

Steller Sea Lion (*Eumetopias jubatus*) 2019-2023

Bibliography

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NCRL subject guide 2023-04

<https://doi.org/10.25923/bkfd-b671>

May 2023



U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
NOAA Central Library – Silver Spring, Maryland

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Background & Scope

The goal of this bibliography is to provide a comprehensive review of the scientific literature published on the Steller sea lion (SSL), *Eumetopias jubatus*, from August 2019 through May 2023.

“The Steller (or northern) sea lion (*Eumetopias jubatus*) is the largest member of the family Otariidae, the ‘eared seals,’ which includes all sea lions and fur seals. Steller sea lions are named for Georg Wilhelm Steller, the German surgeon and naturalist on the Bering expedition who first described and wrote about the species in 1742. While they are the only living member of their genus, they share parts of their range with a smaller related species, [California sea lions](#). Steller sea lions' impressive low-frequency vocalizations sound more like roars than California sea lions' barks. They also share parts of their range with another otariid: [northern fur seal](#).

Historically, Steller sea lions were highly abundant throughout many parts of the coastal North Pacific Ocean. Indigenous peoples and settlers hunted them for their meat, hides, oil, and other products, and today sea lions are an important subsistence resource for Alaska Natives.

Because of unexplained widespread population declines in Alaska, Steller sea lions were first listed under the [Endangered Species Act](#) (ESA) in 1990. In 1997 NOAA Fisheries recognized two distinct population segments, listing the eastern distinct population segment (DPS) as threatened and the western DPS as endangered. The eastern DPS has since recovered and is no longer listed, which is a significant achievement under the ESA. The western DPS remains endangered.” -[NMFS](#)

Section I – Abundance and Population Trends

This section contains relevant literature on population trends, abundance, demographics, reproduction, mortality, vital rates, and surveys.

Section II – Behavior

This section contains relevant literature on social behavior and ecology, communication, territoriality, harassment, hauling out, and maternal attendance.

Section III – Bibliographies and Encyclopedia Articles

This section contains bibliography and encyclopedia articles on Steller Sea Lions.

Section IV – Conflicts and Deterrents

This section contains relevant literature on human interactions, conflicts, and deterrents including targeted acoustic startle technology, human conflict, and biting.

Section V – Disease and Parasites

This section contains relevant literature on disease and parasites affecting Steller sea lion populations.

Section VI – Foraging and Diving Behavior

This section contains relevant literature on foraging, diet, Steller Sea Lion prey, stable isotopes, and diving behavior.

Section VII – Genetics

This section contains relevant literature on genome mapping, population genetics, and viral genetics.

Section VIII – Movements, Distribution, and Habitat Use

This section contains relevant literature on breeding philopatry, dispersal, regional differences, and geographic range.

Section IX – Physiology

This section contains relevant literature on endocrinology, blood cell morphology, growth, biomechanics, metabolism, thermoregulation, fasting, body composition, digestion, and the nervous system.

Section X– Predation

This section contains relevant literature on predation on or by Steller Sea Lions.

Section XI – Program, Co-Management, and Method Assessment

This section contains relevant literature on evaluations of management programs, co-management, research programs, and study methodology.

Section XII – Threats

This section contains relevant literature on noise, health risks including contaminants, and anthropogenic threats including entanglement, illegal shooting, pollution and climate change.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; Digital Science's Dimensions.ai; Lens.org; ProQuest's Science and Technology collections including Aquatic Science Fisheries Abstracts; Elsevier's Science Direct; Elsevier's Science Direct; EBSCO's Academic Search Complete and Environment Complete; NOAA's Institutional Repository; Department of Fisheries and Oceans Canada; and Google Scholar. Only English language materials were considered.

