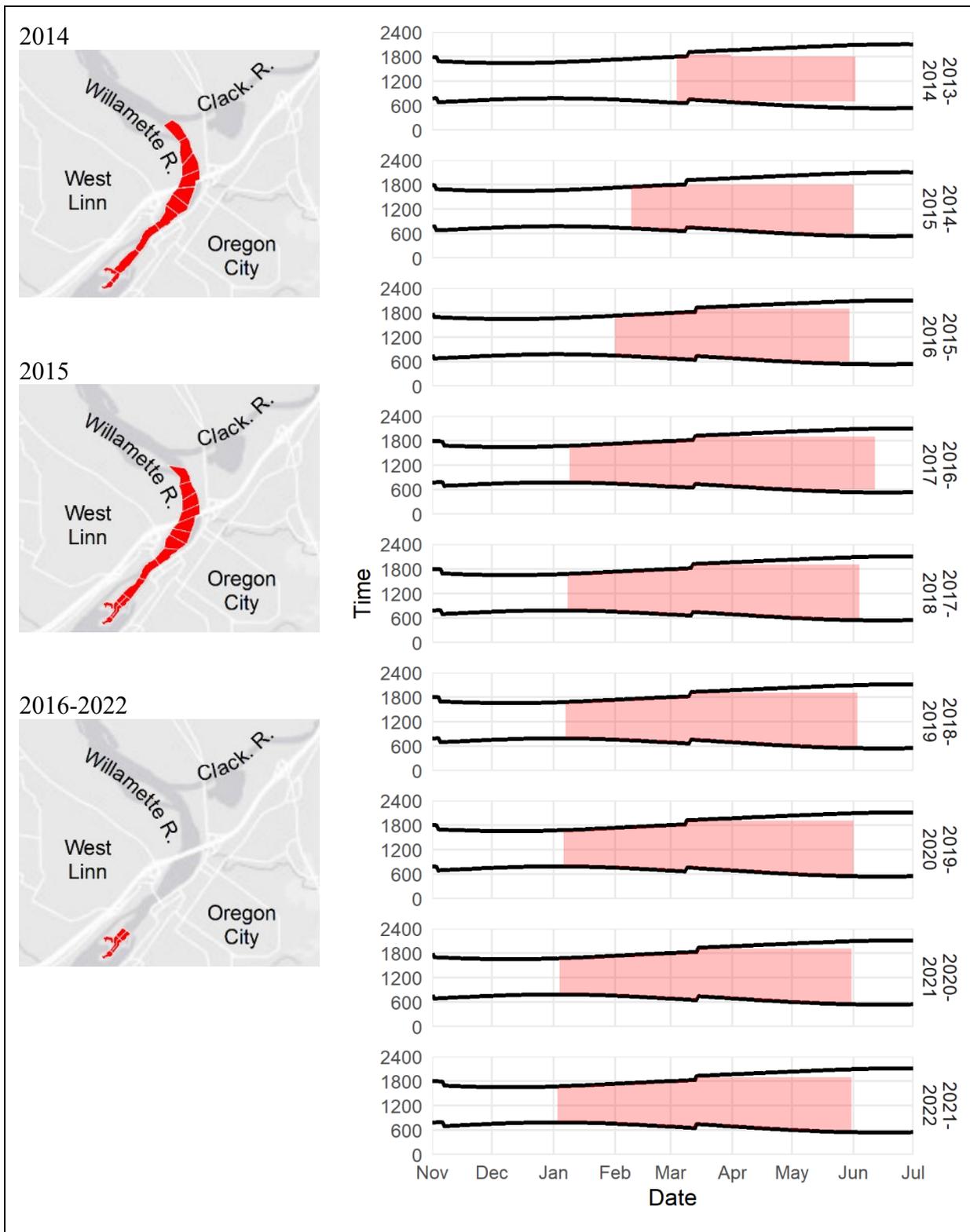


Figure 2. Illustration of the spatial (left) and temporal (right) coverage of the sampling frame by season. Red shaded areas depict time and area included in the sampling frame; dark black lines on the graph at right indicate sunrise and sunset, adjusted for daylight savings.

