Oregon
Kate Brown, Governor

Department of Fish and Wildlife
450 Main Street
Oregon City, OR 97405

November 1, 2022

Scott Rumsey, Ph.D.
Regional Administrator, West Coast Region
National Marine Fisheries Service
1201 Northeast Lloyd Boulevard, Suite 1100
Portland, OR 97232

Dear Dr. Rumsey,

The following information comprises our 2022 annual report to the National Marine Fisheries Service (NMFS) from the Oregon Department of Fish and Wildlife (ODFW), documenting compliance with the terms and conditions of our authorization for the lethal removal of predatory California sea lions (CSLs) in the vicinity of Willamette Falls (Oregon City, Oregon) under §120 of the Marine Mammal Protection Act (MMPA). This authorization was granted November 14, 2018, for a 5-year period until November 14, 2023; this report covers the period from November 1, 2021, through October 31, 2022. Please note, however, that during this period we also conducted concurrent removals under the broader Columbia River Basin MMPA §120(f) authorization granted on August 14, 2020. For completeness we have noted removals under both authorities although removals under MMPA §120(f) will also be reported separately at a later date.

<u>Terms and Conditions</u>

<u>No. 1</u>
The State of Oregon lethally removed two individually identifiable predatory CSLs that were having a significant negative impact on ESA-listed salmonids at Willamette Falls. (An additional CSL was removed during this period at Willamette Falls under concurrent MMPA §120(f) authority and will be reported separately at a later date.)

<u>No. 2</u>
Under our concurrent MMPA §120(f) authorization, CSLs are not required to meet the removal criteria defined in condition 1 of our Willamette Falls MMPA §120 authorization. We therefore did not request that any new CSLs be added to the Appendix of individuals meeting the criteria for removal at this location.

No. 3
The State of Oregon did not exceed the limit of taking more than one percent of the current PBR for CSLs (14,011).

No. 4
The State of Oregon consulted with our Institutional Animal Care and Use Committee (IACUC) prior to conducting work during the 2021-2022 field season in order to review protocols for capture, holding, and euthanasia of individually identifiable predatory CSLs.

No. 5
No pre-approved permanent holding facilities requested CSLs and therefore all animals meeting the criteria for removal were euthanized according to IACUC-approved methods.

No. 6
The State of Oregon has ensured that transfer or disposal of any carcass or parts were done in accordance with applicable laws, and worked with researchers to make carcasses, tissues or parts of lethally removed animals available for research and/or education.

No. 7
The State notified the Regional Administrator, NMFS West Coast Region, in writing of all sea lion removal operations within the required three-day period.

No. 8
The State of Oregon developed and continued the multi-year monitoring plan to evaluate 1) the impacts of CSL predation on UWR spring-run Chinook salmon and UWR winter steelhead; and 2) the effectiveness of permanent removal of individually identifiable predator CSLs as a method to reduce adult salmonid mortality. The State has or will perform by the end of the authorization period, the following actions:

a) monitored and reported specific CSLs observed, including when animals were removed and residence time at Willamette Falls;
b) monitored and reported the number of prey observed and estimated to have been taken;
c) monitored, evaluated, and reported on expedience (number of days animal present before removal) of removal;
d) monitored and reported key population parameters for UWR spring-run Chinook salmon and UWR winter steelhead populations so that changes in population status can be detected;
e) ensured that monitoring efforts included other pinnipeds that occurred in the vicinity of Willamette Falls;
f) will update the population viability analysis for UWR spring-run Chinook salmon and UWR winter steelhead after 5 years of implementation (after December 2023) to determine, to the extent possible, any changes in the estimated extinction risk to the salmonid stocks in question.

No. 9

This letter describing our compliance with the terms and conditions of the 2018 LOA and the attached two reports on monitoring and management activities conducted in 2021-2022 represents our annual monitoring reports to NMFS. The State of Oregon is currently planning to conduct similar work in 2022-2023.

No 10

See condition 2.

No. 11

We understand that the authorization may be modified, suspended, or revoked by NMFS at any time given 72 hours' notice to the State.

No. 12

We understand that this authorization is valid until November 14, 2023, at which time it may be extended by NMFS for an additional period to be determined by NMFS. Please note, however, that we do not intend to request an extension given that we have also started conducting concurrent removals under the broader Columbia River Basin MMPA §120(f) authorization granted on August 14, 2020.

The State of Oregon remains committed to pursuing all reasonable approaches to reduce pinniped predation on threatened Willamette River salmonids. As you know, however, existing non-lethal tools have proven ineffective, and no effective new options have been identified. While we would prefer to find and implement successful non-lethal methods for reducing predation, permanent removal of some number of habituated predatory sea lions may continue to be necessary for the foreseeable future.

We thank you for your assistance and support of our work to monitor and reduce sea lion predation on threatened salmonids below Willamette Falls and elsewhere in the lower Columbia River basin. Please let us know if we can provide further information related to our annual reporting obligations.

Sincerely,

Michael Brown
Marine Mammal Program Leader

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

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

November 1, 2022

Oregon Department of Fish and Wildlife

Project staff:

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INTRODUCTION

Willamette Falls is a natural waterfall located approximately 26 miles from the confluence of the Columbia and Willamette Rivers. While sea lions were not historically present there, they increasingly began occurring in the 1990s, prompting the Oregon Department of Fish and Wildlife (ODFW) to begin a monitoring program at this location in 1995. Due to further increases in the 2000s, ODFW conducted a non-lethal hazing program in 2010, 2011, and 2013. The non-lethal hazing program, despite expending considerable resources, had minimal effect on reducing predation or the number of sea lions present and was discontinued in favor of implementation of a rigorous monitoring program. In 2014, 27 individual California sea lions (CSLs; *Zalophus californianus*) were noted in the area. This increased to 35 CSLs in 2016, and more than 40 in 2017. Because of these growing numbers of sea lions, the State initiated management action to prevent a scenario similar to those seen at Ballard Locks, WA (see Fraker and Mate 1999) and Bonneville Dam on the lower Columbia River (see Tidwell et al. 2021).

In 2017, the State of Oregon submitted an application to the National Marine Fisheries Service (NMFS) to remove a number of CSLs present below Willamette Falls under §120 of the Marine Mammal Protection Act (MMPA). This was in part due to findings of the Upper Willamette River Winter Steelhead Population Viability Study conducted by ODFW scientists (ODFW 2019), which concluded the upper Willamette River native (winter) steelhead were at significant risk of extinction due to predation by CSLs present at this location. On November 14, 2018, NMFS approved the state's application and the first removals of CSLs at Willamette Falls began on December 12, 2018.

At this same time, the Endangered Salmon Predation Prevention Act of 2018 became law on December 18, 2018. This law amended the MMPA by replacing the existing §120(f) titled "California sea lions and Pacific harbor seals; investigation and report" with a new §120(f) titled "Temporary Marine Mammal Removal Authority on the Waters of the Columbia River or its Tributaries". On June 13, 2019, ODFW, along with its many state and tribal co-management partners, submitted an application to NMFS under the newly amended MMPA to remove CSLs—and for the first time Steller sea lions (SSLs; *Eumetopias jubatus*, eastern stock)—in the lower Columbia River Basin (CRB), including the Willamette River. NMFS subsequently approved this application and issued a letter of authorization to ODFW and its managing partners on August 14, 2020.

