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EVALUATION OF PINNIPED PREDATION ON ADULT SALMONIDS AND OTHER FISH IN THE BONNEVILLE DAM TAILRACE, 2022

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Cover Photo: Steller sea lions basking in the Bonneville Dam tailrace.

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Past reports and more information on the Pinniped Monitoring Program at Bonneville Lock and Dam can be found at the following link:

http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Pinnipeds/

Executive Summary

California sea lions (CSL; *Zalophus californianus*) and Steller sea lions (SSL; *Eumetopias jubatus*) seasonally aggregate at the base of Bonneville Dam to feed on Pacific salmon, steelhead (*Oncorhynchus spp.*), and White Sturgeon (*Acipenser transmontanus*). Due to predation on several species listed as threatened or endangered under the federal Endangered Species Act (ESA), the Federal Columbia River Power System 2020 Biological Opinion continued the requirement for the U.S. Army Corps of Engineers to monitor the seasonal presence, abundance, and predation activities of sea lions at Bonneville Dam. Here we report these data for the 2021-2022 season. Per requirements of National Oceanic Atmospheric Administration, we monitor and report data for the fall and winter period of 2021 and the traditional spring period of 2022. Abundance was monitored daily, while predation sampling began when there were ≥ 20 pinnipeds in the tailrace of Bonneville Dam.

Approaching the fall season (August – December) the first pinnipeds were observed returning to the Bonneville tailrace in late-July 2021. Daily abundance monitoring recorded between 28 July and 31 December 2021 resulted in an average of 17.5 ± S.D. 11.0 SSLs each day, with only one CSL observed during the same period. Fall fish predation monitoring began on 22 August 2021 when the abundance of pinnipeds was consistently ≥ 20 and continued variably at the Powerhouse 2 tailrace during daylight hours until 30 October 2021[1].

Monitoring continued during the traditional spring season (January – May). Daily abundance monitoring was recorded from 5 January through 21 May, with an average of 9.8 ± S.D. 15.4 SSLs and 2.1 ± S.D. 3.3 CSLs observed each day. Predation sampling was initiated on 3 April 2022 due to the 20-animal trigger and concluded on 21 May 2022 when pinnipeds were nearly absent from the dam.

Sea lion predation on Chinook, Coho, and steelhead salmon was monitored during the fall (Aug – Dec) and spring (April – May) seasons to estimate the number of fish killed and to determine the percentage of the yearly run of each fish species that was consumed by SSL and CSL during each observation period. The following consumption estimates with 95% confidence intervals and associated percent of run consumed are derived from predation events observed during the observation periods covered in this report.

- Fall 2021 Chinook Salmon: 1305 (642 – 1746); 0.4%
- Spring 2022 Chinook Salmon: 4437 (3423 – 5324); 3.1%
- Fall 2021 steelhead: 61 (19 – 97); 0.2%
- Spring 2022 steelhead: 68 (3 – 117); 8.6%
- Fall 2021 Coho: 297 (200 – 392); 0.1%
- Fall 2021 White Sturgeon: 1119 (786 – 1414); N/A
- Spring 2022 White Sturgeon: 40 (0 – 79); N/A

Data provided by the 20 years of USACE pinniped monitoring has been used to inform management actions and has contributed to changes that are now being realized. The number of CSLs has been reduced because of management efforts. The number of SSL remain at high levels and new impacts from this species are now being documented. White Sturgeon and winter steelhead are disproportionately impacted by SSL at Bonneville Dam. The recent efforts by state and tribal management agencies to trap and remove SSL from the Bonneville tailrace may lessen these impacts, but the sustained impacts to these fish populations should be noted by fish managers.

[1] Total predation at Bonneville Dam during this time is likely higher than these estimates due to predation in other tailraces.

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Introduction and Background

Centuries of interspecific competition for anadromous salmonids between marine mammals and humans (SBFC, 1889; Thwaites, 1969) has contributed to the persecution of some marine mammal species in the Pacific Northwest (Braje & Rick, 2011; Newby, 1973; Scheffer, 1950). Chief among these competing species, the pinnipeds (seals and sea lions) in Oregon and Washington were targeted for population reduction through bounty-incentivized removal programs by state wildlife managers which contributed to reducing populations to all-time lows (NOAA, 2016a; Pearson & Verts, 1970; Peterson & Bartholomew, 1967). In response to the universal decline of marine mammal stocks, the Marine Mammal Protection Act (MMPA) was enacted in 1972 and effectively buoyed some northwest pinniped stocks to all-time high levels in the following 30 years (Brown et al., 2005; Jeffries et al., 2003). Concomitant to the success of the MMPA (Magera et al., 2013), salmonid stocks declined to a point where many are now listed under the Endangered Species Act of 1973, especially those of the Columbia River and its tributaries (NFSC, 2015). The flux of predator and prey in the Columbia River has now transitioned to high numbers of protected pinnipeds, and low numbers of threatened and endangered salmonids.

Historical pinniped distribution in the Columbia River system has been detailed through archaeological records, whereby seal (Family: Phocidae [true seals]) remains were documented at river kilometer 314 (river mile 195) near Celilo Falls (Lyman et al., 2002), a falls now inundated by The Dalles Reservoir. Sea lions (Family: Otariidae [eared seals]) have historically frequented the lower portions of the Columbia River system (i.e. the Columbia Estuary), but there is no evidence of congregations of these animals in the river section of what is now Bonneville Dam (BON) in the time preceding dam construction (i.e. 1938) nor in the six decades following construction (Keefer et al., 2012). The dam is largely impassable for pinnipeds but its tailrace area is now commonly frequented by sea lions and an occasional harbor seal (*Phoca vitulina*).

Sea lions were first documented at BON in the late 1980s when California sea lions (CSL; *Zalophus californianus*) were sporadically observed depredating spring Chinook Salmon (*Oncorhynchus tshawytscha*) (Stansell, 2004). Steller sea lions (SSL; *Eumetopias jubatus*) were first documented at BON in 2003 (Keefer et al., 2012). Anecdotal observation suggested the duration of residency and amount of salmonid predation by pinnipeds increased in subsequent years, leading fish managers to question the potential impact such predators may be having on migrating adult salmonid fish runs (NMFS, 1997).

Analyses of pinniped-salmonid interactions in or near the Columbia River suggest that all life stages of salmonids are at risk of predation by pinnipeds (Brown et al., 2017; Chasco et al., 2017), and that some salmonid runs are at greater risk of predation and potential extinction than others (Falcy, 2017; Keefer et al., 2012). As such, pinniped predation on imperiled salmonids in the Columbia River has garnished considerable attention and continues to be a focus of concern and research (Kinsey, 2007).

Because BON is the lowermost Columbia River dam, it passes a greater diversity and number of anadromous migrants than any other dam on the river, and therefore has the potential to have the largest impact on fish passage (Evans et al., 2016). Pinniped predation at the dam has spurred concern for impacts to ESA listed salmonids for almost two decades. The U.S. Army Corps of Engineers (USACE) Fisheries Field Unit (FFU) initiated a pinniped monitoring program in the early 2000s in response to these concerns and to fulfill requirements established through various ESA consultations with National Marine Fisheries Service (NMFS) regarding the operation and maintenance of the Federal Columbia River Power System. This monitoring effort, pinniped predation deterrence measures, and NMFS Biological Opinion (BiOp) requirements have been adjusted and refined over the past 20 years.

Potential impacts of fish predators at hydroelectric dams have long been of concern to fish managers (Evans et al., 2016; Schilt, 2007) and can present challenges to management agencies (Friesen & Ward, 1999; McKinney et al., 2001). The Columbia River System of hydroelectric dams is one of the most advanced hydropower systems in the world and has been subject to in-depth study and analysis of fish predator activities and deterrence (Roscoe & Hinch, 2010; Patterson et al., 2017). Focus was historically given to the predation of out-migrating juvenile salmonids given the extensive suite of predators that can depredate these younger age classes including warm water fish (Mesa et al., 1994; Poe et al., 1991; Sorel et al., 2016) and piscivorous birds (Collis et al., 2002). However, attention has now been turned to upstream migrating adult fish exposed to pinniped predation. Like natural fish passage impediments (e.g., waterfalls, cascades, chutes), hydroelectric dams can delay upstream fish passage and cause fish to congregate while searching for ladder entrances (Kareiva et al., 2000; Quinones et al., 2015). These delays increase the time that fish are vulnerable to predation by pinnipeds (Naughton et al., 2011; Stansell, 2004), a clade known to be efficient predators of Pacific Northwest fishes (Weise & Harvey, 2005).

In November 2018, USACE, Bonneville Power Administration (BPA) and the U.S. Bureau of Reclamation (USBR) – collectively, the Action Agencies – reinitiated consultation with NMFS and submitted a Biological Assessment (BA) that included certain pinniped monitoring and management activities as part of the Proposed Action. The purpose of this consultation was to provide ESA coverage for operation and maintenance of the Columbia River system until the Columbia River System Operations (CRSO) Environmental Impact Statement (EIS) and associated Record of Decision (ROD) and ESA consultations were completed. The interim BiOp issued by NMFS on 29 March 2019 shaped USACE pinniped monitoring and management actions through much of the 2020 passage season. In association with the CRSO EIS, a new Biological Assessment was submitted by the Action Agencies in January 2020 and NMFS issued a new BiOp in July 2020 (Biological Opinion for Operation and Maintenance of the Fourteen Multiple-Use Dam and Reservoir Projects in the Columbia River System | NOAA Fisheries). The CRSO ROD (CRSO Home (army.mil)) was signed on 28 September 2020 and USACE began operating under the 2020 BiOp on that date (NOAA 2022). Overall requirements were similar under these two consultations.

In accordance with these ESA requirements, USACE implemented the following pinniped monitoring and management activities from July 2021 to June 2022:

- Installed sea lion exclusion devices at all adult fish entrances at BON year-round.
- Continued to fund dam-based hazing of pinnipeds observed in the vicinity of fish ladder entrances at BON and on an ad hoc basis at The Dalles Dam. Hazing at BON was required from 1 March through 31 May and from 15 August through 31 October.
- Provided support to state wildlife management agencies and the Columbia River Inter-Tribal Fish Commission (CRITFC) pursuant to their sea lion management programs, including crane support and access.
- Monitored predation by sea lions at BON when abundance was ≥ 20 sea lions and reported results to NMFS and other regional partners via the Fish Passage Operations and Maintenance (FPOM) work group. This report meets the requirement to submit an annual report to NMFS.

In 2021-2022, the objectives of the FFU pinniped monitoring program were to:

1. Determine the seasonal timing and abundance of pinnipeds present at the BON tailrace, documenting individual CSL and SSL presence and predation activity when possible.
2. Monitor the spatial and temporal distribution of pinniped predation attempts, estimate the number of adult salmonids (*Oncorhynchus spp.*), White Sturgeon (*Acipenser transmontanus*), Pacific Lamprey (*Entosphenus tridentatus*), and other fishes consumed by pinnipeds in the BON tailrace.
3. Estimate the proportion of the adult salmonid run consumed by pinnipeds.
4. Monitor the effectiveness of deterrent actions (e.g., exclusion gates, acoustics, harassment, and other measures) and their timing of implementation on runs of anadromous fish passing BON.

Of note is the altered sea lion management scope of the states of Oregon, Washington, and Idaho (collectively: the States) and the Columbia Inter-Tribal Fish Commission (CRITFC) since the passage of the Endangered Salmon Predation Prevention Act (S. 3119) which allows these management agencies to lethally remove SSL and CSL at select areas on the Columbia River including below Bonneville Dam without the restrictions of the previous lethal removal authority for CSL. This change in authority removes the reporting requirements and documentation required previously. Specifically, requirements of residency and abundance metrics are no longer needed. As such, the reporting metrics presented this year will not have some data that have previously been reported.

This report is a summary of abundance and predation monitoring and deterrence efforts implemented from 28 July 2021 to 21 May 2022 by, or coordinated with, the aforementioned agencies. For brevity and ease of communication we have appended the study design, description of the BON tailrace system, life history of the pinniped and fish species studied, and the general study approach to Appendix 1. We present a brief overview of the study design and methods to help orient readers then present current data partitioned by species and, where possible, contrast it to previous estimates to elucidate the trends of pinniped presence and predation on adult migratory fish at BON. We encourage readers not familiar with the previous 20 years of reports to read the material in Appendix 1 before digesting the new data.