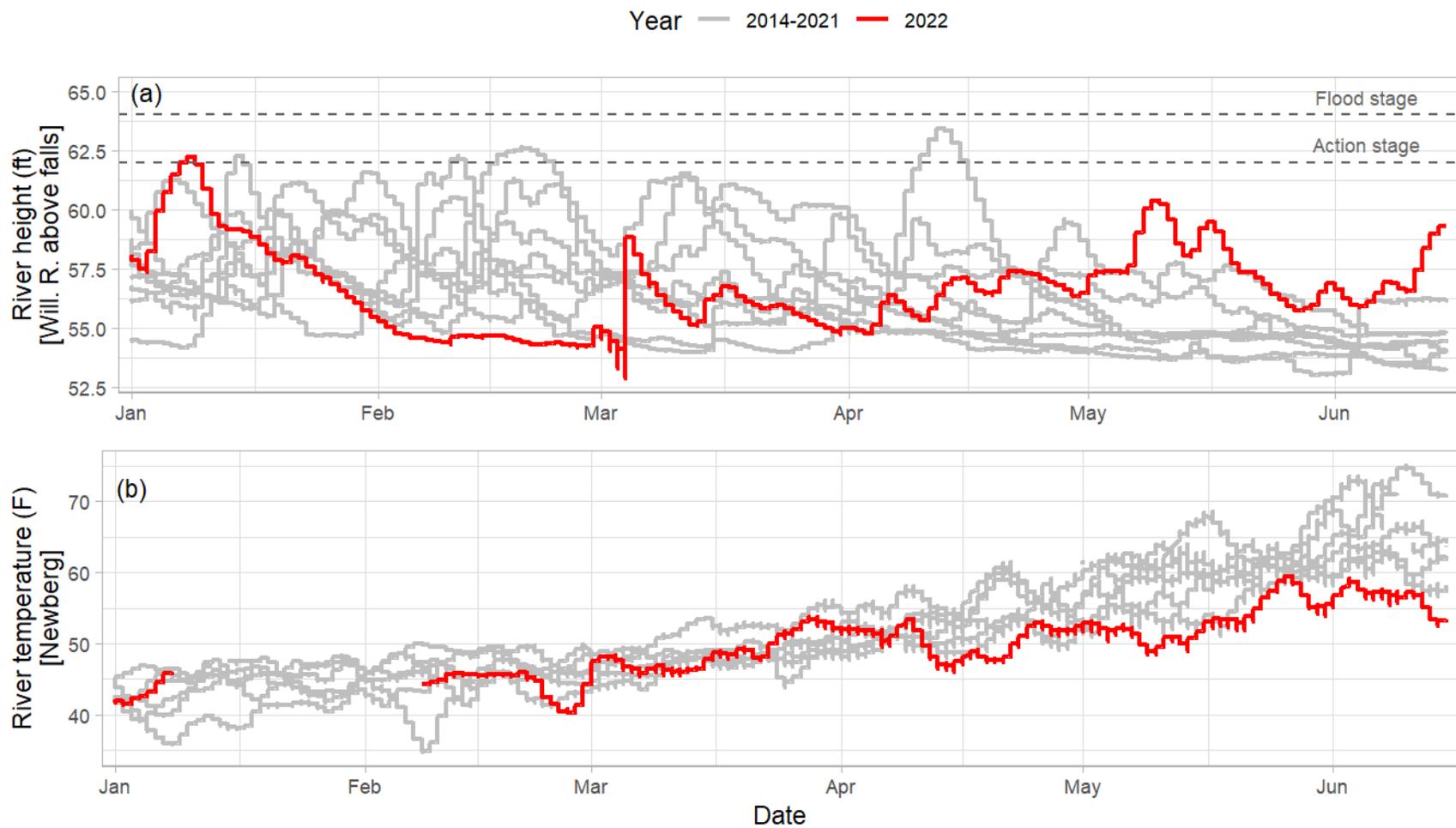


Figure 3. Height (a) and temperature (b) of the Willamette River upstream of Willamette Falls by year.