This report summarizes work conducted under our MMPA §120 authority at Willamette Falls during the fall 2021-spring 2022 field season. (There was no management report for the fall 2019-spring 2020 season since it was largely suspended due to COVID-19.) For completeness, we report on removals taken under both our original 2018 authorization (Willamette Falls §120) as well as our jointly held 2020 authorization (CRB §120(f)) although removals under the latter will also be reported separately at a later date. Specifically, we report here on the management aspects of this work whereas the monitoring requirements are provided in a separate report (see Wright et al. 2022).

METHODS

Trapping

Sea lions were captured using haul-out traps placed at the upstream end of Sportcraft Landing Moorages on the Willamette River, approximately 1.7 km downstream of Willamette Falls. Sea lions use these traps as haul-out sites, entering and exiting traps via a vertically sliding door, which was pad-locked open prior to a scheduled capture attempt. Armed traps were monitored in person, or remotely via game cameras by ODFW staff. Wireless trap monitoring sensors were installed on all trap doors to automatically notify project staff by text in the event of an unplanned trap closure. In addition, manually operated safety pin devices further protected against the event of an unplanned trap closure.

Trap doors were closed using a remote-controlled magnetic release mechanism. Once sea lions were captured, they were herded into holding cages on a barge built specifically to handle sea lions. Once animals were moved from the trap to a transfer cage on the barge, plywood boards were placed on all sides of the transfer cage to reduce visual stimuli and stress on the animal. Two boats were then used to move the barge downriver to a boat ramp where sea lions were transferred onto trucks for transport to a secure off-site facility.

Animals may be held up to 48 hours as per the Willamette Falls IACUC, although animals are typically held for less than three hours in the covered transfer cage either indoors or outdoors and are regularly monitored and wet down with a hose to reduce the chance of thermal stress. If an approved zoo or aquarium facility were available to receive candidate sea lions for permanent holding, then captured animals would be given a health screening by field staff and veterinarians, including members of the States' Institutional Animal Care and Use Committee. If an animal passed the health screening it would be transferred to an approved temporary housing facility prior to shipment to a zoo or aquarium. If an animal failed the health exam, or if there were no approved facilities prepared to accept an animal, then it would be chemically euthanized. Euthanized animals were necropsied and various samples (e.g., teeth, stomachs, whiskers) were collected and stored for later analysis.

Diet analysis

Stomachs and large intestines from euthanized animals were collected and processed following standard procedures (e.g., see Lance et al. 2001) in order to gather dietary information. Undigested remains were washed through a series of nested sieves (2mm, 1mm and .05mm) and all parts were collected for later identification. Samples were identified using a dissecting microscope to the lowest possible taxonomic level by comparing all identifiable prey remains (e.g., bones, otoliths, cartilaginous parts, lenses, teeth and cephalopod beaks) against a reference collection of fish from the northeastern Pacific Ocean and Oregon estuaries. Prey were enumerated by pairing of skeletal structures (otoliths, tail structures, mouthparts, etc.) to achieve the greatest number of prey in the sample. Enumeration takes into account both left and right sides of paired structures and also size of recovered prey remains.

Effect of removals

The effect of the sea lion removal program at Willamette Falls was assessed in several ways. First, we compared monitoring data from pre- and post- removal authority years. This included 1) estimates of sea lion abundance and 2) estimates of predation on salmonids and other prey. See Wright et al. (2022) for methodological details and additional results not presented here. Second, the effect of removals was characterized by estimating how many salmonids would have been required over the expected post-removal lifetimes of individual sea lions had they not been removed. This was done using an agent-based modeling (ABM) approach (see Appendix 1 for details). Results are based on summaries of 300 model runs and only on animals removed under Willamette Falls §120 authority. Note that this work is ongoing and subject to revision as new data becomes available and as new modeling approaches are evaluated.

RESULTS

Trapping

Active trapping effort below Willamette Falls occurred during two weeks in May 2022 in which three CSLs were captured and euthanized (Table 1). The average weight of the euthanized CSLs was 327 kg (720 lbs), with a range of 197-472 kg (434-1040 lbs). Age data based on sectioned teeth are not yet available

Diet analysis

Gastro-intestinal (GI) tracts were collected from euthanized sea lions, all of which contained undigested prey remains (Table 2). Collectively, the three GI-tracts contained undigested remains of at least three adult spring Chinook salmon (*Oncorhynchus tschawytscha*), nine steelhead (*O. mykiss*), and three unidentifiable adult salmonids (*Oncorhynchus spp.*). A small sample of salmonid bones were submitted for genetic identification and will be reported at a later date. Additional prey recovered included 25 Pacific lamprey (*Entosphenus tridentatus*) and one shad (*Alosa sapidissima).*

Effect of removals

Monitoring results showed that CSL management at Willamette Falls resulted in substantial decreases in both CSL abundance (Figure 1) and salmonid predation (Figure 2), particularly during the late fall and winter months when listed winter steelhead are most at risk from sea lion predation. The cumulative number of salmonids predicted to have been "saved" due to the 37 CSLs removed exclusively under the Willamette Falls §120 authority was 14,117 fish (95% percentile confidence interval: 7,943-22,448 fish) (Figure 3, Appendix 1).

DISCUSSION

We continued to make progress during the fourth season of the Willamette Falls sea lion management program, removing one-half of the estimated six individual California sea lions observed there during spring 2022. These removals bring the grand total to 45 California sea lions and one Steller sea lion that have been removed below Willamette Falls under all applicable §120 authorities. Despite this continued progress, it is nonetheless clear that additional removals have and will become increasingly difficult due to a decrease in trap use by both sea lion species. However, since many sea lions at Willamette Falls also forage at Bonneville Dam, removals at the latter site will partially mitigate trapping challenges at Willamette Falls, although there too trap use may be in decline. Despite the emerging challenge of removing the remaining animals at these sites, management efforts at Bonneville Dam and Willamette Falls continue to serve as an effective inter-agency effort to solve a difficult and complex natural resource problem.

ACKNOWLEDGEMENTS

We would like to acknowledge and thank the following people for their help and assistance during the 2021-2022 field season:

- ODFW: Shaun Clements, Chris Kern, Tucker Jones, Dave Fox, Kevleen Melcher, and Debbie Ames
- Confederated Tribes of the Grande Ronde: Kelly Dirksen
- PSMFC: Dave Colpo, Geana Tyler
- NMFS: Robert Anderson
- Oregon State Police
- Clackamas County Sheriff Marine Unit
- Sportcraft Landing Moorages

Funding was provided by ODFW and NMFS. Activities were authorized under MMPA §109(h) and §120.