Study Design

Summary of Methods

We sample the cumulative abundance of pinnipeds in the three tailraces below BON using daily visual encounter surveys from multiple vantage points on the dam. Trained observers watch for predation events in the tailraces during sampled daylight hours using a stratified sampling design to enable estimates of predation during times not observed. Bootstrap sampling of these estimates provides bounded estimates of predation by week, for each fish species, and by each species of pinniped and therein allow bounded estimates on impact to each fish run. The methods are briefly expanded on below, though we encourage all readers not familiar with the data to reference Appendix 1 for a detailed description of methodological approach.

Pinniped abundance was documented daily to ensure predation sampling began as soon as the 20-animal trigger was met, at which time sampling began for pinniped-fish predation. Predation sampling continues each week after reaching the 20-animal trigger until the daily abundance of pinnipeds drops and remains below 20 animals. During the fall and winter period of 2021 sampling occurred at Powerhouse 2 based on dam operations that impact fish passage. The priority powerhouse for power generation influences fish ladder access and dictates which tailraces are sampled. During the spring period of 2022, all three tailraces were observed for predation sampling each week, except for the exclusion of the spillway during the first week when it was not operational. These methods are consistent with prior years in which sampling location was dependent on powerhouse priority.

Quantification of Abundance

We conducted independent point counts once per day in the three tailraces of BON and at known haul-out locations using field glasses. The point count includes the mouth of Tanner Creek, a tributary often utilized for spawning just downstream of BON that is a known location of pinniped predation on adult salmonids. Counts were conducted in a short period of time (e.g. ≤ 20 minutes) to reduce the possibility of counting animals transiting between locations more than once. Point counts were conducted during morning or evening civil twilight when most pinnipeds are hauled out to ensure a more accurate count. We derived a daily maximum pinniped abundance by summing the individual count data at each location and for each species. Linear interpolation was used for days that counts were not taken (i.e. weekends and holidays), and in doing so, we present the maximum number of animals observed at the dam on each day irrespective of time of day. As management requirements have changed, we did not attempt to describe the residency or recruitment metrics for each species of sea lion. For more specifics regarding methodological assumptions and techniques see Appendix 1.

Quantification of Predation

Surface observations of pinniped-fish interactions have been utilized to measure the number of fish and species consumed by pinnipeds at several locations including the last 20 years at BON and nine years at Willamette Falls (Roffe & Mate, 1984; Tidwell et al., 2021; Wright et al., 2018,). Trained observers documented all surface predation events that occurred within a select sampling location and time period using field glasses. We employed a stratified random sampling design with bootstrap analyses to estimate the number of fish consumed per strata (week) with confidence intervals (Tidwell et al. 2018).

We provide estimates of fish predation during the fall and winter period for the Powerhouse 2 tailrace by assessing fish passage at the Washington Shore fish ladder. Due to dam operations and powerhouse prioritization, we monitored and assessed passage at Powerhouse 2 from 22 August to 30 October 2021. For analysis of impacts to fish species, we present the number of fish crossing these fish ladders during the respective times (www.FPC.org) and provide an estimate of the percent of these fish that were consumed during the study period. Any inference of these data to the entire tailrace area or locations downstream need be made with caution.

Similarly, we provide estimates of fish predation during the spring period for all three tailraces and present the number of each fish species that cross both the Washington Shore fish ladder at Powerhouse 2 and the Bradford Island fish ladder at Powerhouse 1 between 3 April and 21 May 2022. This period was historically 1 January – 31 May, but the 20-animal trigger truncated the sampling period as it has in recent years. We analyze the impact to each fish species by estimating the percent of these fish consumed during the study period.

All data were compiled and manipulated in the USACE Pinniped Access Database. Data were exported to Microsoft Excel and all analyses were done in Program R (Version 4.2.1) and SAS (Version 12.1).

Results

Abundance

Pinnipeds were generally absent from BON between 28 May and 28 July 2021, during which time only one SSL was sporadically observed on five separate days. No observations were made 15-28 July during the summer period of known general pinniped absence. Daily abundance counts, and the abundance data presented herein began on 28 July 2021 at which time two SSL were present.

Fall Abundance

We documented 51 individual SSLs between 28 July and 31 December 2021. Only one CSL and no harbor seals were observed in the fall observation season. Across the fall and winter period, the daily average abundance of SSLs was 17.5 ± S.D. 11.0 animals. Due to the variable nature of the daily abundance data, we present the median of 16.0 SSLs as well.

The number of SSLs enumerated increased gradually throughout August from a single animal to 28 on 31 August. They were present in higher numbers in September and October with an average of 27 per day, and a seasonal peak of 51 on 13 September. There was a slight resurgence in late November, though numbers remained lower than September and October and declined quickly into an average of 8 per day during December (Figure 1B).

Spring Abundance

We documented 62 individual SSLs and 25 individual CSLs during the 5 January – 21 May 2022 time period (Table 1). No harbor seals were observed in the spring observation season. Across the spring season, CSLs had an average of 2.1 ± SD 3.3 animals per day, whereas SSLs had an average of 9.8 ± SD 15.4.

During the spring, CSLs were present from late March through late May, with the first individual of the season observed on 23 March. CSLs were present throughout the season in low numbers compared to the 10-year average (Figure 1A), peaking at 20 individuals on 26 March with a secondary peak of 11 individuals on 7 April, and a daily mean of 4.8 individuals through April and May. In general, there were very few CSLs at BON in spring 2022 with most days having eight or fewer CSLs present (Figure 1A).

Steller sea lions were present throughout the spring observation period, although in varied abundance. During January through March, SSLs were present in low numbers averaging 1.5 animals per day. The number of SSLs increased throughout April with an average of 29.4 animals per day and reached the seasonal peak of 62 animals on 28 and 29 April. During May, SSLs averaged 15.6 animals per day with greater than 50 animals present in the early part of the month and then generally decreasing until there were zero by the end of the month (Figure 1B). During April and May, the SSL daily mean was 23.9 individuals.

Table 1. Minimum estimated number of individual pinnipeds observed at Bonneville Dam tailrace areas and the hours of observation during the spring sampling period, 2002 to 2022.

Year	Total Hours Observed	California Sea Lions	Steller Sea Lions	Harbor Seals	Total Pinnipeds
2002	662	30	0	1	31
2003	1,356	104	3	2	109
2004	516	99	3	2	104
2005*	1,109	81	4	1	86
2006	3,650	72	11	3	86
2007	4,433	71	9	2	82
2008	5,131	82	39	2	123
2009	3,455	54	26	2	82
2010	3,609	89	75	2	166
2011	3,315	54	89	1	144
2012	3,404	39	73	0	112
2013	3,247	56	80	0	136
2014	2,947	71	65	1	137
2015	2,995	195	69†	0	264
2016	1,974	149	54†	0	203
2017	1,142	92	63†	1	156
2018	1,410	67	66†	1	134
2019	836	26	50†	0	76
2020	331	34	45†	2	81
2021	132	24	62†	0	86
2022	205	25	62†	0	82

* Observations did not begin until March 18 in 2005.

† In 2015, 2016, 2017, 2018, 2019, 2020, 2021, and 2022 the minimum estimated number of Steller sea lions (SSL) was 55, 41, 32, 35, 21, 20, 24, and 13 respectively. These counts were less than the maximum number of Steller sea lions observed on one day, so the maximum number observed on one day was used as the minimum estimated number. This difference is driven by a focus on CSLs and lack of brands or unique markers on SSL.

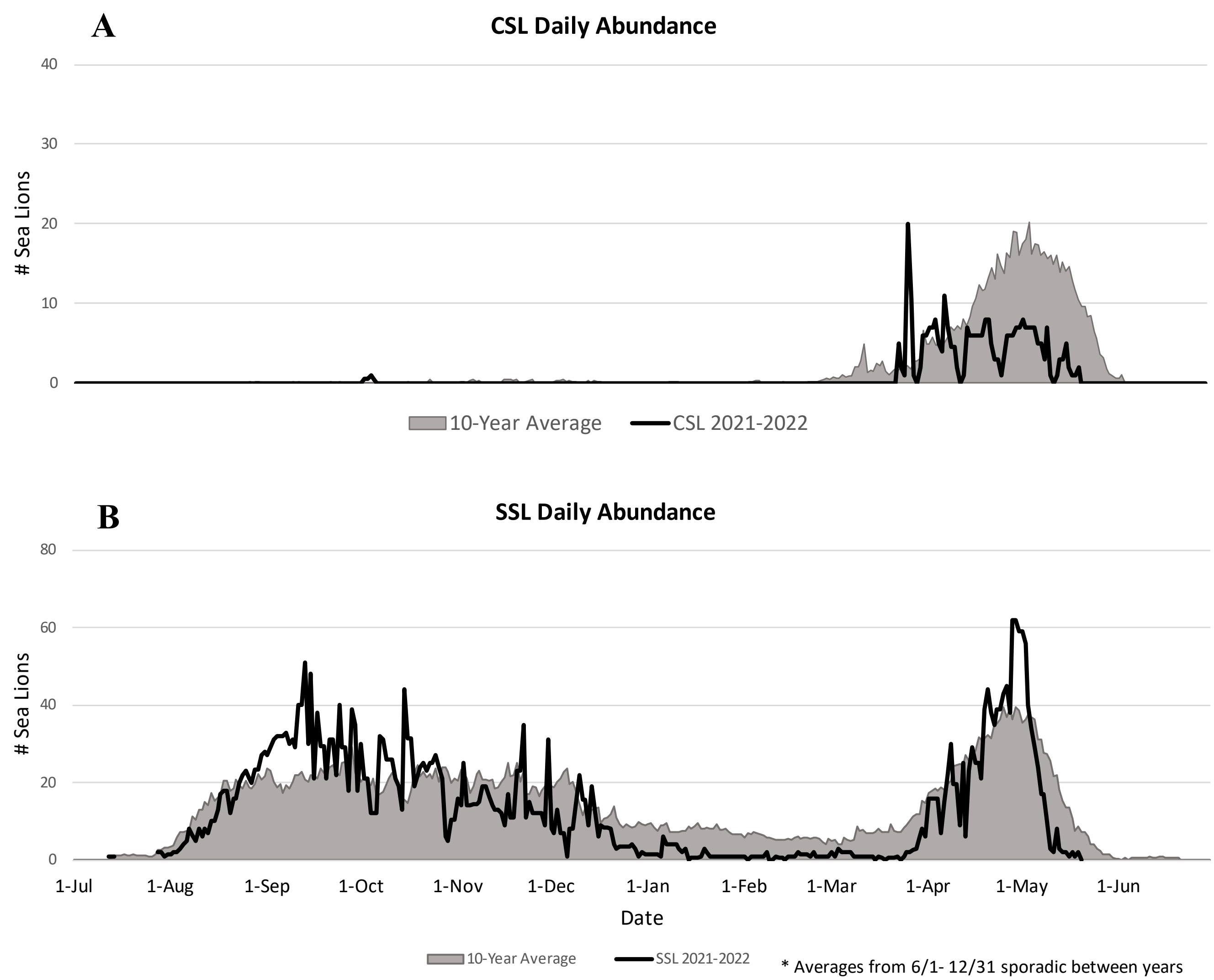

Figure 1. Maximum daily count of pinnipeds by species (SSL: Steller sea lions, CSL: California sea lions) at Bonneville Dam from 1 July 2021 through 30 June 2022 compared to the 10-year maximum daily average. For reference: fall and winter sampling period = 28 July – 31 December 2021 and spring period = 5 January – 21 May 2022. * Averages from 6/1 - 12/31 begin in 2011 but are sporadic between years.

Predation

We recorded 188 independent one-hour observation periods between 22 August 2021 and 30 October 2021 and 205 independent one-hour observation periods between 3 April 2022 and 21 May 2022. Below we present the predation impact on all fish species for each study period (Table 2). All predation estimates are presented as the bootstrap calculated adjusted estimate (i.e. raw count data expanded for missing hours and adjusted for unidentified fish catches) and are followed by their associated 95% confidence bounds to display the confidence of the estimate.

Table 2. Fish predation by pinnipeds at Bonneville Dam between 22 August 2021 and 21 May 2022.