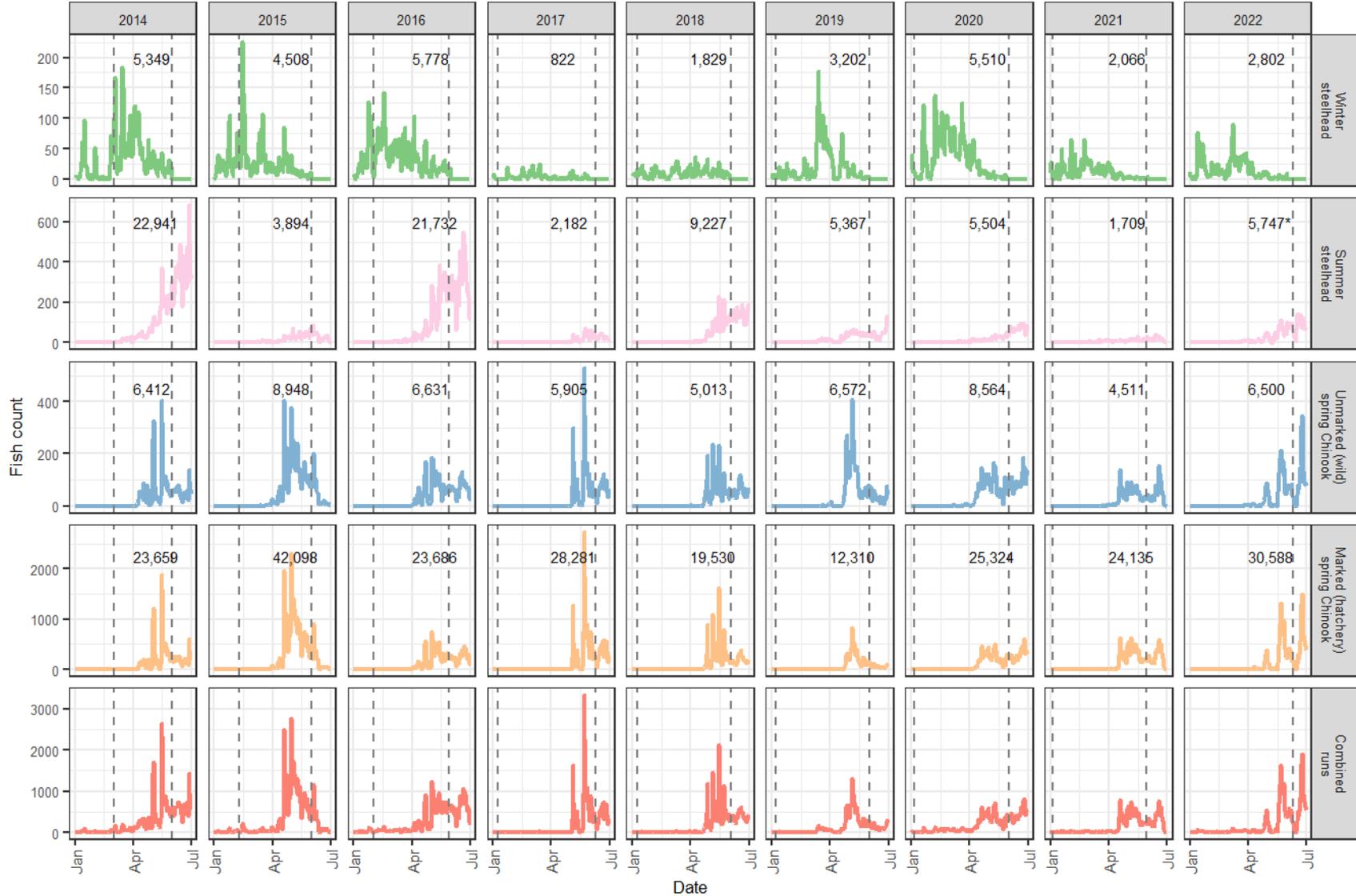


Figure 4. Daily fish counts at Willamette Falls by run and year. Vertical lines indicate study start and end dates; final escapement over falls is inset upper left of each graph. \*Summer steelhead escapement through 8/15/2022.