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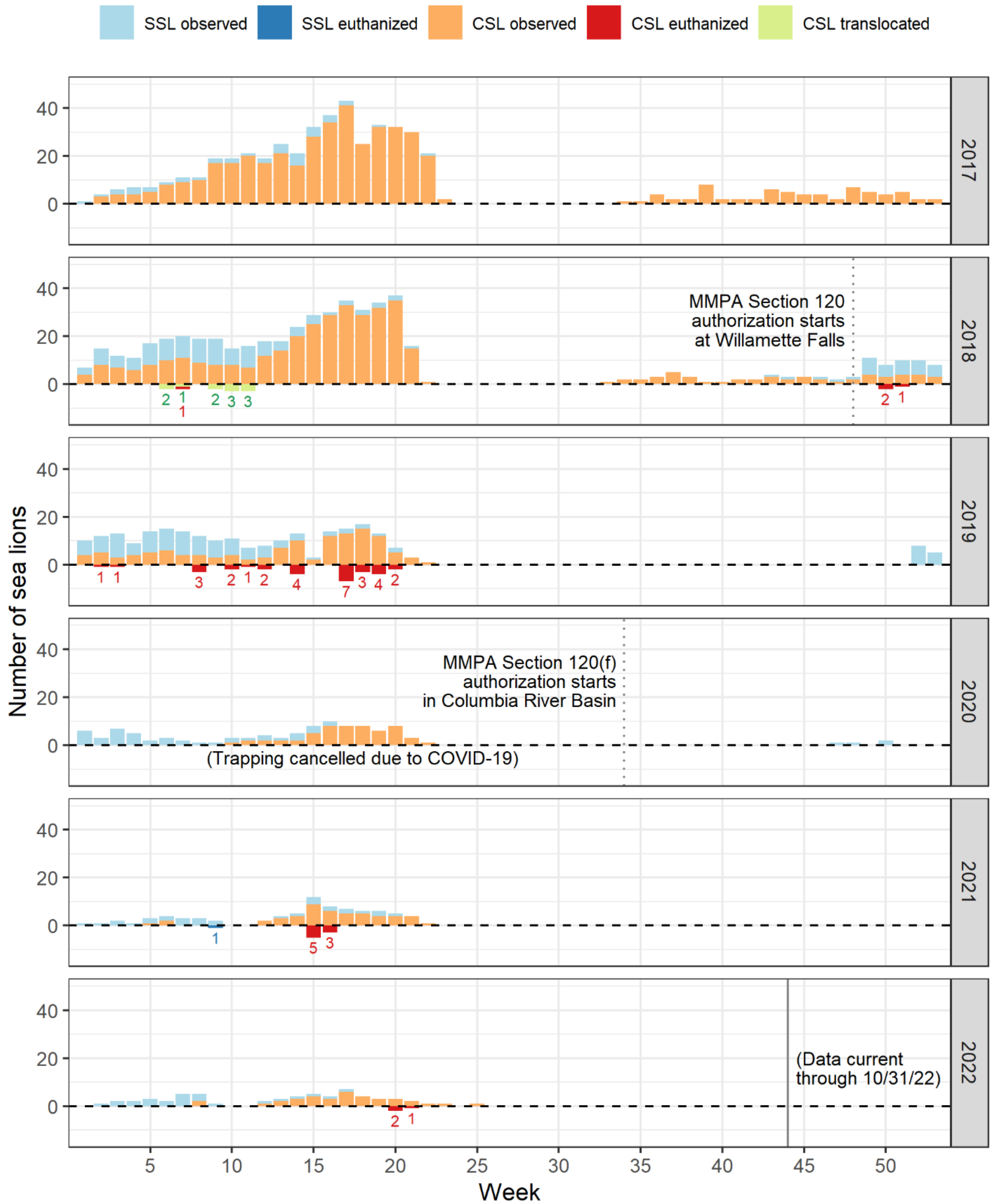

Figure 1. Weekly counts of California sea lions (CSL) and Steller sea lions (SSL) at Willamette Falls, 2017-2022. Non-mutually exclusive count categories include numbers observed, euthanized, or translocated. Observed counts represent the maximum daily count for a given week based on direct observations and/or automated cameras.

Figure 2. Comparison of estimated predation by California sea lions (CSLs) between years with and without removal authority. Error bars indicate 95% confidence interval limits. Estimates only apply to the sampling frame and therefore are minimum estimates due to undercoverage of the target population. Percent potential escapement (%PE) = estimate / (estimate + escapement) x 100.

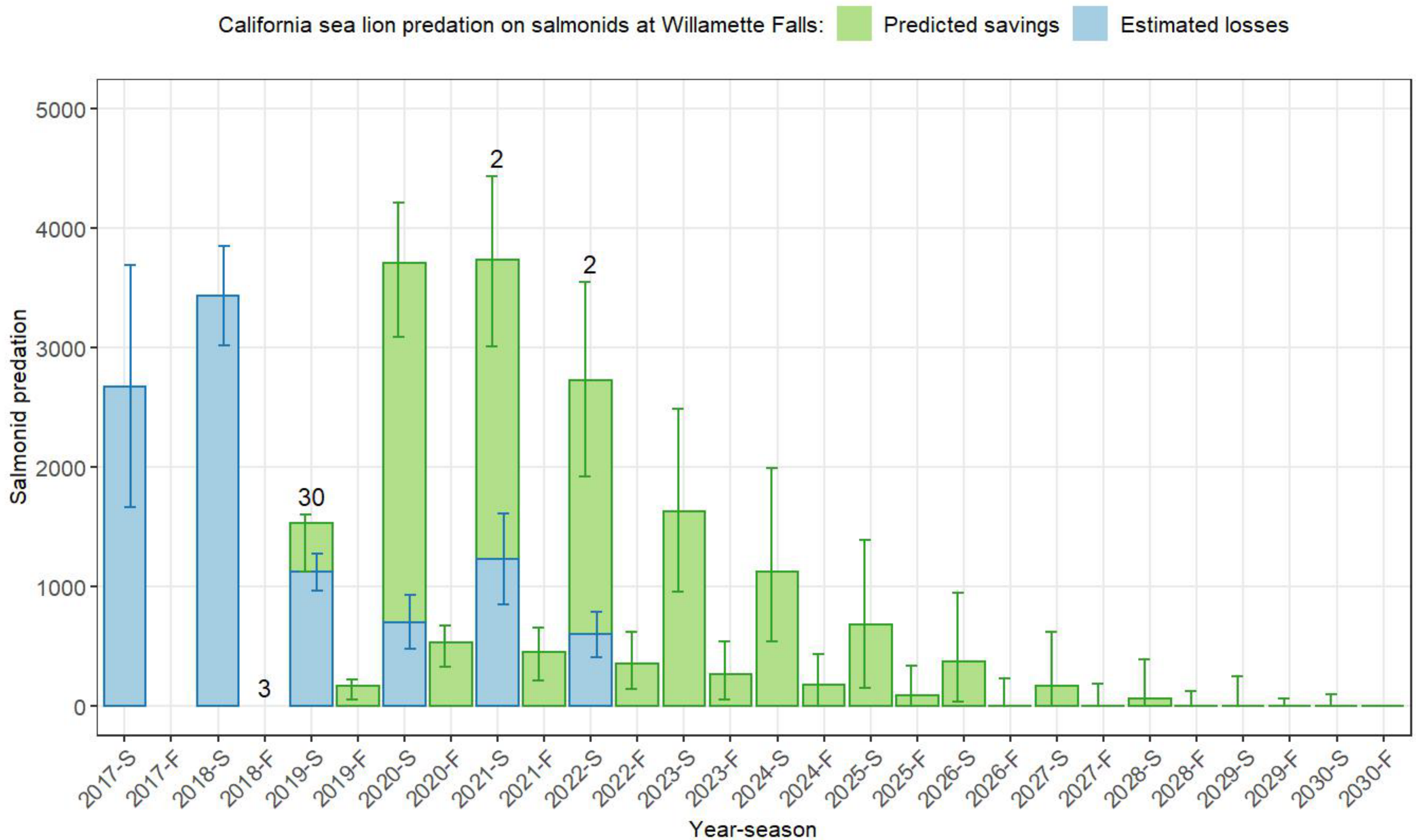

Figure 3. Estimated salmonid predation ("losses") and predicted prey requirements ("savings") at Willamette Falls. Losses are based on design-based estimates of salmonid predation by all CSLs observed at the falls from January-May (see Wright et al. 2022) whereas savings are based on agent-based model predications for the 37 CSLs removed exclusively under Willamette Falls §120 authority (see Appendix 1). Error bars denote 95% confidence intervals; numbers atop error bars indicate removals for a given year and season.