Fish Species	Number of Fish Killed (95% CI)	Percent Run Consumed During Observation Period
Fall Chinook Salmon	1305 (642 – 1746)	0.4%
Spring Chinook Salmon	4437 (3423 – 5324)	3.1%
Steelhead – Aug. – Oct. 2021	61 (19 – 97)	0.2%
Steelhead – April – May 2022	68 (3 – 117)	8.6%
Coho Salmon	297 (200 – 392)	0.1%
White Sturgeon – April – May 2022	40 (0 – 79)	N/A
White Sturgeon – Aug. – Oct. 2021	1119 (786 – 1414)	N/A

Fall Chinook Salmon

An estimated 1305 (642 – 1746) fall Chinook Salmon were consumed in the Powerhouse 2 tailrace during the observed weeks between 22 August and 30 October 2021. During this period 331,884 Chinook and jack Chinook crossed the Washington Shore fish ladder, so we estimate that 0.4% of the passing fish were consumed by pinnipeds (Table 2). During this period there were only SSL present and as such, all predation occurred by SSL. For historical consumption estimates see Table 3.

Spring Chinook Salmon

An estimated 4437 (3423 – 5324) spring Chinook Salmon were consumed across the three tailraces sampled during the observed weeks between 3 April and 21 May 2022. Across this period a total of 144,407 Chinook and jack Chinook crossed BON, so we estimate that 3.1% of the run was consumed by pinnipeds (Table 6). We estimate that SSL account for 2264 (1497 – 2921) spring Chinook consumed, and CSL account for 2190 (1469 – 2852) spring Chinook consumed. For historical consumption estimates see Table 6.

Fall Steelhead

An estimated 61 (19 – 97) steelhead were consumed in the Powerhouse 2 tailrace during the observed weeks between 22 August and 30 October 2021. During this period 37,675 steelhead crossed the Washington Shore fish ladder, so we estimate that 0.2% of the passing fish were consumed by pinnipeds (Table 2). During this period there were only SSL present and as such, all predation occurred by SSL. For historical consumption estimates see Table 3 & 4.

Spring Steelhead

An estimated 68 (3 – 117) steelhead were consumed across the three tailraces sampled during the observed weeks between 3 April and 21 May 2022. Across this period a total of 791 steelhead crossed BON, so we estimate that 8.6% of the run was consumed by pinnipeds (Table 2). This estimate should be used with caution due the small sample size of steelhead observed being consumed. During the spring sampling period we observed six steelhead predation events. Four steelhead were consumed by CSL, and two were taken by SSL. For historical consumption estimates see Table 4.

Coho Salmon

An estimated 297 (200 – 392) Coho Salmon were consumed in the Powerhouse 2 tailrace during the observed weeks between 22 August and 30 October 2021. During this period 198,443 Coho and jack Coho crossed the Washington Shore fish ladder, so we estimate that 0.1% of the passing fish were consumed by pinnipeds (Table 2). During this period there were only SSL present and as such, all predation occurred by SSL. For historical consumption estimates see Table 3.

Fall White Sturgeon

An estimated 1119 (786 – 1414) White Sturgeon were consumed in the Powerhouse 2 tailrace during the observed weeks between 22 August and 30 October 2021. During this period there were only SSL present and as such, all predation occurred by SSL. For historical consumption estimates during the fall season see Table 3.

Spring White Sturgeon

An estimated 40 (0 – 79) White Sturgeon were consumed across all tailraces during the observed weeks between 3 April and 21 May 2022. During this period only SSL were observed predating White Sturgeon, though CSL were present and predating other fish. For historical consumption estimates during the spring season see Table 7.

Pacific Lamprey

We rarely observed lamprey predation during this reporting period. One lamprey catch was recorded in fall 2021 and one in spring 2022. Both lamprey were consumed by SSL. For historical consumption estimates see Table 9.

Other Fish Species

Between 22 August 2021 and 21 May 2022, we observed nine Smallmouth Bass (*Micropterus dolomieu*) and four American Shad (*Alosa sapidissima*) consumed across the three tailraces of BON. While Smallmouth Bass were the most identified species of other fish, we had a similar number of predation events in which the fish consumed were very small and thus could not be identified to species. These fish were likely a mix of juvenile salmonids and native Cyprinids (family *Cyprinidae*).

Table 3. Fall and winter fish predation estimates with associated Standard Error (SE) for Steller sea lions at Bonneville Dam between 2017 and 2021.

Year	Hours Observed	Location	Chinook Salmon (SE)	Coho Salmon (SE)	Steelhead (SE)	White Sturgeon (SE)
2017	139	PH2	401 (281 - 506)	368 (296 - 432)	123 (63 - 172)	238 (183 - 281)
2018	369	PH1	419 (354 - 484)	269 (214 - 323)	293 (244 - 342)	359 (301 - 416)
2019	341	PH2	1,365 (1,222 - 1,497)	156 (99 - 210)	174 (129 - 217)	762 (583 - 915)
2020	234	PH 1&2*	756 (621 - 879)	292 (200 - 373)	75 (40 - 105)	589 (433 - 724)
2021	188	PH2	1305 (642 – 1746)	297 (200 – 392)	61 (19 – 97)	1119 (786 – 1414)

* Split sampling due to dam operations changing priority powerhouse mid-season.

Temporal Distribution of Salmonid Predation Events

Fall Chinook Salmon 2021. An estimated 331,884 fall Chinook Salmon passed the Powerhouse Two tailrace during the fall 2021 observation season between 22 August and 30 October. For comparison, during those same dates cumulative fall Chinook Salmon passage across all fish ladders at BON was 387,666, which is a smaller run estimate when compared to the 10-year average of 560,380. While no predation observations were performed between 1 August and 21 August due to the 20-animal trigger, only 14,011 fall Chinook passed BON during that time. Thus, the majority of the run was monitored for predation, including the peak of the run on 31 August 2021.

Spring Chinook Salmon 2022. An estimated 144,407 spring Chinook Salmon passed BON between 3 April and 21 May; a larger run estimate compared to the 10-year average of 107,996 during those same dates. While no predation observations were performed between 1 January and 2 April 2022 due to the 20-animal trigger, only 920 spring Chinook passed BON during that time. Thus, the majority of the run was monitored for predation, including the peak of the run on 3 May 2022.

Fall Steelhead 2021. An estimated 37,675 steelhead passed the Powerhouse Two tailrace during the fall 2021 observation season between 22 August and 30 October. For comparison, during those same dates the cumulative steelhead passage across all fish ladders at BON was 44,102, which is a smaller run estimate when compared to the 10-year average of 78,544. While no predation observations were performed between 1 August and 21 August 2021 due to the 20-animal trigger, only 11,361 steelhead passed BON during that time. Thus, the majority of the run was monitored for predation, including the peak of the run on 26 August 2021.

Spring Steelhead 2022. An estimated 791 steelhead passed BON between 3 April and 21 May; a smaller run estimate compared to the 10-year average of 1,367 during those same dates. No predation observations were performed between 1 January and 2 April due to the 20-animal trigger, and 1,922 steelhead passed BON during that time. Therefore, the majority of the run was not monitored for predation. Moreover, we cannot produce estimates of impact to the winter steelhead run (i.e. 16 November – 31 March) this year due to the lack of predation sampling between 31 October 2021 and 2 April 2022.

Coho Salmon 2021. An estimated 198,443 Coho Salmon passed the Powerhouse Two tailrace during the fall 2021 observation season between 22 August and 30 October. For comparison, during those same dates cumulative Coho Salmon passage across all fish ladders at BON was 245,607, which is a larger run estimate when compared to the 10-year average of 96,174. While no predation observations were performed between 1 August and 21 August 2021 due to the 20-animal trigger, only 802 Coho Salmon passed BON during that time. Thus, the majority of the run was monitored for predation, including the peak of the run on 31 August 2021.

Upstream Observations

During the tenure of this monitoring program, pinnipeds have been documented transiting the navigation lock of BON to the forebay. Although uncommon, it has been documented multiple times over the years. Some CSLs have even taken up residence in the Bonneville Reservoir and have lived between BON and The Dalles Dam for multiple years. We did not record, nor were we notified of any pinnipeds being observed above BON during this reporting period.

Deterrents and Management

Physical Barriers

Due to pinnipeds entering the fishways of BON in years past, physical barriers were developed to preclude entry of pinnipeds into the fishways. Metal grating installed at the fishway entrances termed Sea Lion Exclusion Devices (SLEDs) were deployed at all entrances for the duration of this monitoring period. SLEDs continue to be effective at keeping pinnipeds out of the fishways, as none were observed in fishways during this reporting period (Appendix 2).

Non-Lethal Harassment

Hazing of pinnipeds by USDA staff was ongoing between 1 July and 30 June 2022 dependent on seasonal presence.

Trapping and Removal

State and tribal management agencies trapped and removed sea lions at Bonneville Dam during this reporting period. Twenty-four SSLs were removed during the fall of 2021 and in spring of 2022 they removed 14 CSLs and nine SSLs (Edwards et al., 2022). For additional information on sea lion management at Bonneville Dam visit https://www.dfw.state.or.us/fish/sealion/.

Discussion

Pinniped abundance sampling during 2021-2022 revealed that CSL and high SSL abundance was similar to the 2020-2021 reporting period, and predation on ESA and other runs of salmon and fish species now predominantly occurs by SSL. Below we explore the data in reference to previous years and discuss emerging and continuing trends.

Abundance

The average number of SSLs during the fall and winter of 2021 was 38.9% lower than 2020 and 1.7% lower than the 10-year average (Figure 1B). Over the last ten years we have documented increasing numbers and earlier arrival of SSLs to BON in the fall and winter. Most of the branded and identifiable SSL that returned in the fall and winter remained at BON through the spring which contributed to the growing number of SSLs. However, given the limited brands these animals have, the number of individual SSL that foraged at BON this year is difficult to estimate and is likely much higher than this year's daily maximum count of 62 SSLs. The average number of SSLs during spring season of 2022 was 10.1% lower than last year and 25.8% lower than the previous 10-year average (Figure 1B). The decline in SSL is a new result and likely the result of management's newly enacted authority to lethally remove SSL.

The average number of CSLs during the spring of 2022 was similar to the spring of 2021 wherein there were less than three CSL present per day on average between 5 January and 21 May. Albeit CSL had minimal daily presence, we documented a 40% increase in CSL abundance relative to spring of 2021 owing to select marked periods of high CSL abundance at BON (Figure 1A). Despite these short periods of high CSL abundance we documented a 57.1% decrease from the 10-year average (Figure 1A). The last three years data suggest that management efforts to remove CSL have resulted in fewer animals coming to BON but doing so in large groups for short periods of time.

The duration of SSL presence at BON during the winter months has been increasing since 2011, wherein animals are returning to the dam shortly after the spring season and staying for the winter (Tidwell et al., 2019). However, this year we documented a reversal of the pattern, wherein SSL stayed away from the dam two weeks longer than the previous year. During the 2021-2022 season we sporadically observed one SSL between 28 May and 28 July 2021, but only on five separate days during the two-month period. SSLs were largely away from the tailraces of BON for approximately eight weeks, as opposed to six weeks of SSL absence in 2020. This is the first time since 2011 that SSL presence at the dam has gone down. Albeit the two-week interval is small, the direction of change is noteworthy and may be the result of two factors that have merit to the monitoring program.

First, many of the individually identifiable SSL that have been branded or possess unique marks that allow reliable identification have been returning to the dam for > 10 years and are now in the last years of life. Likely senescing from the population and dying of natural causes. Second, the removal effort of managers is starting to be realized wherein, 24 SSL were removed in fall of 2021, and fewer habituated SSL were available to return to BON in spring of 2022. The removal efforts at both the Willamette Falls site, 64 river miles away, and BON synergistically function to remove offending predatory SSL from the system as in the 2021-22 year we again documented SSL going between the two sites in the same week. A relationship that has been well documented during the spring and now the fall season (Stansell, 2004; Tidwell et al., 2020).

Predation

Predation sampling during the 2021-2022 season was limited by the 20-animal trigger. We emphasize that the fish consumption estimates presented herein apply only to the period and tailraces sampled each season. Like previous years, all three tailraces were sampled during the spring, while only the Powerhouse 2 tailrace was sampled during the fall and winter period. As such, the estimates represent solely the sampled period of the selected tailrace. Extrapolation of these consumption estimates to all three tailraces are beyond the scope of the required work. Previous data collected from the fall and winter season as directed by NOAA since 2017 can be found in Table 3, but we caution that inference be made respective of dates and locations sampled. We reiterate that fish passage and the subsequent impact of pinnipeds on each run was assessed using only the date range sampled, rather than the passage dates as defined by the Fish Passage Plan.