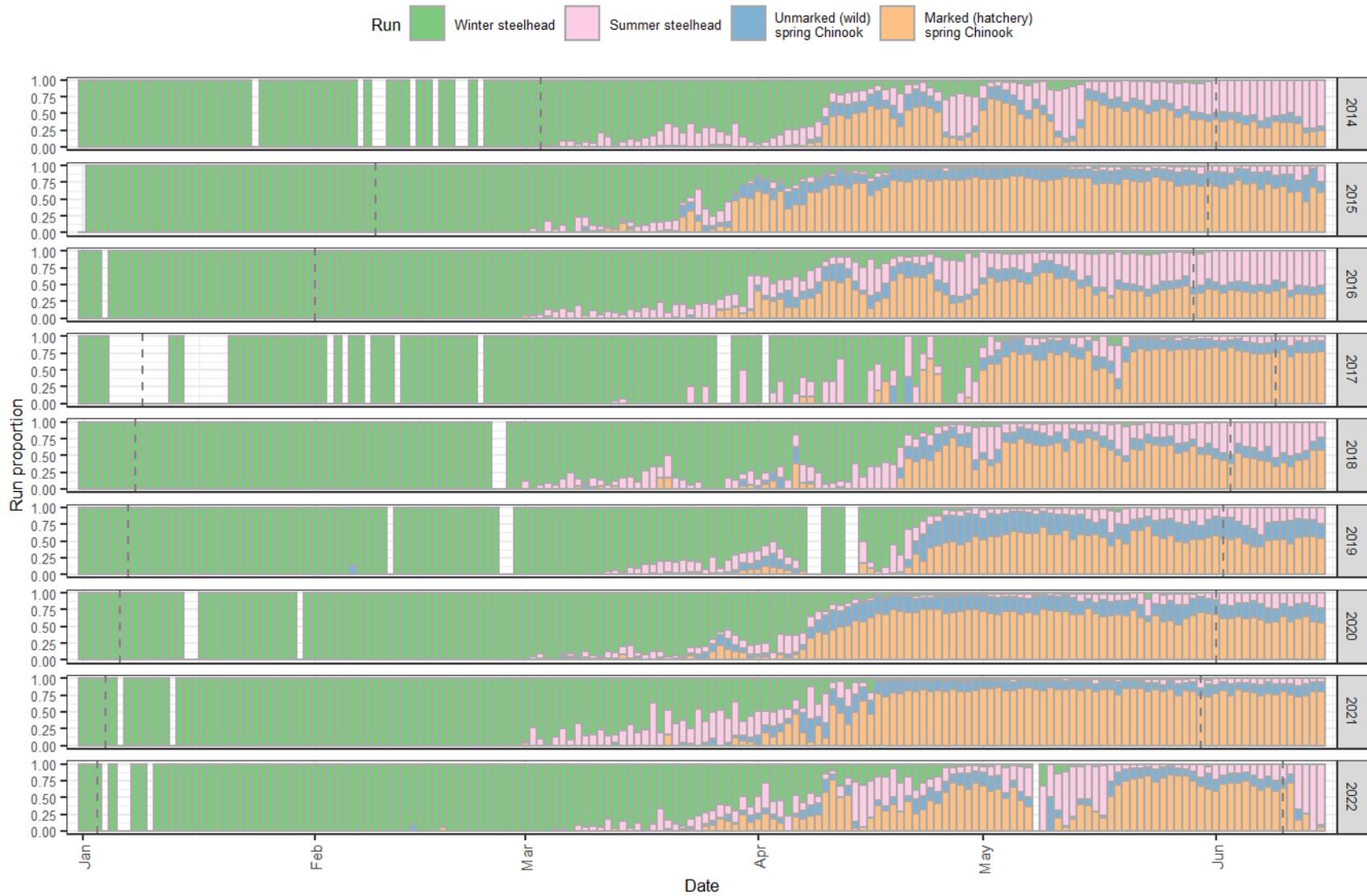


Figure 5. Daily passage composition over Willamette Falls by year. Dashed lines indicate study dates.