Table 1. Weekly summary of sea lion capture effort and outcomes at Willamette Falls, 11/1/2021-10/31/2022. Table includes animals removed under letters of authorization for Willamette Falls §120 (valid 11/14/2018-11/14/2023) and Columbia River Basin §120(f) (valid 8/14/2020-8/14/2025).

		Euthanized	
Week(s) of	Trap effort (days)	California sea lions	Steller sea lions
2021-11-01 to 2022-05-14*	0	NA	NA
2022-05-15	3	2	0
2022-05-22	3	1	0
2022-05-29 to 2022-10-31*	0	NA	NA
	6	3	0

*No use of traps by sea lions.

Table 2. Minimum number of individual prey recovered from gastro-intestinal tracts (stomach and large intestines) collected from three euthanized California sea lions (CSL) captured at Willamette Falls, 11/1/2021-10/31/2022. Table includes animals removed under letters of authorization for Willamette Falls (WF) §120 (valid 11/14/2018-11/14/2023) and Columbia River Basin (CRB) §120(f) (valid 8/14/2020-8/14/2025).

Date	Sea lion species	ID	Removal authority	Adult Chinook salmon	Adult Steelhead	Unknown adult salmonid	Pacific lamprey	Shad
2022-05-16	CSL	ZW007	CRB §120(f)	1	3		2	
2022-05-17	CSL	R07	WF §120	2	5		19	
2022-05-25	CSL	X520	WF §120		1	3	4	1
Total				3	9	3	25	1

Appendix 1. An agent-based model for predicting cumulative post-removal prey requirements of sea lions removed under section 120 of the Marine Mammal Protection Act.

1. Introduction

Under section 120 of the Marine Mammal Protection Act (MMPA), NOAA Fisheries has authorized the lethal removal of sea lions in the Columbia River basin to reduce predation on salmon and steelhead listed under the Endangered Species Act as well as other species of conservation concern (NMFS 2022). As part of the terms and conditions of the authorization, permitees are required to report annually on the expected benefits of the takings such as the actual or predicted predation impacts on prey species of concern.

Direct observation of prey consumption by marine mammals is usually not possible except for unique situations such as surface feeding on large or difficult to consume prey (adult salmonids, sturgeon, and lamprey) from elevated observation substrates such as at Bonneville Dam and Willamette Falls (e.g., van der Leeuw and Tidwell 2022, Wright et al. 2022). Even in these exceptional situations, however, estimates are typically conservative (i.e., underestimates) since they include only an unknown fraction of an individual animal's daily foraging activity in both space and time. Furthermore, it is usually not possible to attribute predation events to a known sea lion due to either a complete lack of identifying marks or imperfect detectability of such marks when they exist. Lastly, consumption estimates based on direct observation only address past events and not predation that can be expected to occur in the future.

One method that overcomes some of these limitations is bioenergetics modeling. In this approach, the daily energy requirement of an animal is estimated and then translated into prey-specific biomass requirements which in turn can be translated into numbers of individual prey. Furthermore, the bioenergetics model can be nested in a series of models that describe other processes affecting total lifetime biomass requirements such as survival, growth, site fidelity, residency, and diet composition. Since such a complex series of models quickly becomes intractable using standard analytical approaches, one possible approach to analyzing such a system is to use agent- or individual-based models (ABMs/IBMs) (An et al. 2021, Grimm et al. 2020, Macal 2016, Sibley et al. 2013).

The objective of this exercise was to develop a sea lion management ABM to predict the cumulative, post-removal prey requirements of sea lions removed under MMPA §120. Note that this model is still under active development and will be updated annually as new data become available and sub-models are refined.

2. Methods

This draft model description follows the Overview, Design concepts, and Details (ODD) protocol for describing individual- and agent-based models (Grimm et al. 2006), as updated by Grimm et al. (2020). Additional detail will be added in future reports. The model was developed and implemented in R 4.2.1 (R Core Team 2022).

2.1. Overview: Purpose and pattern

The primary purpose of the sea lion management ABM is to predict the cumulative number of prey (particularly salmonids) required over the projected post-removal hypothetical lifetime of California sea lions and/or Steller sea lions that were authorized for removal under MMPA §120.

We define three patterns as the criteria for model usefulness: 1) estimates of per capita biomass consumption that are consistent with the published literature; 2) per capita biomass consumption as a percent of body mass that are consistent with the published literature; and 3) estimates of numbers of prey consumed that are consistent with observed data.

2.2. Overview: Entities, state variables, and scales

Entities in the model are individual sea lions that were removed under MMPA §120.

Each sea lion has a unique ID and the following variables: age in years; whether or not they survived the annual time step; growth in body mass per annual time step; whether or not they returned (site fidelity) to an upriver site per seasonal time step; and the residency duration per seasonal time step. Within a seasonal time-step, additional variables included biomass requirements for up to three prey items. Species (CSL, SSL), sex (male), location (Bonneville Dam, Willamette Falls), season (fall = July-December; spring = January-June), and diet composition were fixed and did not vary by annual, seasonal, or daily time steps.

The model is currently non-spatial, so the environment is not represented, and sea lions only have one location per season (Bonneville Dam or Willamette Falls). The model runs at three different time scales: annual (survival, growth), seasonal (fidelity, residency, diet), and daily (bioenergetics).

2.3. Overview: Process overview and scheduling

Processes: The model was developed to cover the life cycle of nuisance sea lions as it pertains to their time at terminal upriver feeding sites in the Columbia River Basin. It is structured in a combination of several deterministic and stochastic processes (see Fig. 1).

Schedule: The simulation starts one-year post-removal for each sea lion (within-year biomass requirements will be added at a later date). Each animal's probability of surviving to the first-year post-removal is determined by a species-, sex- (male), and age-specific survival probability as defined in a Bernoulli trial where the probability of success (survival) is based on the published literature. If an animal survives then its age is incremented and body mass increases by an age-specific factor based on the published literature (stochasticity in growth may be added at a later date).

Next, the probability of returning to an upriver site for a given location and season is determined independently for each sea lion based on a Bernoulli trial where the site fidelity (return probability) is based on empirical data from marked animals from Bonneville Dam and Willamette Falls. Next, residency duration is estimated independently for each sea lion based on a single sample from a Poisson distribution where the parameter is based on empirical data from marked animals from Bonneville Dam and Willamette Falls.

Next, a within-season daily loop starts based on the residency where, for each day, location- and season-specific biomass requirements are estimated based on a bioenergetics model for up to three prey types. Currently the biomass requirement is converted to number of fish at the end of the simulation based on mean prey weights but future updates to the model may convert biomass to fish numbers at the daily level (e.g., using a multinomial distribution to select prey types). Sea lions migrate downriver at the end of the residency period and the annual loop begins again with the survival step.

2.4. Design: Design concepts

The 11 design concepts (basic principles, emergence, adaptation, objectives, learning, prediction, sensing, interaction, stochasticity, collectives, and observation,) will be included at a later date

2.5. Details: Initialization

Each individual's state variable (age, mass, fidelity, residency) is initialized based on either individual-specific empirical data or estimated from such data. Initial age and mass at removal are either based on tooth aging and weighing the animal at time of removal, respectively, or these values are imputed based on the observed data. Additional initialization details will be included at a later date.

2.6. Details: Input data

Three input files (besides agent data) are imported into the model: survival data, growth data, and diet composition data. These are defined in separate model scripts and are based on either the published literature or observed data.