Predation on Chinook Salmon

It has been hypothesized that early returning spring Chinook Salmon are disproportionately consumed relative to later returning fish due to the presence of pinnipeds aggregated at the dam when the fish first arrive. The early arriving spring Chinook Salmon are also hypothesized to be most often composed of ESA listed stocks (Keefer et al. 2012). This season, predation sampling did not occur during the early portion of the run and therein impacts to these stocks cannot be addressed. Like previous years, pinnipeds left the dam prior to run cessation and as such, the late running fish were able to pass BON without predator impact in the near-dam environment.

Fall Chinook Salmon. In the weeks sampled between 22 August and 30 October 2021, we estimate that 1,305 Chinook salmon were consumed in the Powerhouse 2 tailrace, which constitutes 0.4% of the run during that time (Table 2). Withstanding the above caution, we draw inference of consistent inter-year impacts by SSL based on the data collected during the fall/winter sampling periods from 2017 to 2020. During this four-year period the average estimate of consumption for fall Chinook Salmon was 735 fish and 0.6% of the run (Table 3). The 2021 consumption estimate is higher than the 4-year average for fall Chinook Salmon consumed, though it presents a lower percent impact to the run.

Spring Chinook Salmon. In the weeks sampled between 3 April and 21 May 2022, we estimate 4,437 spring Chinook Salmon were consumed in all three tailraces, which constitutes 3.1% of the run during that time (Table 2). For comparison, the 10-year average estimate was 4,209 spring Chinook Salmon consumed, and the 10-year average for percent of run consumed was 3.2% (Table 6). The 2022 consumption estimate is similar to the 10-year average of fish consumed and similar to the 10-year average percent of run consumed.

Of interest to spring Chinook consumption was the species-specific consumption estimates; we estimate the daily maximum of unique CSL was 20 individuals, SSL was 62 individuals yet the percent impact to the run was nearly identical with CSL consuming 1.5% of the run and SSL consuming 1.6%. Despite their low abundance, CSL consumed as many spring Chinook Salmon as SSL. Factors influencing this observation may include: 1) Kleptoparasitism of CSL salmon kills by SSL which leads to increased CSL predation attempts, 2) cryptic consumption by SSL previously documented such as sub-surface predation, downstream predation out of the study area, or predation in the turbulent waters of the spillway where observation is more difficult (Tidwell et al. 2018), or 3) increased motivation by CSL to kill spring Chinook Salmon perhaps due to their short duration at BON. Ultimate causation of the difference cannot be determined but should be monitored in coming years as removals continue as the potential differences in behavior or motivation to kill spring Chinook Salmon would all impact the monitoring program and evaluation of the removal program.

Predation on Steelhead

Steelhead crossing BON during the spring have historically been analyzed as a single entity, but they are functionally recognized as two distinct varieties: the winter run, defined as those steelhead crossing BON between 16 November and 31 March, and the summer run which cross after 31 March (Busby et al., 1996; Withler, 1966). In 2019, we sampled the entire run period and found that more than 13% of the run was consumed by pinnipeds with the vast majority being consumed by SSLs. As in the 2021 season, we cannot produce estimates for the 2022 season because sampling did not occur between 16 November 2021 and 2 April 2022 (i.e., the majority of the winter steelhead passage season). However, the recently depauperate steelhead returns, the previously documented impacts by SSL, and the estimated number of steelhead consumed after the defined dates partitioning Summer from Winter steelhead as presented below (i.e. 8 % of the run) beget attention be paid to steelhead impact by sea lions at BON.

Both pre-spawn steelhead and post-spawn steelhead kelts are vulnerable to pinniped predation at BON. Due to the magnitude of the kelt outmigration from the Snake and Columbia Rivers (Colotelo et al., 2014; Evans et al., 2004,), and because each powerhouse at BON has effective adult downstream passage routes (Wertheimer, 2007), it is likely that the adults consumed include some kelts. Thus, the impacts documented herein suggest that pinniped predation has a greater impact on steelhead than on other species of concern. In part due to ecological variables (e.g., cold waters, low fish abundance near BON) and in part due to the steelhead's complex life histories (e.g., iteroparity), the impacts of SSL predation on ESA-listed winter and summer steelhead are an issue of concern that needs to be addressed and managed accordingly.

Fall Steelhead. In the weeks sampled between 22 August and 30 October 2021, we estimate that 61 steelhead were consumed in the Powerhouse 2 tailrace, which constitutes 0.2% of the run during that time (Table 2). Withstanding the above caution, we draw inference of consistent inter-year impacts by SSL based on the data collected during the fall/winter sampling periods from 2017 to 2020. During this four-year period the average estimate of consumption for steelhead was 166 fish and 1.1% of the run (Table 3). The 2021 consumption estimate is lower than the 4-year average for fish consumed and presents a lower percent impact to the run.

Spring Steelhead. In the weeks sampled between 3 April and 21 May 2022, we estimate that 68 steelhead were consumed in all three tailraces, which constitutes 8.6% of the run during that time (Table 2). For comparison, the 10-year average estimate was 247 steelhead consumed, and the 10-year average for percent of run consumed was 6.2% (Table 4). The 2022 consumption estimate is lower than the 10-year average of fish consumed and higher than the 10-year average percent of run consumed.

Between 2007 and 2021 the average consumption of winter and summer steelhead has been 7.1% of the run (Table 4). Components of these runs are ESA listed and as such, merit attention from managers. As cautioned, the sampling methods used to provide these estimates produce minimum consumption estimates. Therein, potential impacts to listed steelhead runs are likely much higher, and suggest that impacts to ESA listed steelhead are two-fold more severe than the impacts to the spring Chinook Salmon that initiated concern and have driven policy to manage sea lions to protect the runs.

Predation on Coho Salmon

In the weeks sampled between 22 August and 30 October 2021, we estimate that 297 Coho Salmon were consumed in the Powerhouse 2 tailrace, which constitutes 0.1% of the run during that time (Table 2). Withstanding the above caution, we draw inference of consistent inter-year impacts by SSL based on the data collected during the fall/winter sampling periods from 2017 to 2020. During this four-year period the average estimate of consumption for Coho Salmon was 271 fish and 1.3% of the run (Table 3). The 2021 consumption estimate is similar to the 4-year average for fish consumed, though it presents a lower percent impact to the run.

Predation on White Sturgeon

White Sturgeon consumption by pinnipeds at BON has changed considerably over the last 20 years, but recent trends warrant immediate attention by managers as the dynamics and species compositions have changed and the potential impacts to White Sturgeon are now perhaps more severe. Prior to SSL monitoring during the fall and winter, White Sturgeon predation was documented exclusively by SSL during the spring. Between 2008 and 2012 more than one thousand White Sturgeon were consumed each spring with a peak in 2011 of over 3,000 fish consumed. After 2012, White Sturgeon predation dropped sharply and between 2015 and 2017 we estimate that less than 100 sturgeon were consumed each spring. Fall and winter monitoring was implemented in 2017 and we now document that the decreased springtime consumption of White Sturgeon has been offset by increased and significant fall and winter consumption of the fish. Consumption estimates of fall and winter SSL are now as large as the springtime estimates during the peak spring periods of 2008 – 2012.

Fall White Sturgeon. In the weeks sampled between 22 August and 30 October 2021, we estimate that 1,119 White Sturgeon were consumed in the Powerhouse 2 tailrace. Data collected during the fall and winter season of 2017 through 2020 showed an estimated average of 487 White Sturgeon consumed throughout the observation periods each year (Table 3). The consumption estimate for 2021 of 1,119 fish is two times higher than previous years, which had an estimated consumption range of 238-762.

Spring White Sturgeon. In the weeks sampled between 3 April and 21 May 2022, we estimate that 40 White Sturgeon were consumed across all BON tailraces. SSLs were responsible for all depredation of White Sturgeon during this time period, despite the continuous presence CSLs. This consumption estimate is lower than the 10-year average of 383, but a drastic increase from the single observed catch in 2021.

White Sturgeon depredation by pinnipeds has distinctively changed over the past decade; while 40 estimated predation events during the spring may not be cause for immediate concern, the fall and winter consumption demands more attention from judicious fish managers in the coming years. Our data validated our findings of the previous four years and suggests that the impact to White Sturgeon is greater during the fall and winter months than during the spring. It is worth noting that the minimum consumption estimates presented during the fall and winter here suggest that three months of sampling across all three tailraces this spring resulted in an estimate of 40 sturgeon consumed, and three months sampling in one tailrace in the fall and winter resulted in an estimate of 1,119 White Sturgeon consumed in just that tailrace. Why more fish are killed in the fall and winter than the spring is unclear, but the additive mortality of White Sturgeon over time at BON may be contributing to the questionable status of the stock.

Predation on Lamprey

Only two Pacific Lamprey predation events were observed during the fall 2021 and spring 2022 observation periods, with one predation event occurring in each season. Both depredated Pacific Lamprey were consumed by SSL. It is likely that pinnipeds are consuming significant numbers of lamprey in the BON tailrace. Since our observations are limited to above-surface actions, we suspect subsurface predation may be occurring.

Additional unreported consumption of Pacific Lamprey is supported by ODFW dietary analysis of pinnipeds removed from BON. In the fall of 2021 and spring of 2022, ODFW analyzed the gastro-intestinal tracts of 47 sea lions, including 33 SSL and 14 CSL. The gastro-intestinal tracts of SSLs included 31 fish identifiable as Pacific Lamprey, 20 of which were found in a single SSL (Edwards et al., 2022). While no Pacific Lamprey remains were found within the GI-tract of any removed CSL in this reporting period, some have been reported in previous years' dietary analyses.

Predation on Other Fishes

Across both sampling periods we documented several predation events on other fish species which is consistent with previous years. Smallmouth Bass, American Shad, and Asian Carp are typically consumed, however, the Juvenile salmon documented by Edwards et al. 2022 likley incorporate to this group as well and explain the GI contents described above. Of note is the fall predation documented on ESA-listed Chum Salmon in years past, but not this season. We have previously reported that Chum Salmon predation occurring in the BON tailraces is likely a smaller subset of predation events occurring immediately below the BON tailraces in the vicinity of Pierce and Ives islands where Chum Salmon spawn (Tidwell et al. 2019). The potential impact to Chum Salmon based on observed pinniped abundance and predation at BON is concerning and worth management's attention.

Deterrence and Management

Physical Barriers

Physical barriers at fish ladder entrances (e.g. SLEDs, FOGs) continue to be the most effective deterrent mechanism currently employed (Appendix 2). They successfully excluded all pinnipeds from entering the fish ladders this season. Given the near year-round residency of SSLs, continuing to deploy the devices year-round is warranted.

Hazing

As discussed in previous reports, the value of hazing pinnipeds with conventional methods continues to be questioned. The recurrence of habituated pinnipeds following increased and prolonged hazing events over the last decade suggest its functionality is minimal. The select benefit of current hazing techniques might be the brief moments of time when active hazing is occurring, which has been found to dissuade active foraging behaviors (Götz & Janik, 2013). A two-year analysis of SSL response to dam-based hazing at BON was published by the authors in 2021 and found that SSL habituate to hazing quickly (Tidwell et al., 2021). The study found that except for the initial application of hazing, SSL did not leave the tailrace, continued foraging, and had levels of vigilance comparable to baseline levels when no hazing was present. Thus, empirical evidence specific to BON now exists to challenge the effort and expense of applying dam-based hazing.

Removal

The passage of the Endangered Salmon Predation Prevention Act gave management the authority to remove SSL and CSL without requirements of predation, hazing, or residency. As shown through fish consumption and CSL abundance data, the removal of CSL over the last decade has contributed to a reduced ESA listed fish impact. The novel removal of SSL at BON occurred this year and shows promise as a management tool. The recurrence of highly habituated and identifiable individuals decreased with the removal of each animal. Future management actions for SSL may further reduce the impact to ESA listed salmon and sensitive stocks.

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References

Beddington, J. R., R. J. H. Beverton, and D. M. Lavigne. 1985. Marine mammals and fisheries. George Allen and Unwin, London, UK.

Boehme, L., A. Baker, M. Fedak, M. Arthun, K. Nicholls, P. Robinson, D. Costa, M. Biuw, and T. Photopoulou. 2016. Bimodal winter haul-out patterns of adult Weddell Seals (*Leptonychotes weddellii*) in the southern Weddell Sea. *PloS One,* 11(5): e0155817.

Braje, T. J., and Rick, T. C. (Eds.). 2011. Human Impacts on Seals, Sea Lions, and Sea Otters: Integrating Archaeology and Ecology in the Northeast Pacific. University of California Press.