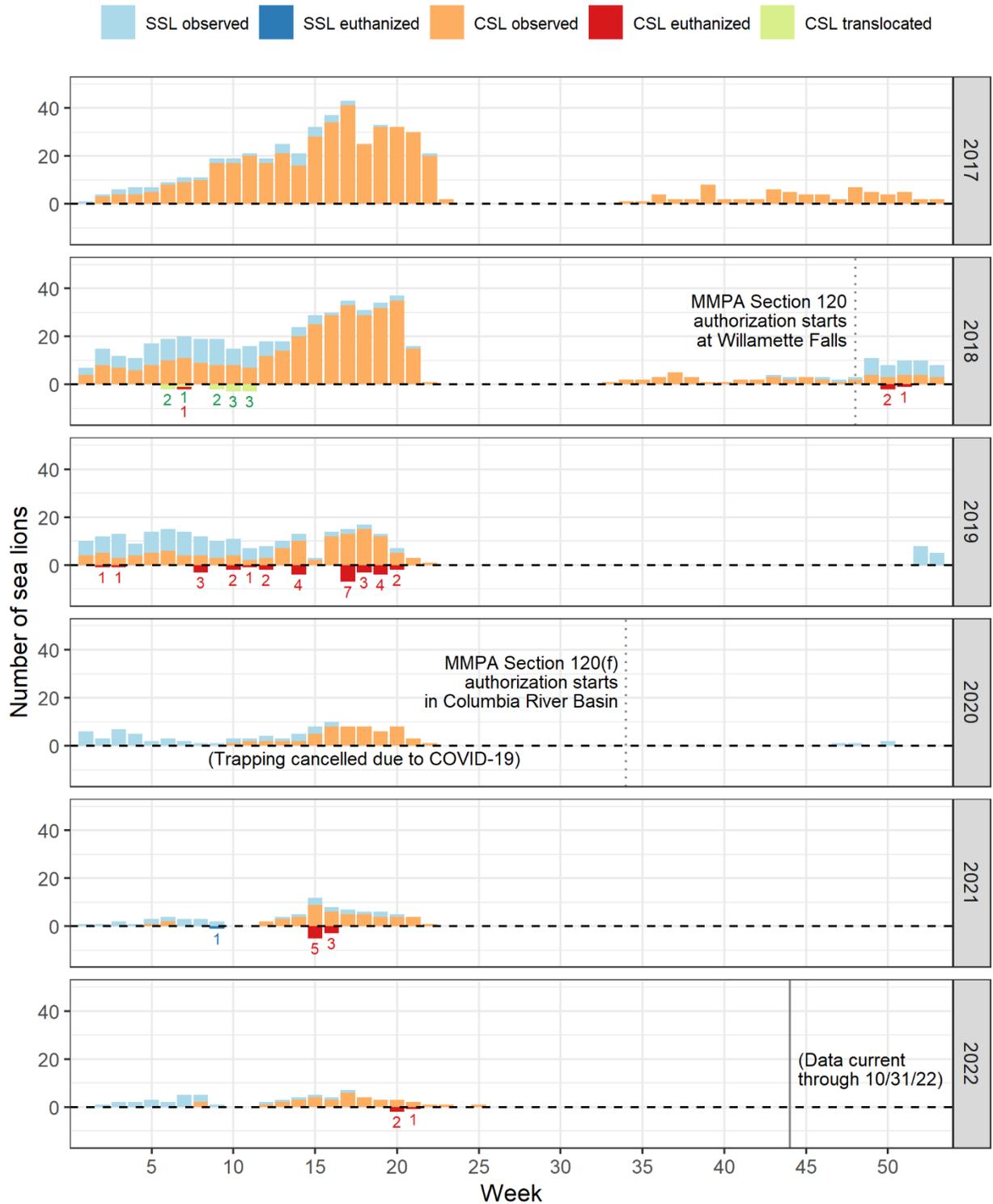


Figure 6. Weekly counts of California sea lions (CSL) and Steller sea lions (SSL) at Willamette Falls, 2017-2022. Numbers translocated or euthanized are summed over the week; numbers observed are the minimum number of unique individuals observed for that week and may include animals translocated or euthanized.