2.7. Details: Sub-models

There are six sub-models in the ABM; two of these operate at the annual time scale (survival, growth), three at the seasonal time scale (fidelity, residency, diet), and one at the daily time scale (bioenergetics). Each agent (sea lion) only occurs at one location based on where it was removed (Bonneville Dam or Willamette Falls) but may occur for up to two seasons (Spring, Fall) depending on their observed resight history; if the animal is unmarked then it can only occur during the season in which it was removed.

For animals that have not yet been aged, we approximated their ages based on either 1) for CSLs, the subset of animals of similar actual or estimated weight that have been aged, or 2) for SSLs, approximate age-at-mass data from the Winship et al. (2006). Model results will likely change in future reports as actual age data become available.

2.7.1. Survival sub-model (annual)

The probability of an animal surviving each annual time step was based on a species-, sex-, and age-specific survival rate (Table 1, Fig. 2). In the ABM, each individual at each time step lives or dies based on the outcome of a Bernoulli trial where the probability of success (survival) equals the species-, sex-, and age-specific survival rate. If the animal survives, then it advances to the growth sub-model after which its age is increased by one year regardless of whether it was removed in the spring (before its birthday) or the fall (after its birthday). For animals removed in the spring the probability of surviving from spring of year i to spring of year $i + 1$ closely matches the assumptions of the survival estimates since parturition is during the summer. For fall removals of animals that may occur upriver in both the spring and fall, the meaning of annual survival becomes more ambiguous and will be refined in subsequent models. If the animal dies, then that particular run in the overall simulation is complete for that animal. Model runs that result in no biomass requirements due to mortality and/or not returning to the upriver sites are temporarily retained in order to estimate summary statistics.

2.7.2. Growth sub-model (annual)

The amount of food an animal requires per day is a function of many factors but the most important is an animal's metabolic rate which in turn is a function of its body mass as stated in Kleiber's equation (adults; from Winship et al. 2002):

$$\text{Basal metabolism (BM in kJ d}^{-1}\text{)} = 292.88 \times M^{0.75}$$

where M is body mass (kg). The growth sub-model is still under development but is currently based on relative rates of change from the mass-at-age models of Winship et al. (2006) (Fig. 3). Asymptotes of 1000 lbs (454 kgs) and 2000 lbs (907 kgs) were used to cap growth for CSLs and SSLs, respectively. In the ABM, the growth process is currently deterministic but future versions of the model will add stochasticity.

2.7.3. Site fidelity sub-model (seasonal)

The site fidelity sub-model estimates the probability of an animal returning to an upriver location in a given season given that it's known to be alive. For example, CSL "2n11" was branded at Bonneville Dam in 2016 but not detected there again until 2018; his estimated fidelity rate or probability of returning was therefore one year (2018) out of two (2017, 2018) or 0.5. If that same animal had also been seen on the coast in 2020 his estimated fidelity would have been one year (2018) out of four (2017-2020) or 0.25. Removal animals that were unmarked or marked but only seen one year (e.g., removed same year as marking) were given the average fidelity rate for the species-, location-, and season. In the ABM, the probability of an animal returning is based on the outcome of a Bernoulli trial where the probability of success (returning) equals the fidelity parameter for that animal (either ID-specific or based on the average of the species-location-season).

It is important to note that the estimated fidelity rates are likely biased low due to imperfect detectability of marked animals since 1) in any given year a marked animal may occur but not be detected and 2) prior to marking they are undetectable by definition even though they may have occurred there for multiple years. In addition, as with other datasets, there is a time lag between data collection and data entry so new resights are continually being added and therefore fidelity estimates will likely be revised in future reports.

2.7.4. Residency sub-model (seasonal)

The residency sub-model estimates the number of days an animal stays at a given location in a given season given that they have returned. Residency rates were calculated based on the elapsed days between the first and last date a marked animal was observed but only after first removing seasons in which they were marked and/or removed in order to avoid negatively biasing rates by including artificially left- or right-censored seasons.

As with the site fidelity sub-model, imperfect detectability of marked animals likely led to conservative estimates of residency (i.e., too low). On the other hand, residency may have been overestimated in some cases if animals made temporary within-season trips to and from an upriver site rather than staying there the entire time between first and last detection. This latter behavior was observed in the early years of research at Bonneville Dam, but it is unknown to what extent it currently occurs. In addition, apparent residency rates for CSLs at both Bonneville Dam and Willamette Falls have declined over time. Future versions of this ABM could incorporate the apparent decline in residency rather than including the mean value although the point of the exercise is to predict what might have happened had there been no intervention and in that case the residency rates would most likely have remained high or have even increased.

2.7.5. Diet sub-model (seasonal)

The current version of the diet sub-model contains six diets, one for each of the species-, location-, and season-specific categories, and each containing up to three types of prey (Table 2). The diets are based on a combination of expert opinion, scat and gastro-intestinal tract analyses, and predation observations (anecdotal and probability based). Currently the diets are fixed but future versions of the ABM will introduce stochasticity into the diet composition. Energetic densities (kJ g-1) of prey are treated as fixed except for the "other" category which draws from a uniform distribution.

Total biomass requirements are converted to numbers of fish based on average prey weights. Currently only salmonid fish numbers are calculated but future versions of the model may include sturgeon, lamprey, and possibly other species. Prey size currently enters the modeling process after the ABM run is complete and total prey-specific biomass estimates have been calculated. Future versions of the ABM may treat prey size as a separate sub-model and also include stochasticity by randomly drawing prey sizes from a distribution of values rather than treating it as fixed.

2.7.6. Bioenergetics sub-model (daily)

The final component of the ABM is the bioenergetics sub-model which was modified from Winship et al. (2002). This sub-model estimates the daily biomass requirement for prey category *i* and predator *j* based on the following formula

$$BR_{ij}[kg\ d^{-1}] = \frac{GER[kJ\ d^{-1}] \times prey_i}{ED_i[kJ\ g^{-1}]} \div 1000$$

where GER is the gross energy requirement

$$\frac{P + (A_j \times BM_j)}{E_{HIF} \times E_{f+u}}$$

and A is the energetic cost of activity

$$A_j = water_j * A_{water} + (1 - water_j) * A_{land}$$

Additional parameter definitions and values are described in Table 3. (Note that the update to the denominator of GER found in Winship and Trites (2003) was not used since it is not applicable to high energetic densities such as that found in Pacific lamprey.)

In contrast to many other bioenergetic models (e.g., Winship et al. 2002), for this particular application the model was greatly simplified since it is only for one sex (males), one age-class (non-pups), and for relatively short periods of time which meant that production (growth in body mass) could be omitted. Future versions may include production, however, since Steller sea lions are now included and have longer annual residency times at Bonneville Dam than California sea lions for which the model was originally intended. On the other hand, biomass requirements for growth in adults have shown to be small relative to requirements such as basal metabolism, activity, and waste (e.g., see Fig. 1 in Winship et al. 2002) so omitting it from the model is not likely to negatively bias the results.

2.8. Sensitivity analysis

Sensitivity analysis will be implemented in future versions of the ABM exercise.

3. Results

A total of 37 California sea lion agents were initialized for the ABM (Table 4). The ABM was run 300 times resulting in a grand total of 26,451,900 records. Filtering out non-survivors, non-returners, and non-residents (artifacts of book-keeping and validation code) reduced the working dataset to 1,711,320 records. The predicted number of salmonids required by sea lions had they not been removed was 14,118 fish (95% percentile confidence interval was approximately 7943 to 22,448 fish).