Brown, R., S. Jeffries, D. Hatch, and B. Wright. 2017. Field Report: 2017 Pinniped research and management activities at Bonneville Dam. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Ave., Corvallis, OR 97330.

Brown, R. F., B. E. Wright, S. D. Riemer, and J. Laake. 2005. Trends in abundance and status of harbor seals in Oregon: 1977-2003. Marine Mammal Science 21(4):657-670.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast Steelhead from Washington, Idaho, Oregon, and California. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division.

Chasco, B. E., I. C. Kaplan, A. C. Thomas, A. Acevedo-Gutiérrez, D. P. Noren, M. J. Ford, M. B. Hanson, J. J. Scordino, S. J. Jeffries, K. N. Marshall, A. O. Shelton, C. Matkin, B. J. Burke and E. J. Ward. 2017. Competing tradeoffs between increasing marine mammal predation and fisheries harvest of Chinook salmon. *Scientific Reports*, 7:15439.

Clark, C., M. Brown, D. Hatch, and J. Dupont. 2021. Annual report: 2021 Columbia River Basin research and management activities. Washington Department of Fish and Wildlife, 600 Capitol Way N, Olympia, WA 98501-1091.

Cochran, W. G. 1977. Sampling Techniques, 3rd edition. Wiley, New York.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: implications for losses of juvenile salmonids to avian predation. *Transactions of the American Fisheries Society, 131*(3):537-550.

Colotelo, A. H., R. A. Harnish, and B. W. Jones, and 10 other authors. 2014. Passage Distribution and Federal Columbia River Power System Survival for Steelhead Kelts Tagged Above and at Lower Granite Dam, Year 2. PNNL-23051, prepared for the U.S. Army Corp of Engineers, Walla Walla District, Walla Walla Washington, by Pacific Northwest National Laboratory, Richland Washington.

Edwards, J., Wright, B., Clark, C., Brown, M., Valentine, S., Hatch, D., and Powell, J. 2022. Annual report: 2022 Columbia River Basin research and management activities. Washington Department of Fish and Wildlife, 600 Capitol Way N, Olympia, WA 98501-1091.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. *Society for industrial and applied mathematics.*

Evans, A. F., Q. Payton, A. Turecek, B. Cramer, K. Collis, D. D. Roby, P. J. Loschl, L. Sullivan, J. Skalski, M. Weiland, and C. Dotson. 2016. Avian predation on juvenile salmonids: spatial and temporal analysis based on acoustic and passive integrated transponder tags. *Transactions of the American Fisheries Society*, *145*(4): 860-877.

Evans, A. F., R. E. Beaty, M. S. Fitzpatrick, and K. Collis. 2004. Identification and enumerations of Steelhead kelts at Lower Granite Dam. *Transactions of the American Fisheries Society* 133:1089-1099.

Falcy, M. 2017. Population Viability of Willamette River Winter Steelhead: an assessment of the effect of sea lions at Willamette Falls. ODFW report. Available at: http://people.oregonstate.edu/~falcym/Report.pdf (Accessed November 20, 2017).

Feldkamp, S. D., R. L. DeLong, and G. A. Antonelis. 1989. Diving patterns of California sea lions, Zalophus californianus. *Canadian Journal of Zoology*, *67*(4): 872-883.

Friesen, T. A., and D. C. Ward. 1999. Management of northern pikeminnow and implications for juvenile salmonids survival in the lower Columbia and Snake Rivers. *N. Am. J. Fish. Manage.* 19:406-420

Good, T. P., R. S. Waples, and P. Adams, editors. 2005. Updated status of federally listed ESUs of West Coast salmon and Steelhead. NOAA Technical Memorandum NMFS-NWFSC-66.

Götz, T., and V. M. Janik. 2013. Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. *Marine Ecology Progress Series*, 492:285-302.

Jeffries, S. J., and J. Scordino. 1997. Efforts to protect a winter Steelhead run from California sea lions at the Ballard Locks. In G. Stone, J. Goebel, and S. Webster (editors), *Pinniped Populations, Eastern North Pacific: Status, Trends, and Issues*. New England Aquarium, Boston, MA and Monterey Bay Aquarium, Monterey, CA. pp.107-115.

Jeffries, S. J., Huber, H. R., Calambokidis, J., and J. Laake. 2003. Trends and status of harbor seals in Washington State: 1978-1999. *Journal of Wildlife Management* 67(1):208-219.

Jones, K. E., C. B. Ruff, and A. Goswami. 2013. Morphology and biomechanics of the Pinniped jaw: mandibular evolution without mastication. *The Anatomical Record,* 296:1049–1063.

Kareiva, P., M. Marvier, and M. McClure. 2000. Recovery and management options for spring/summer Chinook salmon in the Columbia River Basin. *Science*, *290*(5493): 977-979.

Keefer, M. L., C. A. Peery, and C. C. Caudill. 2008. Migration timing of Columbia River Spring Chinook Salmon: Effects of temperature, river discharge, and ocean environment. *Transactions of the American Fisheries Society*, 137:1120-1133.

Keefer, M. L., R. J. Stansell, S. C. Tackley, W. T. Nagy, K. M. Gibbons, C. A. Peery, and C. C. Caudill. 2012. Use of radiotelemetry and direct observations to evaluate sea lion predation on adult Pacific Salmonids at Bonneville Dam. *Transactions of the American Fisheries Society*, *141*(5):1236-1251.

Kinsey, W. W. 2007. "*Zalaphus*" (Sea Lion) and "*Oncorhynchus*" (Salmon/Steelhead): Protected Predator Versus Protected Prey. *Nat. Res. & Env*. 22(2): 36-40.

Laake, J. L., S. R. Melin, A. J. Orr, D. J. Greig, K. C. Prager, R. L. DeLong, and J. D. Harris. 2016. California sea lion sex- and age specific morphometry. U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-312, 21 p. http://dx.doi.org/10.7289/V5/TM-AFSC-312.

Lyman, R. L., J. L. Harpole, C. Darwenti, and R. Church. 2002. Prehistoric occurrence of pinnipeds in the lower Columbia River. *Northwestern Naturalist,* 83:1-6.

Madson, P. L, B. K. van der Leeuw, K. M. Gibbons, and T. H. Van Hevelingen. 2017. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2016. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR. http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Pinnipeds/Pinniped_2016.pdf.

Magera, A. M., Flemming, J. E. M., Kaschner, K., Christensen, L. B., and H. K. Lotze. 2013. Recovery trends in marine mammal populations. *PloS One* 8, e77908.

McKinney, T. A., D. W. Speas, R. S. Rogers, and W. R. Persons. 2001. Rainbow trout in a regulated river below Glen canyon dam, Arizona, following increased minimum flows and reduced discharge variability. *N. Am. J. Fish. Manage*., 21: 216-222

Mesa, M. G., T. P. Poe, D. M. Gadomski, and J. H. Petersen. 1994. Are all prey created equal? A review and synthesis of differential predation on prey in substandard condition. *Journal of Fish Biology*, *45*(sA):81-96.

Naughton, G. P., M. L. Keefer, T. S. Clabough, M. A. Jepson, S. R. Lee, C. A. Peery, and C. C. Caudill. 2011. Influence of pinniped-caused injuries on the survival of adult Chinook salmon (Oncorhynchus tshawytscha) and Steelhead trout (Oncorhynchus mykiss) in the Columbia River basin. *Canadian journal of fisheries and aquatic sciences*, 68(9):1615-1624.

Newby, T. C. 1973. Changes in Washington state harbor seal populations, 1942-1972. *Murrelet* 54:5-6.

NFSC (Northwest Fisheries Science Center). 2015. Status review update for Pacific salmon and Steelhead listed under the Endangered Species Act: Pacific Northwest. Available: https://www.nwfsc.noaa.gov/assets/11/8623_03072016_124156_Ford-NWSalmonBioStatusReviewUpdate-Dec%2021-2015%20v2.pdf. [Accessed December 14, 2017].

NMFS (National Marine Fisheries Service). 1997. Investigation of scientific information on the impacts of California sea lions and Pacific harbor seals on salmonids and on the coastal ecosystems of Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-28, Seattle, WA.

NOAA (National Oceanic and Atmospheric Administration). 2014. Marine Mammal Stock Assessment: California Sea Lion: U.S. Stock. Available at: http://www.nmfs.noaa.gov/pr/sars/pdf/stocks/pacific/2014/po2014_ca_sea_lion-us.pdf

NOAA (National Oceanic and Atmospheric Administration). 2016a. 5-year Review: Summary and Evaluation of Upper Willamette River Steelhead and Upper Willamette River Chinook. Available at: http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_Steelhead/2016/2016_upper-willamette.pdf. (Accessed December 14, 2017).

NOAA (National Oceanic and Atmospheric Administration). 2016b. Marine Mammal Stock Assessment: Steller Sea Lion: Eastern U.S. Stock. Available at: http://www.nmfs.noaa.gov/pr/sars/pdf/stocks/pacific/2014/po2014_ca_sea_lion-us.pdf

NOAA (National Oceanic and Atmospheric Administration). 2017. Effectivness review of Marine Mammal Protection Act Section 120 implementation under 2012 Letter of Authorization to Washington, Oregon, Idaho. Appendix C. pp. 13.

NOAA Fisheries. 2020. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response for the Continued Operation and Maintenance of the Columbia River System. NMFS No. WCRO 2020-00113. West Coast Region. Portland, Oregon. July 24, 2020.

Patterson, D. A., K. A. Robinson, R. J. Lennox, T. L. Nettles, L. A. Donaldson, E. J. Eliason, G. D. Raby, J. M. Chapman, K. V. Cook, M. R. Donaldson, A. L. Bass, S. M. Drenner, A. J. Reid, S. J. Cooke, and S. G. Hinch. 2017. Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon. *DFO Can. Sci. Advis. Sec. Res. Doc. 010*, pp. ix + 155.

Pearson, J. P., and B. J. Verts. 1970. Abundance and distribution of harbor seals and northern sea lions in Oregon. *Murrelet* 51(1): 1-5.

Peterson, R. S., and G. A. Bartholomew. 1967. The natural history and behavior of the California Sea Lion. *Amer. Soc. Mammologists, Spec. Publ. No. 1.*

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society*, *120*(4), pp. 405-420.

Quinones, R. M., T. E. Grantham, B. N. Harvey, J. D. Kiernan, M. Klasson, A. P. Wintzer, and P. B. Moyle. 2015. Dam removal and anadromous salmonid (Oncorhynchus spp.) conservation in California. *Reviews in Fish Biology and Fisheries, 25*(1):195-215.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/ (February 2016).

Roffe, T. J., and B. R. Mate. 1984. Abundance and feeding habits of pinnipeds in the Rogue River, *Oregon Journal of Wildlife Management, 48*: 1262-1274.

Roscoe, D. W., and S. G. Hinch. 2010. Effectiveness monitoring of fish passage facilities: historical trends, geographic patterns and future directions. *Fish and Fisheries*, *11*(1):12-33.

SBFC State [Oregon] Board of Fish Commissioners. 1889. First and second annual reports of the State Board of Fish Commissioners to the Governor, 1887-1888.

Schakner, Z. A. and D. T. Blumstein. 2013. Behavioral biology of marine mammal deterrents: A review and prospectus. *Bio. Con.,* 167:380-389.

Schakner, Z. A., M. G. Buhnerkempe, M. J. Tennis, R. J. Stansell, B. K. van der Leeuw, J. O. Lloyd-Smith & D. T. Blumstein. 2016. Epidemiological models to control the spread of information in marine mammals. *Proc. R. Soc. B 283*, 2016237.

Schilt, C. R. 2007. Developing fish passage and protection at hydropower dams. *Applied Animal Behaviour Science*, *104*(3):295-325.

Scheffer, V. B. 1950. The food of the Alaska fur seal. *Trans. 15th N. Amer. Wild. Conf.,* pp. 410-421.

Sepulveda, M., R. A. Quinones, P. Carrasco, and M. J. Alvarez. 2012. Daily and seasonal variation in the haul-out behavior of the South American sea lion. *Mammalian Biology* 77(2012): 288-292.

Sorel, M. H., A. G. Hansen, K. A. Connelly, A. C. Wilson, E. D. Lowery, and D. A. Beauchamp. 2016. Predation by Northern Pikeminnow and Tiger Muskellunge on Juvenile Salmonids in a High-Head Reservoir: Implications for Anadromous Fish Reintroductions. *Transactions of the American Fisheries Society*, 145(3):521-536.

Stansell, R. J. 2004. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2002-2004. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon. 97014. http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Pinnipeds/.