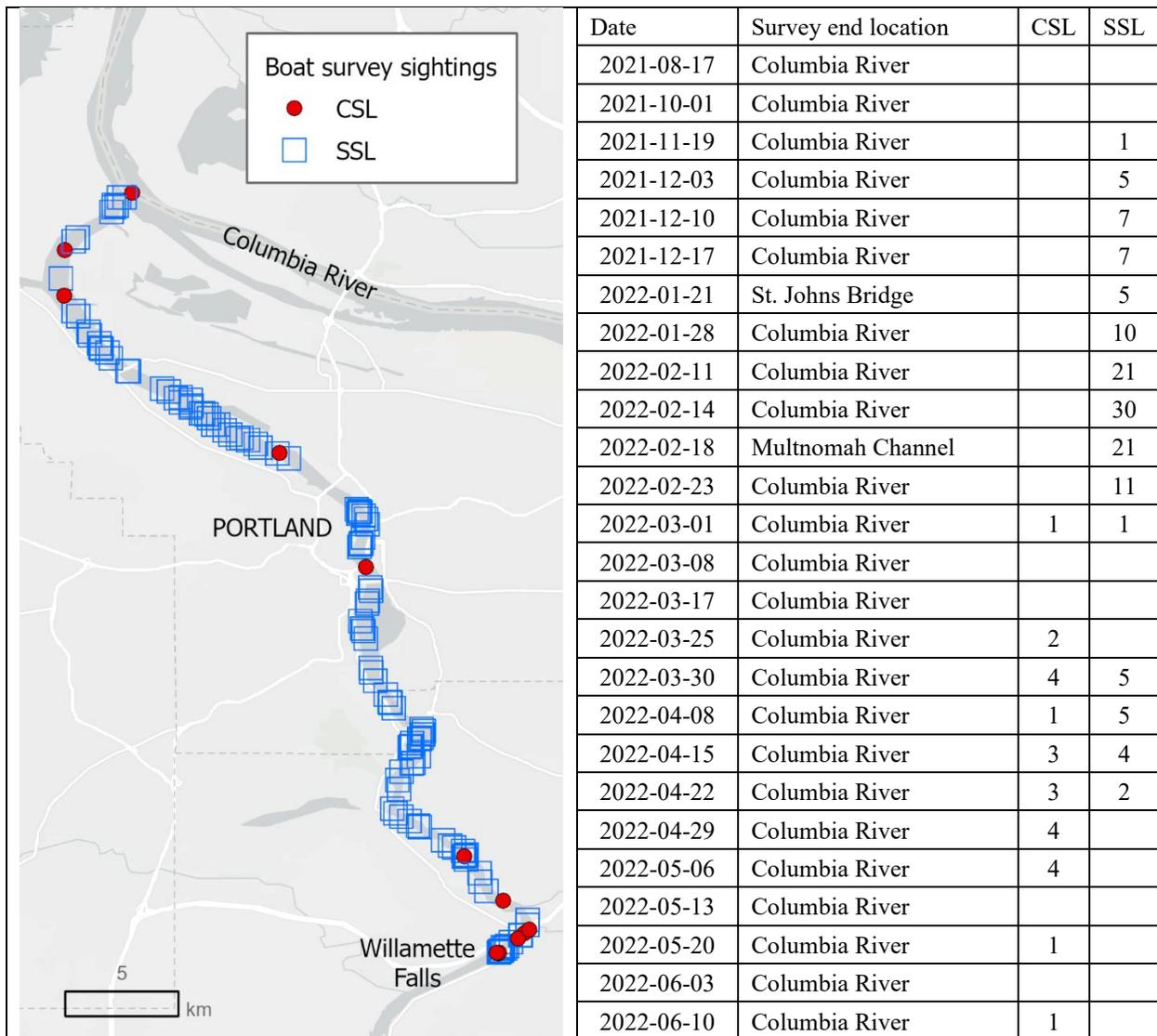


Figure 7. Individual sighting locations (map at left) and total counts (table at right) for California sea lions (CSL) and Steller sea lions (SSL) observed during vessel-based surveys of the Willamette River beginning at Willamette Falls in Oregon City and proceeding downriver to the location noted in table.

Table 1. Summary of all predation events observed at Willamette Falls which includes events from anecdotal observations outside the sampling frame as well as events seen during probability-based sampling assignments. Annual totals are not directly compared except for 2017-2020 due to changes in sampling frame and observation effort between years; the sampling frame in 2021 and 2022 was comparable to the frame in 2017-2020 but observation effort was reduced by approximately one-half.