4. Discussion

Agent-based modeling of the effects of sea lion management has proven to be a useful and effective framework for the continued analysis of this topic. Future work will include continued refinement of each of the sub-models (e.g., fidelity and residency), as well as exploring ways to make the model more spatially and temporally explicit.

While it is important to note that bioenergetic models produce estimates of food requirements and not food consumption, these results were nonetheless consistent with data from captive animals (e.g., Kastelein et al. 1990, 2000). It's also important to note that, in addition to preventing the loss of future fish, removal of habituated sea lions is believed to reduce opportunities for new, naive animals to be recruited into the Bonneville Dam "population", since at least some naive animals are thought to follow habituated animals upriver from haul-outs near the mouth of the river (Schakner et al. 2016), which itself could be included as an additional sub-model in future updates.

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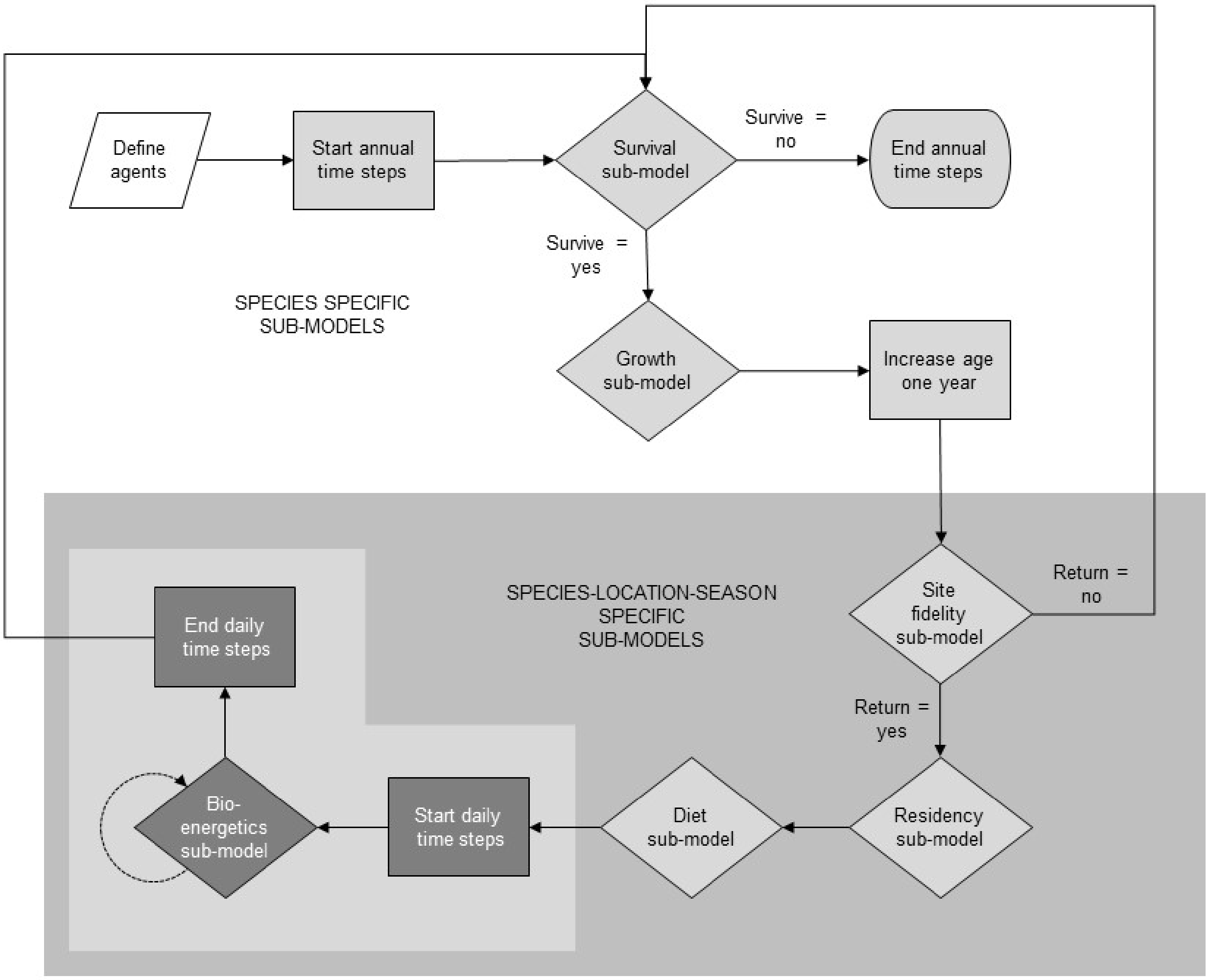

Fig. 1. Flowchart of sea lion management agent-based model.