Steingass, S., S. Pearson, D. Hatch, and J. Dupont. 2020. Annual report: 2020 Columbia River Basin research and management activities. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Avenue, Corvallis, OR 97330.

Tackley, S., R. Stansell, and K. Gibbons. 2008. Evaluation of pinniped predation on adult salmonids and other fishes in the Bonneville Dam tailrace, 2005-2007. U.S. Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, OR 97014. http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Pinnipeds/2008%20PINNIPED%20REPORT.pdf

Thwaites, R. 1969. Original Journals of the Lewis and Clark Expedition, 1804-1806. Arno Press.

Tidwell, K. S., B. K. van der Leeuw, L. N. Magill, B. A. Carrothers, and R. H. Wertheimer. 2018. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2017. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR. 54pp. http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Pinnipeds/2017%20USACE%20pinniped%20monitoring%20report.pdf

Tidwell, K. S., B. A. Carrothers, K. N. Bayley, L. N. Magill, and B. K. van der Leeuw. 2019. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2018. U.S. Army Corps of Engineers, Portland District, Fisheries Field Unit. Cascade Locks, OR. 65pp.

Tidwell, K. S., R. I. Cates, D. A. McCanna, C. B. Ford, and B. K. van der Leeuw. 2020. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2019. U.S. Army Corps of Engineers, Portland District, Fisheries Field Unit. Cascade Locks, OR. 60 pp.

Tidwell, K.S. and B.K. van der Leeuw. 2021. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville dam tailrace, 2020. U.S. Army Corps of Engineers, Portland District, Fisheries Field Unit. Cascade Locks, OR. 43 pp.

Tidwell, K. S., B.A. Carrothers, D.T. Blumstein and Z.A. Schakner. 2021. Steller Sea Lion (*Eumetopias jubatus*) Response to Non-lethal Hazing at Bonneville Dam. *Front. Conserv. Sci.* 2:760866. doi: 10.3389/fcosc.2021.760866

U.S. Army Corps of Engineers. 2016 Fish Passage Plan. Available at http://www.nwd-wc.usace.army.mil/tmt/documents/fpp/2016/ (accessed on October 23, 2017).

U.S. Army Corps of Engineers. Fish Counts and Reports. Adult fish count website, WWW.FPC.ORG (Accessed February 11, 2022).

Watts, P. 1996. The diel hauling-out cycle of harbour seals in an open marine environment: correlates and constraints. *Jour. of Zoology*. 240(1):175-200.

Weise, M. J., and J. T. Harvey. 2005. Impact of the California sea lion (*Zalophus californianus*) on salmon fisheries in Monterey Bay, California. *Fishery Bulletin,* 103(4):685-696.

Wertheimer, R. H. 2007. Evaluation of a surface flow bypass system for Steelhead kelt passage at Bonneville Dam, Washington. *North American Journal of Fisheries Management*, *27*(1): 21-29.

Withler, I. L. 1966. Variability in life history characteristics of Steelhead trout (*Salmo gairdneri*) along the Pacific coast of North America. *J. Fish. Res. Board Can*. 23(3):365-393.

Wright, B. S., S. Jeffries, and D. Hatch. 2018. Field Report: 2018 Pinniped Research and Management Activities at Bonneville Dam. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Avenue, Corvallis, OR 97330. 19pp.

Wright, B. S., T. Murtagh, and R. Brown. 2014. Willamette Falls Pinniped Monitoring Project 2014. Oregon Department of Fish and Wildlife, 7118 NE Vandenberg Avenue Corvallis, OR 97330.

Table 4. Consumption of summer and winter steelhead by pinnipeds at Bonneville Dam tailrace during the spring sampling period from 2007 to 2022.

Year	Bonneville Dam Steelhead Passage	Adjusted Steelhead Consumption Estimate	Percent of Run Consumed
2007[x]	5,188	609 [x]	10.5%
2008	4,367	391	8.2%
2009	4,829	599	11.0%
2010	9,972	413	4.0%
2011	5,279	336	6.0%
2012	5,904	400	6.3%
2013	3,394	218	6.0%
2014	5,696	128	2.2%
2015	5,217	237	4.3%
2016	5,262	302	5.4%
2017	3,241	322	9.0%
2018	3,808	295	7.2%
2019	2,172	208	8.7%
2020*	N/A	N/A	N/A
2021^	375	27	7.2%
2022**	791	68	8.6%

[x] Adjusted estimates did not start until 2008 (Tackley et al. 2008), as such this value is an expanded estimate.

* 2020 sampling occurred between 12 April and 20 May due to COVID-19 pandemic. Only two steelhead observed killed.

^ 2021 sampling occurred between 4 April and 18 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date). Fish passage for 2021 depicts these dates. Only three steelhead were observed killed.

** 2022 sampling occurred between 3 April and 21 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date). Fish passage for 2022 depicts these dates. Only six steelhead were observed killed.

Table 5. Adjusted consumption estimates on adult salmonids (including adults and jacks) by California and Steller sea lions at Bonneville Dam during the spring sampling period from 2002 to 2022.

Year	Bonneville Dam Salmonid Passage	California Sea Lions		Steller Sea Lions		All Pinnipeds	
		Adjusted Salmonid Consumption Estimates	% Run	Adjusted Salmonid Consumption Estimates	% Run	Adjusted Salmonid Consumption Estimates	% Run
2002	284,732	1,010	0.4%	0	0.0%	1,010	0.4%
2003	217,934	2,329	1.1%	0	0.0%	2,329	1.1%
2004	186,771	3,516	1.9%	7	0.0%	3,533	1.9%
2005	81,252	2,904	3.5%	16	0.0%	2,920	3.4%
2006	105,063	3,312	3.1%	85	0.1%	3,401	3.1%
2007	88,474	4,340	4.7%	15	0.0%	4,355	4.7%
2008	147,558	4,735	3.1%	192	0.1%	4,927	3.2%
2009	186,056	4,353	2.3%	607	0.3%	4,960	2.7%
2010	267,167	5,296	1.9%	1,025	0.4%	6,321	2.4%
2011	223,380	2,689	1.2%	1,282	0.6%	3,970	1.8%
2012	171,665	1,067	0.6%	1,293	0.7%	2,360	1.4%
2013	120,619	1,497	1.2%	1,431	1.2%	2,928	2.4%
2014	219,929	2,747	1.2%	1,874	0.8%	4,621	2.1%
2015	239,326	8,324	3.3%	2,535	1.0%	10,859	4.3%
2016	154,074	6,676	4.1%	2,849	1.7%	9,525	5.8%
2017	109,040	2,142	1.9%	3,242	2.8%	5,384	4.7%
2018	100,887	746	0.7%	2,368	2.3%	3,112	3.0%
2019	63,591	176	0.3%	2,022	3.1%	2,201	3.3%
2020*	47,074	373	0.8%	813	1.7%	1,182	2.5%
2021^	64,089	726	1.1%	1,390	2.2%	2,141	3.3%
2022**	145,198	2,231	1.5%	2,275	1.6%	4,530	3.1%

* 2020 sampling occurred between 12 April and 20 May due to COVID-19 pandemic. Fish passage for 2020 depicts these dates.

^ 2021 sampling occurred between 4 April and 18 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date). Fish passage for 2021 depicts these dates.

**2022 sampling occurred between 3 April and 21 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date). Fish passage for 2022 depicts these dates.

Table 6. Consumption of spring Chinook Salmon by pinnipeds at Bonneville Dam tailrace during the spring sampling period from 2002 to 2022. Passage counts of Chinook Salmon includes both adult and jack salmon.

Year	Bonneville Dam Spring Chinook Passage	Chinook Consumption Estimate	Percent of Run Consumed
2002 x ⊥	275,290*	880†	0.3%
2003 x ⊥	210,028	2,313	1.1%
2004 x ⊥	179,193	3,307	1.8%
2005 x ⊥	78,341	2,742‡	3.4%
2006 x ⊥	99,366	2,580	2.5%
2007 x ⊥	83,252	3,403	3.9%
2008	143,139	4,501	3.0%
2009	181,174	4,360	2.3%
2010	257,036	5,909	2.2%
2011	218,092	3,634	1.6%
2012	165,681	1,959	1.2%
2013	117,165	2,710	2.3%
2014	214,177	4,576	2.1%
2015	233,794	10,622	4.3%
2016	148,357	9,222	5.9%
2017	101,734	4,951	4.6%
2018	94,350	2,813	2.9%
2019	61,385	1,974	3.1%
2020 ┘	46,822	1,180	2.5%
2021^	63,713	2,079	3.3%
2022**	144,407	4,437	3.1%

x Adjusted estimates did not start until 2008 (Tackley et al. 2008), as such these values are expanded estimates.
* Fish counts did not start until March 15 in 2002. Chinook passage from January 1 through March 15 was minimal in all other years.
† From March 15 through April 25, used fish passage count split between Chinook Salmon and steelhead to estimate Chinook proportion of unidentified salmonid catch. After April 25, we used observed catch distribution to divide unidentified salmonid consumption.
‡ In 2005 pinniped observations did not start until March 18.
⊥ Passage data altered to meet the Fish Passage Plan run criteria of 1 January – 31 May. Data will differ relative to previously published data.
┘ 2020 sampling occurred between 12 April and 20 May due to COVID 19 pandemic. Fish passage depicts these dates.
^ 2021 sampling occurred between 4 April and 18 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date). Fish passage for 2021 depicts these dates.
** 2022 sampling occurred between 3 April and 21 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date). Fish passage for 2022 depicts these dates.

Table 7. Consumption of White Sturgeon by pinnipeds at Bonneville Dam tailrace during the spring sampling period from 2005 to 2022.

Year	Total Hours Observed	Observed Sturgeon Catch	Adjusted Sturgeon Consumption Estimate
2005	1,109	1	N/A
2006	3,650	265	413
2007	4,433	360	664
2008	5,131	606	1,139
2009	3,455	758	1,710
2010	3,609	1,100	2,172
2011	3,315	1,353	3,003
2012	3,404	1,342	2,498
2013	3,247	314	635
2014	2,947	79	146
2015	2,995	24	44
2016	1,974	30	90
2017	1,142	6	24
2018	1,410	46	148
2019	836	22	187
2020*	331	9	57
2021^	132	1	N/A
2022**	205	4	40

* 2020 sampling occurred between 12 April and 20 May due to COVID-19 pandemic.

^ 2021 sampling occurred between 4 April and 18 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date).

** 2022 sampling occurred between 3 April and 21 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date).

Table 8. Consumption of White Sturgeon by pinnipeds at Bonneville Dam tailrace during the fall sampling period from 2017 to 2021. Please note that only one tailrace is monitored for predation during the fall sampling period.

Year	Total Hours Observed	Observed Sturgeon Catch	Adjusted Sturgeon Consumption Estimate
2017	139	39	238
2018	369	77	359
2019	341	164	762
2020	234	82	589
2021	188	94	1,119

Table 9. Consumption of Pacific Lamprey by pinnipeds at Bonneville Dam tailrace during the spring sampling period from 2002 to 2022.

Year	Total Hours Observed	Observed Pacific Lamprey Catch	Expanded Pacific Lamprey Consumption Estimate	Percent of Total Observed Fish Catch
2002	662	34	47	5.6%
2003	1,356	283	317	11.3%
2004	516	120	816	12.8%
2005	1,109	613	810	25.1%
2006	3,650	374	424	9.8%
2007	4,433	119	143	2.6%
2008	5,131	111	145	2.0%
2009	3,455	64	102	1.4%
2010	3,609	39	77	0.7%
2011	3,315	16	33	0.4%
2012	3,404	40	79	1.4%
2013	3,247	38	66	1.7%
2014	2,947	41	85	1.5%
2015	2,995	108	196	1.6%
2016	1,974	232	501	4.8%
2017	1,142	41	191	1.7%
2018	1,410	16	58	0.04%
2019	836	4	14	0.02%
2020*	331	1	N/A	N/A
2021^	132	0	N/A	N/A
2022**	205	1	N/A	N/A

* 2020 sampling occurred between 12 April and 20 May due to COVID-19 pandemic.

^ 2021 sampling occurred between 4 April and 18 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date).

** 2022 sampling occurred between 3 April and 21 May based on the 20-animal trigger (start date) and when all pinnipeds had departed the tailrace (end date).

APPENDIX 1. Description of the BON tailrace system, life histories of the pinniped and fish species studied, and the methods employed to study pinniped abundance, residency, and the level of fish predation during the fall – winter and spring sampling periods.