Year	Observed California sea lion predation Total events (% by prey type within year)					Observed Steller sea lion predation Total events (% by prey type within year)				
	Salmonids	Lamprey	Sturgeon	Other/ unknown	Total	Salmonids	Lamprey	Sturgeon	Other/ unknown	Total
2014	959 (86.7%)	126 (11.4%)	3 (0.3%)	18 (1.6%)	1106	1 (25.0%)	0 (0%)	3 (75.0%)	0 (0%)	4
2015	1167 (85.3%)	175 (12.8%)	2 (0.1%)	24 (1.8%)	1368	2 (14.3%)	0 (0%)	12 (85.7%)	0 (0%)	14
2016	1001 (83.8%)	182 (15.2%)	0 (0%)	11 (0.9%)	1194	9 (52.9%)	0 (0%)	8 (47.1%)	0 (0%)	17
2017	753 (82.7%)	145 (15.9%)	0 (0%)	12 (1.3%)	910	1 (1.3%)	0 (0%)	69 (92.0%)	5 (6.7%)	75
2018	749 (86.3%)	108 (12.4%)	0 (0%)	11 (1.3%)	868	19 (18.3%)	4 (3.8%)	79 (76.0%)	2 (1.9%)	104
2019	250 (75.3%)	70 (21.1%)	0 (0%)	12 (3.6%)	332	25 (17.7%)	11 (7.8%)	98 (69.5%)	7 (5.0%)	141
2020	166 (81.0%)	32 (15.6%)	0 (0%)	7 (3.4%)	205	14 (25.9%)	0 (0%)	27 (50.0%)	13 (24.1%)	54
2021	116 (74.8%)	34 (21.9%)	0 (0.0%)	5 (3.2%)	155	29 (43.3%)	11 (16.4%)	18 (26.9%)	9 (13.4%)	67
2022	151 (84.8%)	23 (12.9%)	1 (0.6%)	3 (1.7%)	178	11 (16.2%)	5 (7.3%)	44 (64.7%)	8 (11.8%)	68

Table 2. Estimated predation by California sea lions and Steller sea lions at Willamette Falls based on the probability sampling design. Annual totals are only directly comparable for 2017-2022 due to changes in the sampling frame during the first three years of the project. Estimates only apply to the sampling frames and therefore are minimum estimates due to undercoverage of the target population.

Year	Estimated California sea lion predation Total (95% CI)				Estimated Steller sea lion predation Total (95% CI)			
	Salmonids	Lamprey	Sturgeon	Other/ unknown	Salmonids	Lamprey	Sturgeon	Other/ unknown
2014	3690 (3321-4059)	493 (361-624)	19 (0-54)	20 (2-37)	0 NA	0 NA	37 (0-108)	0 NA
2015	5775 (5096-6455)	758 (531-984)	0 NA	106 (36-177)	0 NA	0 NA	34 (0-80)	0 NA
2016	4585 (3680-5490)	1254 (696-1813)	0 NA	45 (0-111)	15 (0-43)	0 NA	15 (0-43)	0 NA
2017	2673 (1658-3688)	747 (415-1078)	0 NA	0 NA	0 NA	0 NA	15 (0-43)	0 NA
2018	3435 (3019-3850)	687 (515-859)	0 NA	0 NA	75 (22-127)	15 (0-43)	194 (28-360)	0 NA
2019	1120 (963-1277)	508 (118-897)	0 NA	0 NA	90 (25-154)	45 (0-90)	60 (3-117)	0 NA
2020	702 (479-924)	134 (37-232)	0 NA	30 (0-86)	75 (0-163)	0 NA	60 (10-109)	30 (0-86)
2021	1227 (844-1610)	443 (242-644)	0 NA	68 (0-150)	136 (0-311)	68 (0-148)	102 (3-201)	0 NA
2022	597 (406-789)	105 (43-166)	0 NA	15 (0-43)	45 (0-98)	30 (0-68)	105 (28-182)	0 NA

Table 3. Estimated run-specific salmonid predation by California sea lions at Willamette Falls based on Monte Carlo modelling of the probability sampling design. Annual totals are only directly comparable for 2017-2022 due to changes in the sampling frame during the first three years of the project. Estimates only apply to the sampling frames and therefore are minimum estimates due to undercoverage of the target population. Percent potential escapement (%PE) = estimate / (estimate + escapement) x 100.