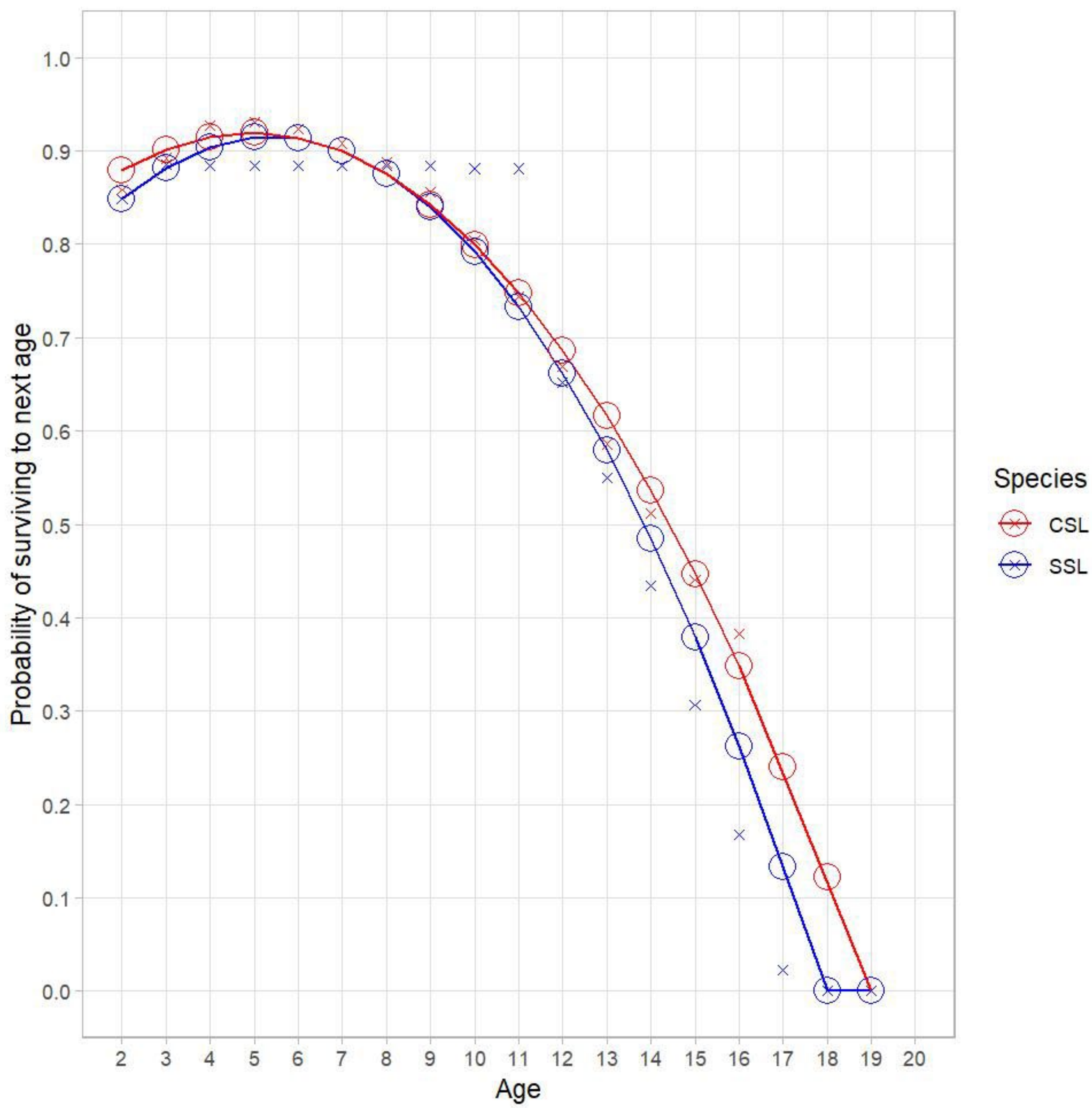

Fig. 2. Survival sub-model. California sea lion (CSL) data from DeLong et al. (2017); Steller sea lion data (points) from Wright et al. (2017; ages 0-11) and Maniscalco et al. (2015; ages >11); lines indicate second order polynomial fits to data. See Table 2 for additional details.

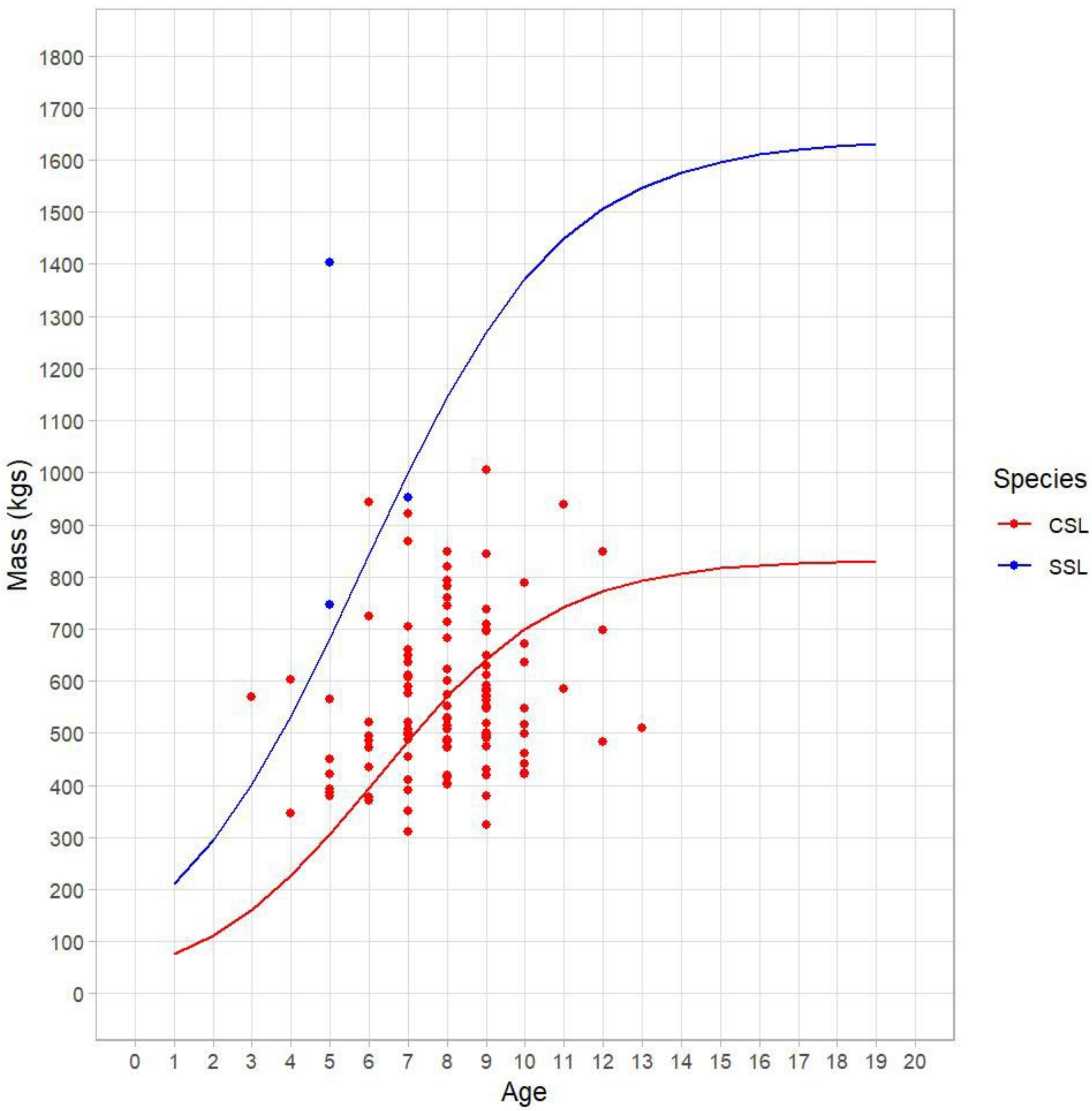

Fig. 3. Growth sub-model. Mass at age growth curves from Winship et al. (2006); points indicate age and weight from sea lions removed at Bonneville Dam and Willamette Falls (age data still pending for many animals).

Table 1. Survival sub-model parameters. Estimate is value from the published literature and indicates probability of surviving to next age (e.g., probability of male CSL surviving from age 2 to age 3 is 0.858). Final indicates predicted value from second order polynomial fit to published estimates (see footnotes).

	Male California sea lion survival probabilities			Male Steller sea lion survival probabilities		
Age	Estimate	Source	Final	Estimate	Source	Final
2[a]	0.858	Table 3, DeLong et al. 2017	0.879	0.848	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.849
3	0.892	Table 3, DeLong et al. 2017	0.901	0.885	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.882
4	0.927	Table 3, DeLong et al. 2017	0.915	0.884	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.904
5	0.931	Table 3, DeLong et al. 2017	0.919	0.884	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.914
6	0.923	Table 3, DeLong et al. 2017	0.914	0.884	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.913
7	0.908	Table 3, DeLong et al. 2017	0.899	0.884	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.900
8	0.887	Table 3, DeLong et al. 2017	0.876	0.884	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.875
9	0.856	Table 3, DeLong et al. 2017	0.842	0.884	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.839
10	0.804	Table 3, DeLong et al. 2017	0.800	0.881	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.792
11	0.744	Table 3, DeLong et al. 2017	0.748	0.881	Averaged 2002-2009 cohorts, Table S2, Wright et al. 2017	0.732
12	0.669	Table 3, DeLong et al. 2017	0.686	0.652	Table S1/Appendix 1b, Maniscalco et al. 2015	0.661
13	0.586	Table 3, DeLong et al. 2017	0.616	0.550	Table S1/Appendix 1b, Maniscalco et al. 2015	0.579
14	0.512	Table 3, DeLong et al. 2017	0.536	0.434	Table S1/Appendix 1b, Maniscalco et al. 2015	0.485
15	0.440	Table 3, DeLong et al. 2017	0.446	0.306	Table S1/Appendix 1b, Maniscalco et al. 2015	0.379
16	0.383	Table 3, DeLong et al. 2017	0.348	0.168	Table S1/Appendix 1b, Maniscalco et al. 2015	0.262
17	0.354[b]	Table 3, DeLong et al. 2017	0.240	0.023	Table S1/Appendix 1b, Maniscalco et al. 2015	0.133
18	0.350[b]	Table 3, DeLong et al. 2017	0.122	0.001	Table S1/Appendix 1b, Maniscalco et al. 2015	0.001
19	0.366[c]	Table 3, DeLong et al. 2017	0.000	0.001[c]	Table S1/Appendix 1b, Maniscalco et al. 2015	0.000

[a] No CSLs <2 years of age have been observed in removal population

[b] Set to NA due to small sample size and high uncertainty in estimates

[c] Set to zero since no male CSL in the study was sighted >19 years of age; survival of male SSL >19 was also effectively zero.