APPENDIX 1: METHODS

STUDY AREA

Bonneville Lock and Dam is in the Columbia River at river mile 146 (river kilometer 235) from the confluence of the Pacific Ocean. The dam spans the Columbia River between the states of Oregon and Washington and is comprised of three concrete structures separated by islands. Pinniped activities historically occur in the tailraces of the dam between the islands. Using the *a priori* knowledge of pinniped behavioral patterns at the dam, we observed pinniped abundance and predation from each of the three tailrace sub-areas downstream of Powerhouse One (PH1), Powerhouse Two (PH2), and the Spillway (SPW) (Figure A1). Elevated observation platforms at these tailraces were used to observe pinniped activity. To facilitate comparison of predation events by tailrace area and provide continuity to previous reports (Madson et al. 2017), we divided each tailrace sub-area into seven zones (Figure A1). Pinniped abundance counts and brand re-sightings were conducted in the three tailrace sub-areas and at Tower Island, a site consistently used as a resting area for pinnipeds (Figure A1). Abundance estimates and brand re-sightings were also collected at Tanner Creek, the nearest downstream tributary approximately one mile from the dam. The States anchored three floating sea lion traps in the vicinity of Tower Island and one in the PH1 forebay during the spring months that CSLs were present, which served as areas for pinnipeds to rest on, facilitating abundance counts and brand re-sighting.

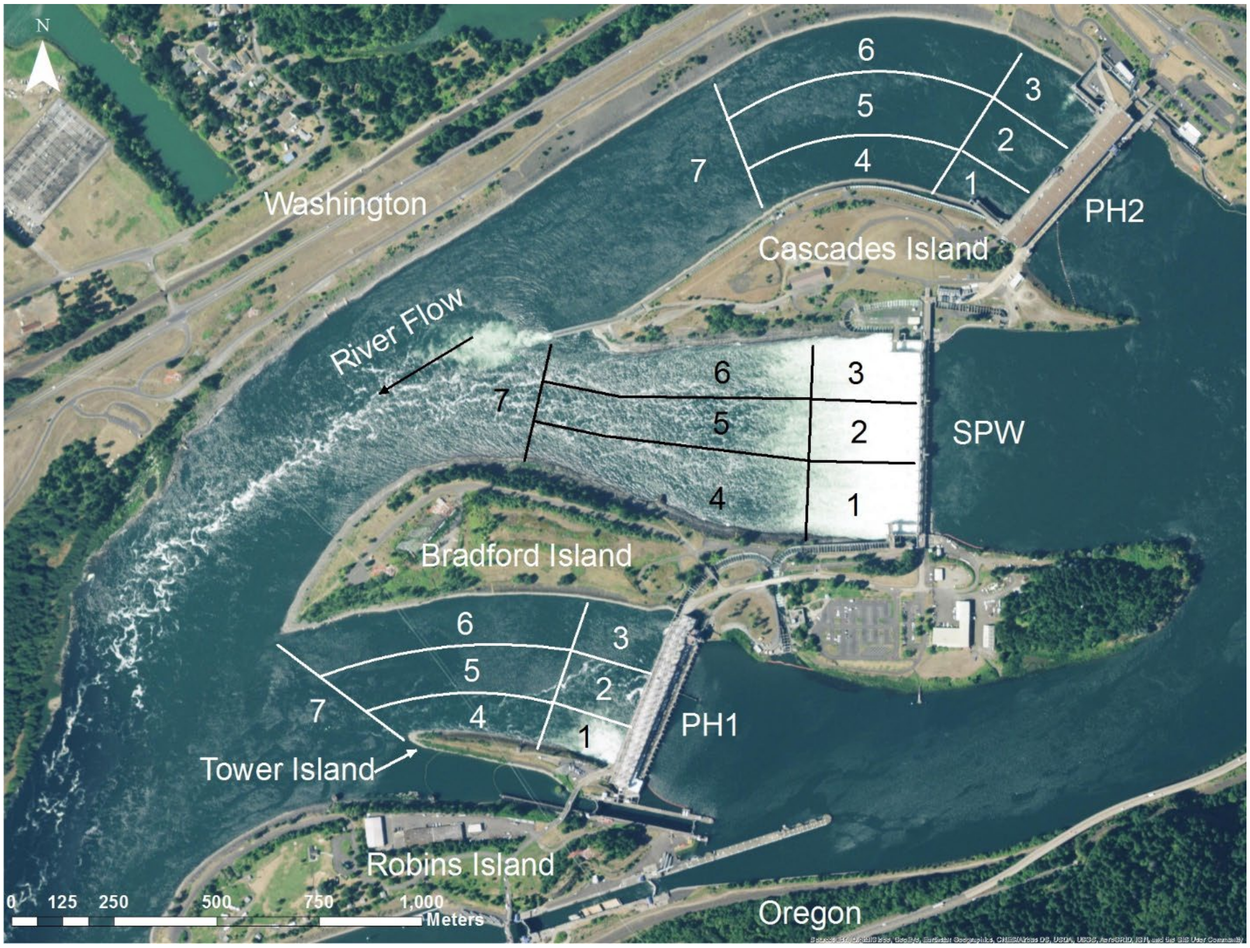

Figure A1. Bonneville Dam study area with Powerhouse One (PH1), Spillway (SPW), and Powerhouse Two (PH2) tailrace sub-areas separated into zones for assigning the location of predation events.

FOCAL SPECIES

Pinnipeds

The Order Pinnipedia evolved ≥ 20 million years ago and has likely overlapped in distribution with anadromous Pacific salmonids for the bulk of this time (Naughton et al. 2011). The co-occurrence and predation of salmonid fish by pinnipeds undoubtedly led to long-standing anthropogenic disdain for the species in the Pacific Northwest, so much so that State wildlife agencies authorized bounty programs to kill as many pinnipeds as possible (Beddington et al. 1985). Since the Marine Mammal Protection Act of 1972, the stocks of CSLs and the Eastern stock of the SSLs have rebounded (NOAA 2014, 2016b), and are now frequently observed along the Pacific Coast.

The rookeries (i.e., breeding and rearing grounds) for the sea lions entering the Columbia River system are primarily the Channel Islands off the coast of southern California for the CSLs, and the Rogue Reef outcroppings off the coast of southern Oregon for the Eastern stock of SSLs (B. Wright personal comm.). Males of both species disperse from rookeries after breeding to forage in waters different from that of the females and sub-adults to regain the weight lost during the prolonged terrestrial breeding periods. Thus, all CSLs and SSLs entering the Columbia River system are males that have left their respective breeding grounds in search of foraging opportunities. Sea lions have been documented at the mouth of the Columbia for several hundred years (Lyman et al. 2002) but have only recently (i.e. < 20 years) been documented consistently traveling to BON to forage. Brand re-sighting and telemetry data suggest that approximately 7% of the CSLs occurring near the mouth of the Columbia River travel to BON to forage (NOAA 2017). These animals represent a mixture of several cohorts including juvenile (2-4 years), sub-adult (5-8 years) and adults (> 8 years) (Laake et al. 2016).

Natural History of Pinnipeds at Bonneville Lock and Dam

Pinnipeds that travel to, and forage at, BON consistently forage in the tailraces of the dam during the day and utilize rock outcroppings and riprap infrastructure to rest on, a process called "hauling out" during the night. Hunting forays from the rocks to the tailraces occur by almost all animals just prior to sunrise after which they can be observed transiting between the tailraces and haul-out locations during daylight hours. They return to the haul-out locations just after sundown where they generally remain through the nighttime.

Pinnipeds can be observed periodically surfacing to breathe when foraging then submerging to pursue prey below the surface. The maximum time submerged under normal conditions for CSLs is 9.9 minutes (Feldkamp et al. 1989), however, at BON foraging dives are generally less than five minutes for both species of pinniped (KST personal obs.) Once captured, larger prey items are brought to the surface and broken through a series of violent head shakes reducing the prey to multiple pieces of manageable size (Jones et al. 2013). Of particular note for monitoring purposes is the prey handling time and capacities of each species; adult SSLs can swallow sizeable spring Chinook Salmon almost whole in a matter of seconds, whereas adult CSLs typically stay at the surface and break the fish into smaller pieces. Thus, handling time differs for each species of sea lion, a difference which likely influences the ability and confidence of observers to document predation and therein may influence inter- and intra-species differences enumerated in this report – SSL predation may be biased low as a result.

Fish Species in BON Tailrace

Pacific salmon and steelhead (*Oncorhynchus spp.*) of the Columbia River system are composed of several species, many of which have distinct evolutionarily significant units (ESU-salmon) or distinct population segments (DPS-steelhead) that have been listed under the ESA. During the fall and winter period the primary salmonid species passing BON are: fall Chinook Salmon (1 August – 15 November), Coho Salmon (15 July – 15 November), summer steelhead (A run: June – August; B run: August – October), and winter steelhead (16 November – 31 March). The primary species passing during the spring sampling period are the spring Chinook Salmon and DPS of winter and summer steelhead. These runs are historically classified by the periods of time at which they cross the dam: spring Chinook Salmon: 14 March – 31 May, ocean-maturing winter steelhead: 16 November – 31 March, and stream-maturing summer steelhead: 1 April – 15 November (Busby et al. 1996).

Due to the temporal overlap of pinnipeds and migrating salmonids, data suggests that early migrating salmonid stocks may be disproportionately impacted by pinniped predation (Keefer et al. 2012), specifically ESU stocks of spring Chinook from the Icicle, Salmon, Deschutes, Clearwater, and Umatilla rivers which have the greatest temporal overlap with pinnipeds. Of these, the Icicle and Salmon river populations are listed as threatened under the ESA (Good et al. 2005).

Different salmonid species and various runs of steelhead and Chinook Salmon are encountered by pinnipeds due to the temporal overlap and misalignment of run chronology as a result of environmental conditions and migration patterns, however the bulk (i.e. > 95%) of salmonids consumed during the spring sampling period are of the spring Chinook and winter steelhead runs (Stansell 2004, Madson et al. 2017). Stocks consumed during the fall and winter include ESA listed B run steelhead, lower Columbia River Coho, select ESUs of the fall Chinook run, and winter steelhead. Analyses of stock specific impacts are beyond the scope of this report but are warranted. Other fish species observed as prey of pinnipeds at BON include: White Sturgeon (*Acipenser transmontanus*), Pacific Lamprey (*Entosphenus tridentatus*), American Shad (*Alosa sapidissima*), and various warm water and introduced fishes (e.g. *Micropterus spp., Cyprinus spp.*). Our monitoring program focus primarily on the number of salmonids, Pacific Lamprey, and White Sturgeon consumed.

SAMPLING METHODS

The pinniped monitoring project has evolved since its initiation in 2002 to better capture the information required by the Biological Opinion and to facilitate research efforts by the States and collaborative agencies. Data informed modifications to sampling schemes and observer effort have produced a robust and cost-effective system to estimate salmonid consumption and pinniped abundance. In short, biological observers trained in fish and pinniped identification use field glasses (8 X 42 magnification) to document pinniped activity at predetermined locations above the tailraces of the dam (Figure A1) at a scheduled interval to develop estimates of predation and abundance.

Monitoring: Abundance, Residency, and Recurrence

We quantified the number of pinnipeds present at the BON project each day by conducting point counts of animals from a distance using field glasses. Sampling began when the first pinniped was observed in the summer and terminated when the last pinniped left in the spring. To maximize the accuracy of point counts, we used historical data and pinniped behavior to inform the optimal times at which to perform point counts. Previous data revealed a strong diel pattern (Stansell 2004, KST unpub. data), whereby, the greatest number of pinnipeds are consistently observed hauled out during the evening and crepuscular hours, a pattern consistent with some pinniped natural foraging cycles (Boehme et al. 2016, but see: Watts, 1996, Sepulveda et al. 2012). As such, we generally conduct one point count per day during the morning or evening civil twilight.

The abundance data provided herein represent a conservative estimate of pinnipeds at BON on any one day. All pinnipeds in the three tailraces and on Tower Island were counted, however, submerged animals, animals in transit between locations but out of sight, and the ingress and egress of animals to BON occurs and may potentially influence our abundance estimates. To avoid double counting animals transiting between count locations, we sampled all locations in one five-minute period at each site, a period of time short enough to individually count animals before they could move between sites and long enough to ensure submerged animals will have surfaced and could be counted.