Year	Winter steelhead		Summer steelhead		Unmarked (wild) spring Chinook salmon		Marked (hatchery) spring Chinook salmon	
	Total (95% CI)	%PE (95% CI)	Total (95% CI)	%PE (95% CI)	Total (95% CI)	%PE (95% CI)	Total (95% CI)	%PE (95% CI)
2014	780 (563-998)	12.7% (9.5%-15.7%)	710 (499-922)	3% (2.1%-3.9%)	496 (349-643)	7.2% (5.2%-9.1%)	1704 (1413-1994)	6.7% (5.6%-7.8%)
2015	561 (370-752)	11.1% (7.6%-14.3%)	172 (74-270)	4.2% (1.9%-6.5%)	901 (668-1133)	9.1% (6.9%-11.2%)	4142 (3594-4689)	9% (7.9%-10%)
2016	916 (635-1196)	13.7% (9.9%-17.2%)	767 (543-990)	3.4% (2.4%-4.4%)	651 (436-866)	8.9% (6.2%-11.5%)	2252 (1744-2759)	8.7% (6.9%-10.4%)
2017	270 (148-392)	24.7% (15.2%-32.3%)	180 (68-291)	7.6% (3.1%-11.8%)	397 (196-599)	6.3% (3.2%-9.2%)	1826 (1064-2588)	6.1% (3.6%-8.4%)
2018	503 (351-655)	21.6% (16.1%-26.4%)	517 (341-694)	5.3% (3.5%-6.9%)	467 (308-627)	8.5% (5.8%-11.1%)	1947 (1589-2304)	9.1% (7.5%-10.6%)
2019	280 (156-405)	8% (4.6%-11.2%)	109 (32-186)	2% (0.6%-3.4%)	254 (149-358)	3.7% (2.2%-5.2%)	477 (345-608)	3.7% (2.7%-4.7%)
2020	22 (0-51)	0.4% (0%-0.9%)	34 (0-73)	0.6% (0%-1.3%)	151 (60-242)	1.7% (0.7%-2.7%)	495 (318-671)	1.9% (1.2%-2.6%)
2021	25 (0-60)	1.2% (0%-2.8%)	44 (0-102)	2.5% (0%-5.6%)	186 (56-316)	4.0% (1.2%-6.5%)	971 (629-1314)	3.9% (2.5%-5.2%)
2022	50 (0-102)	1.8% (0%-3.5%)	109 (34-184)	1.9%* (0.6%-3.1%)*	90 (23-156)	1.4% (0.4%-2.3%)	348 (212-485)	1.1% (0.7%-1.6%)

\*Summer steelhead escapement through 8/15/2022.

Appendix A. Sampling design metadata describing the Willamette Falls sea lion monitoring program, 2014-2022.

Year	Stratum	Sites	Staff	Dates	Weeks	Hours	$N$ PSUs	$M$ SSUs	$K$ TSUs	Frame clusters	$n$ PSUs	$m$ SSUs	$k$ TSUs	Sample clusters	Sampling fraction	Weight	Frame elements	Sample elements	Elements per cluster
2014	F	3	2	Mar 3 - Jun 1	13	1,001	7	7	16	784	5	2	12	120	15.3%	6.53	6,006	929	7.66
	R	9	2	Mar 3 - Jun 1	13	1,001	7	20	16	2,240	5	2	12	120	5.4%	18.67	18,018	966	8.04
		12	4							3,024				240	7.9%		24,024	1,895	
2015	F	6	2	Feb 9 - May 31	16	1,239	7	14	16	1,568	5	2	12	120	7.7%	13.07	14,868	1,101	9.48
	R	10	2	Feb 9 - May 24	15	1,155	7	22	16	2,464	5	2	12	120	4.9%	20.53	23,100	1,122	9.37
		16	4							4,032				240	6.0%		37,968	2,223	
2016	F	6	2	Feb 1 - May 29	17	1,389	7	16	16	1,792	5	2	12	120	6.7%	14.93	16,668	1,114	9.30
2017	F	6	2	Jan 9 - Jun 9	22	1,750	7	16	16	1,792	5	2	12	120	6.7%	14.93	21,000	1,413	11.71
2018	F	6	2	Jan 8 - Jun 3	21	1,653.5	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,842	1,337	11.14
2019	F	6	2	Jan 7 - Jun 2	21	1,647	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,764	1,327	11.05
2020	F	6	2	Jan 6 - May 31	21	1,642.5	7	16	16	1,792	5	2	12	120	6.7%	14.93	19,710	1,329	11.08
2021	F	6	1	Jan 4 - May 30	21	1,636	na	na	na	3,272	na	na	na	96	2.9%	34.08	19,632	576	6
2022	F	6	1	Jan 3 - Jun 5	22	1,721.5	7	16	16	1,792	5	2	12	120	6.7%	14.93	20,658	1,388	11.6