Table 2. Diet sub-model parameters.

Location	Species	Season	Diet component #1				Diet component #2			Diet component #3		
			Prey	%	ED* (kJ/g)	Weight** (kg)	Prey	%	ED* (kJ/g)	Prey	%	ED* (kJ/g)
Bonneville	CSL	Spring	Spr. Chi. salmon	90	7.2	5.7	NA	0	NA	Other	10	~U(3, 7.2)
Bonneville	SSL	Spring	Spr. Chi. salmon	45	7.2	5.7	W. sturgeon	45	4.4	Other	10	~U(3, 7.2)
Bonneville	SSL	Fall	Salmonid	30	5.9	5.4	W. sturgeon	60	4.4	Other	10	~U(3, 7.2)
Willamette	CSL	Spring	Salmonid	90	5.9	5.4	P. lamprey	5	25.65	Other	5	~U(3, 7.2)
Willamette	CSL	Fall	Salmonid	70	5.9	5.4	NA	0	NA	Other	30	~U(3, 7.2)
Willamette	SSL	Spring	Salmonid	30	5.9	5.4	W. sturgeon	60	4.4	Other	10	~U(3, 7.2)

*Energetic density (ED) sources: salmonids (O'Neil et al 2014), sturgeon (pers. com. P. Stevens, ODFW), lamprey (Clemens et al. 2019), other (Winship and Trites 2003).

**Mean weight sources: salmonids (predation-weighted mean of salmon and steelhead at Willamette Falls, Jepson et al. 2015); spring Chinook salmon (CRTIFC, 2004-2007).

Table 3. Bioenergetics sub-model parameters.

Symbol	Description	Value	Units	Source
P	Production (energy invested in growth)	0	kJ d^{-1}	See methods
A_{water}	Water metabolic rate multiplier	~triangle(2.5, 4.0, 5.5)	Unitless	Winship et al. (2002)
A_{land}	Land metabolic rate multiplier	~triangle(1.0, 1.2, 1.4)	Unitless	Winship et al. (2002)
$water_{j\,=\,CSL}$	Percent of time spent in the water	~triangle(0.08, 0.78, 1)	%	Unpublished data, ODFW & WDFW
$water_{j\,=\,SSL}$	Percent of time spent in the water	~triangle(0, 0.68, 1)	%	Unpublished data, ODFW & WDFW
BM_j	Basal metabolism	$292.88 \times M_j^{\ 0.75}$	kJ d^{-1}	Winship et al. (2002); adults
M_j	Body mass	f_i(mass, age)	kgs	Growth sub-model
E_{f+u}	Fecal and urinary digestive efficiency	~U(0.81, 0.89)	%	Winship et al. (2002)
E_{HIF}	Energy utilization efficiency	~U(0.85, 0.90))	%	Winship et al. (2002); maintenance
$prey_i$	% of total diet biomass comprised of prey *i*	0-100	%	Diet sub-model
ED_i	Energetic density of prey *i*	3-25.65	kJ g^{-1}	Diet sub-model

Table 4. Agent data used to initiate the model.

	ID	Capture date	Age	Age_est	Mass_kgs	Mass_est	Season	Fidelity_p	Fidelity_est	Residency_d	Resisidency_est
1	U278	20181212	9	0	259	1	Fall	1.00	0	26	0
	U278	20181212	9	0	259	1	Spring	1.00	0	100	0
2	X551	20181212	7	0	259	1	Fall	1.00	0	35	1
	X551	20181212	7	0	259	1	Spring	1.00	0	83	0
3	Rn03	20181220	9	0	315	0	Fall	1.00	1	35	1
4	1n89	20190109	8	0	219	0	Fall	1.00	1	62	0
	1n89	20190109	8	0	219	0	Spring	1.00	0	49	0
5	U971	20190115	8	0	345	0	Fall	1.00	0	63	0
	U971	20190115	8	0	345	0	Spring	1.00	0	103	0
6	1n63	20190220	8	0	230	0	Fall	1.00	1	49	0
	1n63	20190220	8	0	230	0	Spring	1.00	0	61	0
7	FT 8n2	20190220	8	0	298	0	Spring	0.83	1	43	1
8	FT 8n3	20190220	8	0	193	0	Spring	0.83	1	43	1
9	2n27	20190306	9	0	248	0	Fall	1.00	0	4	0
	2n27	20190306	9	0	248	0	Spring	1.00	0	60	0
10	FT 8n1	20190306	10	0	283	0	Spring	0.83	1	43	1
11	C057	20190313	7	0	300	0	Fall	1.00	0	25	0
	C057	20190313	7	0	300	0	Spring	1.00	0	96	0
12	U221	20190322	8	0	324	0	Spring	1.00	0	44	0
13	X297	20190322	10	0	305	0	Fall	1.00	1	35	1
	X297	20190322	10	0	305	0	Spring	1.00	0	47	0
14	1n64	20190403	9	0	225	0	Spring	1.00	0	56	0
15	FT 8n4	20190403	12	0	279	0	Spring	0.83	1	43	1
16	FT 8n7	20190403	12	0	360	0	Spring	0.83	1	43	1
17	Rn04	20190405	11	0	335	0	Spring	0.83	1	43	1
18	1n37	20190423	8	0	337	0	Spring	1.00	0	39	0
19	1n78	20190423	9	0	295	0	Spring	1.00	0	36	0
20	1n82	20190424	8	0	359	0	Spring	1.00	0	50	0
21	2n50	20190424	9	0	222	0	Spring	1.00	0	28	0

22	1n07	20190425	9	0	295	0	Spring	1.00	0	31	0
23	C099	20190425	8	0	191	0	Spring	1.00	0	47	0
24	X668	20190425	9	0	259	0	Spring	1.00	0	29	0
25	FT 8n9	20190430	7	0	198	0	Spring	0.83	1	43	1
26	U642	20190501	8	0	233	0	Spring	1.00	0	21	0
27	FT 8n11	20190502	9	0	318	0	Spring	0.83	1	43	1
28	FT 8n10	20190507	7	0	319	0	Spring	0.83	1	43	1
29	FT 8n5	20190507	9	0	224	0	Spring	0.83	1	43	1
30	2n51	20190508	8	0	337	0	Spring	1.00	0	34	0
31	FT 8n12	20190508	7	0	374	0	Spring	0.83	1	43	1
32	FT 8n13	20190517	14	0	334	0	Spring	0.83	1	43	1
33	FT 8n8	20190517	7	0	306	0	Spring	0.83	1	43	1
34	U902	20210413	8	1	259	1	Spring	1.00	0	16	0
35	X53	20210420	8	1	259	1	Spring	1.00	0	33	0
36	R07	20220517	8	1	472	0	Spring	0.67	0	28	0
37	X520	20220525	8	1	197	0	Spring	0.50	0	9	0