Abundance – The daily pinniped abundance for each species is presented as the highest point count taken for each species each day irrespective of time of day. For periods when FFU staff were not present to collect point count data (i.e. weekends, holidays), linear interpolation between the most recent days surrounding the missing period was used to estimate abundance. In doing so, we present the estimated maximum number of pinnipeds that could have been near BON each day.

Yearly maximums of individually identifiable animals are presented to document how many pinnipeds of each species were observed throughout the season. Since not all CSLs are branded and very few SSLs are branded, we present the yearly maximum count as either: 1) the greatest number of animals in any single point count (sum of all three sub-tailraces, Tower Island, and Tanner Creek), or 2) the cumulative number of uniquely identifiable animals observed during the season, whichever is higher. This approach combines two metrics (annual individual accounts or daily high counts) and provides the estimated yearly maximum because either, all the animals were individually identified at some point or were observed in one point count and thus were mutually exclusive counts of individuals. However, the latter method does have the potential to be biased low, as a non-identifiable individual could have been to BON during the season but was not present during the highest daily point count of the season. This is most often applied to the SSLs due to the limited brands on the animals. Thus, the yearly maximum abundance is a conservative measure of the most animals documented throughout the year.

Residency – Historically this metric was required to facilitate management of CSL in the BON tailrace. With the passing of the Endangered Salmon Predation Prevention Act these data are no longer required and therein were not reported this year. However, the data exist and if requested can be furnished.

Recurrence – Similar to Residency, this metric is no longer required but the data are available upon request.

Monitoring: Chronology of Fish Passage, Methods of Estimating Fish Predation

Estimating Fish Predation

Surface observations of pinniped-prey interactions were used to enumerate the number and species of each fish killed by each pinniped species. This method is useful and has been employed elsewhere (see Roffe and Mate 1984, Wright et al. 2014), and consistently applied at BON for > 19 years. All attempted (i.e., loss) and successful (i.e. catch/stolen) predation events were recorded, as well as the time and location of the predation event, species of fish, species of pinniped, unique pinniped identification (if possible), length of sturgeon (if applicable), and interactions with other pinnipeds during the predation event (i.e. cleptoparasitism).

Sub-surface predation and consumption has been documented previously, particularly with the larger SSL and smaller fish, and may artificially truncate the estimated number of fish consumed (Stansell 2004). However, as noted, this is almost exclusively an SSL issue and likely only influences the counts of the smallest spring Chinook (i.e., jacks) and smaller steelhead. However, we recognize that some CSL sub-surface predation may occur. Due to the nature of observing wild animals *in situ* with field glasses, not all predation events were easily recognizable. In instances when fish were too mangled, actively being swallowed, or too far from the observer to be recognized, the predation event was recorded with all pertinent data and the fish species was listed as "unidentifiable."

The process of accounting for the unidentifiable fish in the predation estimate has evolved over the years. Historically, the program monitored pinniped activity extensively (i.e. all daylight hours and some nighttime observations) and therein justified using the raw data of observed predation events with a correction factor applied based on *a priori* knowledge of observer skill level, program structure, and pinniped behavior (Stansell 2004). Presently we use the "adjusted consumption estimate" developed by Tackley et al. (2008) which incorporates the unidentifiable fish predation events evenly across other predation events based on the number and species of fish consumed that day. For example, assume 24 fish were caught in one day, 20 identified, and four unidentified. Of the identified fish, 10 were Chinook Salmon and 10 steelhead. The four unidentified fish catches would be proportionally distributed to two Chinook Salmon and two steelhead. In this manner we provide the adjusted estimate – a parsimonious estimate of how many of each fish species were consumed each day – which is the functional unit utilized to estimate the total number of fish consumed for the season.

Being readily identifiable and not easily mistaken for any other fish in the Columbia River, the Pacific Lamprey was not applied to the adjusted estimates. Therein, Pacific Lamprey consumption estimates reported here are merely expanded for hours not observed and have not been adjusted. It is possible that Pacific Lamprey are consumed underwater albeit observers rarely report Pacific Lamprey being brought to the surface in a mostly consumed state. However, since it is possible, the estimates provided here are minimum consumption estimates. Moreover, based on the tendency for Pacific Lamprey to pass at nighttime and the lack of night-time predation monitoring there is potential for Pacific Lamprey predation to go unrecorded, again indicating that the estimates provided herein, are minimal estimates.

Sampling Design for Predation Estimates

As in previous years, a Stratified Random Sampling design (SRS) (Cochran 1977) was implemented to account for hours not observed across the three tailraces of the dam each week (Madson et al. 2017). This season we elected to consistently apply a systematic sampling design with even coverage within each strata week. A design that is different from last season which involved a combination of simple and stratified random sampling within weeks. We describe the methods and assumptions of these designs below.

Each seven-day week (arbitrarily assigned as Sunday-Saturday) served as a stratum. For example, in 2019 the fall and winter sampling period had 18 strata weeks from 26 August – 31

December and the spring sampling period of 2020 had 6 strata weeks between 12 April and 20 May. Five of seven days (Monday-Friday) were sampled during each stratum except for federal holidays. These missing samples were incorporated with weighting (sampling effort to sample total) to the predation estimate. Given the diel foraging activity of the pinnipeds at BON, the sample coverage for each stratum was based on civil twilight (morning), sunrise, sunset, and civil twilight (night) for Cascade Locks, OR (six miles east of BON). We conducted observations for the maximum number of two conjoined 30-minute sampling units between morning and night. If the 60-minute sampling unit was ≥ 15 minutes before or after civil twilight, the first 30-minute interval was removed from the daily sample and the next sample block was used. Doing so ensured enough light to facilitate positive identification of both pinniped and fish species and maximized the potential to randomly select a sampling unit during all hours of daylight. The sample rate is expressed as the percentage of daylight hours sampled per total daylight hours available in the week (i.e. stratum).

During predation sampling, the distribution of observations was selected by assigning a number to each tailrace and randomly selecting one of the tailraces for sampling. Once the initial tailrace was selected, the sampling occurred in a systematic stepwise progression across each tailrace for that day. The process was then repeated for every Monday – Friday of each week for the entire season. This random systematic process facilitates two important components of the sampling design: first, it eliminates travel between sites which, therefore, allows assumptions of equal and complete coverage to be upheld, and second, ensures equal and random assignment of sampling to all tailrace areas during all daylight hours.

Given that the levels of pinnipeds and fish fluctuate across the sampling seasons (i.e. high heterogeneity), but remain relatively consistent within weeks (i.e. high homogeneity), we utilized a bootstrap resampling method, a technique widely applied to provide more robust measures of confidence for stratified sampling designs (Efron 1982), to estimate the mean catch and associated confidence intervals (CI) of fish consumed during the focal sampling period.

We elected to bootstrap across the entire sample due to the highly stochastic runs of fish and pinniped numbers. We treated the hourly observation samples as the target population and sampled, with replacement, 999 times from the observations over the focal sampling period to measure the population parameter of interest, the mean number of (adjusted) fish consumed. With this approach, some data points can appear at multiple times during the resampling. Among the 999 resampled data sets, the entire sample (all observation data) and the total observations during each week were kept constant. For example, if there were 35 and 40 observations during week 1 and week 2, respectively, our resampling maintained the same observation size for each of the 22 weeks (e.g., 35 for week 1, 40 for week 2, etc).

We estimated the total catch of every resampled table (999 estimates) and calculated the confidence intervals for the true mean (μ) using the distribution of delta [$\delta^* = \overline{x}^*$ -$\overline{x}$)]. $\overline{x}^*$ is the mean of the bootstrap sample and $\overline{x}$ is the sample mean. The bootstrap 95% confidence intervals for μ is as: [$\overline{x} - \delta^*_{0.025}, \overline{x} - \delta^*_{0.975}$].

In doing so, we provide the bootstrap estimated number of each fish caught by pinniped species with bootstrapped measures of variance for each estimate. If confidence intervals overlapped zero as a result of small sample sizes, we report the estimated number of fish consumed as the lower bound of variation and the calculated 95% confidence boundary as the upper level of predation.

All calculations and comparisons of consumptions were conducted with the adjusted consumption data unless otherwise noted.

Calculation of Predation Estimates for Percent of Run Taken

To facilitate inter-year comparisons and determine estimated total predation by pinnipeds and by fish run size, we present the percentage of each fish species taken by each species of pinniped calculated as the estimated number of fish consumed by pinnipeds divided by the total passage count (i.e. estimated number of fish that successfully passed BON) from the beginning of the sample period to the end of the sample period multiplied by 100. Salmon count data (daytime counts, all adult salmonids including jacks) were obtained from the USACE Fish Counts and Reports adult fish count website (WWW.FPC.ORG).

The calculation of fish consumed divided by fish that passed only during the monitored interval is an adopted change based on last year's analysis that required calculation of pinniped impact to several species in-light of constraints to sampling not previously accounted for (see Tidwell and van der Leeuw 2021). That is, since predation is now monitored across the entire year when 20 pinnipeds or more are present, there is disjunct monitoring across runs. Moreover, run timing and species composition is much more dynamic with year-round sampling. As such, reporting on the impact to the run of estimated fish consumed divided by the number of fish that passed during the observation period is the most conservative measure of interpreting the data and provides parsimony. It should be noted that these changes were employed first in 2020 and are used again this year with the intent to continue to calculate in a similar fashion moving forward.

Chronology of Fish Passage

We present passage for each sampling period of each year and when needed compare to the ten-year average to inform how the passage and abundance of salmonids may interact with the estimated consumption by pinnipeds. With these passage estimates, we also recognize that environmental co-factors have been shown to influence passage rates (Keefer et al. 2008, Evans et al. 2016).

DATA ANALYSIS AND REPORTING

Descriptive statistics are reported throughout with the mean and associated standard error as the measure of spread (i.e., $\overline{x} \pm$ S.E.). Adjusted estimates of predation are reported as the bootstrapped mean with associated 95% confidence intervals (CI). Analyses were performed with JMP (version 12) and Program R (version 3.3.2).

DETERRENTS AND MANAGEMENT ACTIVITIES

Deterrents to Fish Predation

A variety of methods have been implemented to deter pinnipeds from eating salmonids near priority areas (Jeffries and Scordino 1997, Gotz and Janik 2013, Schakner and Blumstein 2013). Presently, hazing and physical exclusion devices are used in concert to deter pinnipeds at BON. Hazing consists of a combination of non-lethal deterrents including cracker shells (small charges of explosive ordinance), rubber buckshot, boat chasing, and underwater percussive devices known as seal bombs. USDA personnel haze from the face of the dam to deter pinnipeds from approaching the fish ladder entrances and boat-based CRITFC crews haze the pinnipeds in the dam tailraces and attempt to push them downstream and away from the fish ladder entrances. We report the descriptive statistics of these efforts and discuss their use throughout the season.

Due to the repeated entry of pinnipeds to the fish ladders at BON, physical exclusion devices were constructed starting in 2006 to block pinnipeds but allow fish passage. Specially designed gates called Sea Lion Exclusion Devices (SLEDs) are now installed throughout the season at all eight fishway entrances of BON (Appendix 2). In addition to the eight SLEDS, there is smaller physical exclusion grating installed on the 16 Floating Orifice Gates (FOGs) along the face of Powerhouse 2 that allow fish to enter the collection channel and pass via the Washington Shore fishway. The FOGs at Powerhouse 2 provide additional fishway entry points for migrating adult salmonids, but the installed gratings are sized to preclude pinniped entry. Temporary Sea Lion Incursion Barriers (SLIBs) were constructed for the purpose of providing additional height on top of the FOGs. We detail the chronology of installation and efficacy of these physical exclusion devices herein.

Management Activities

Pursuant to the Section 120 authorization of the Marine Mammal Protection Act issued to the States, and to facilitate detailed studies of pinniped population dynamics at BON, the USACE supported the States operation of floating pinniped traps in the tailrace and forebay of the dam. From these traps, alphanumeric “hot” brands were placed on otherwise non-branded CSLs and SSLs. The traps also serve to allow for lethal removal of CSLs listed for removal. For specificity to state managers actions, we direct attention to the involved agencies for further details about sea lion management activities (e.g. http://www.dfw.state.or.us/fish/sealion/).

APPENDIX 2. **Sea lion exclusion device (SLED) at Bonneville Dam fishway entrance (A) (Tackley et al. 2008) and installed (B) (Photo by Bjorn van der Leeuw, USACE), floating orifice gate (FOG) (C) (unknown source), and sea lion incursion barriers on top of FOGs (D) (Photo by Patricia Madson, USACE).**

A.

B.

C.

D.