Section I: Abundance and Population Trends

Best, B. D., Fox, C. H., Williams, R., Halpin, P. N., & Paquet, P. C. (2023). Updated Marine Mammal Distribution and Abundance Estimates in British Columbia. *Journal of Cetacean Research & Management*, 15(1), 9-26. <https://doi.org/10.47536/jcrm.v15i1.511>

Information relating to the distribution and abundance of species is critical for effective conservation and management. For many species, including cetacean species of conservation concern, abundance estimates are lacking, out of date and/or highly uncertain. Systematic, line-transect marine mammal surveys were conducted in British Columbia's (BC) coastal waters over multiple years and seasons (summer 2004, 2005, 2008, and spring/autumn 2007). In total, 10,057km of transects were surveyed in an 83,547km² study area. Abundance estimates were calculated using two different methods: Conventional Distance Sampling (CDS) and Density Surface Modelling (DSM). CDS generates a single density estimate for each stratum, whereas DSM explicitly models spatial variation and offers potential for greater precision by incorporating environmental predictors. Although DSM yields a more relevant product for the purposes of marine spatial planning, CDS has proven to be useful in cases where there are fewer observations available for seasonal and inter-annual comparison, particularly for the scarcely observed elephant seal. The summer abundance estimates (with lower and upper 95% confidence intervals; all DSM method unless otherwise stated), assuming certain trackline detection (underestimates true population size) were: harbour porpoise (*Phocoena phocoena*) 8,091 (4,885–13,401); Dall's porpoise (*Phocoenoides dalli*) 5,303 (4,638–6,064); Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) 22,160 (16,522–29,721); humpback whale (*Megaptera novaeangliae*) 1,092 (993–1,200); fin whale (*Balaenoptera physalus*) 329 (274–395); killer whale (all ecotypes; *Orcinus orca*), 371 (222–621); common minke whale (*B. acutorostrata*) 522 (295–927); harbour seal (total; *Phoca vitulina*) 24,916 (19,666–31,569); Steller sea lion (total; *Eumetopias jubatus*) 4,037 (1,100–14,815); and northern elephant seal (CDS method; *Mirounga angustirostris*) 65 (35–121). Abundance estimates are provided on a stratum-specific basis with additional estimates provided for Steller sea lions and harbour seals that were 'hauled out' and 'in water'. This analysis updates previous estimates by including additional years of effort, providing greater spatial precision with the DSM method over CDS, novel reporting for spring and autumn seasons (rather than summer alone), and providing new abundance estimates for Steller sea lion and northern elephant seal. In addition to providing a baseline of marine mammal abundance and distribution, against which future changes can be compared, this information offers the opportunity to assess the risks posed to marine mammals by existing and emerging threats, such as fisheries bycatch, ship strikes, and increased oil spill and ocean noise issues associated with increases of container ship and oil tanker traffic in British Columbia's continental shelf waters.

Canadian Science Advisory Secretariat. (2021). *Trends in Abundance and Distribution of Steller Sea Lions (Eumetopias jubatus) in Canada*. Retrieved from <https://publications.gc.ca/site/eng/9.902176/publication.html>

Fisheries and Oceans Canada (DFO) has conducted 14 breeding season aerial surveys since the early 1970s to monitor the Steller sea lion population in British Columbia (BC). Surveys are timed to provide counts of both pups and non-pups (juveniles and adults). DFO has also conducted periodic fall and winter aerial surveys to examine seasonal changes in abundance and distribution of Steller sea lions overwintering in BC. In 2017 a total of 6,640 pups and 25,113 non-pups were counted. Models fit to the counts indicate a possible slowing in the annual rate of growth in pup production since 2013, but not in the rate of growth in the non-pup component of the population. An estimate of the total population size

was obtained by applying a correction factor to non-pup counts to account for animals that were at sea and missed during surveys. The adjusted 2017 breeding season population estimate was 43,200 (95% CI of 38,700 to 48,200) suggesting no significant change from the previous assessment. The winter survey in 2017 provided an estimate of 52,700 (95% CI 41,000 to 67,800) Steller sea lions wintering in the coastal waters of BC. Larger numbers of sea lions estimated from winter surveys compared to breeding season surveys appear to be due to a net influx of animals from rookeries outside of BC. The number of rookeries and year-round haulout sites continues to increase in BC waters. The Potential Biological Removal (PBR) for Steller sea lions during the summer breeding season is 2,474 for Canadian waters.

Esquible, J., & Atkinson, S. (2019). Stranding Trends of Steller Sea Lions *Eumetopias jubatus* 1990-2015. *Endangered Species Research*, 38, 177-188. <https://doi.org/10.3354/esr00945>

Distinct population segments of Steller sea lion (SSL) *Eumetopias jubatus* have experienced different population trends over the last 5 decades, rendering the need for retrospective study. By identifying long-term stranding trends of SSLs we can develop a better understanding of factors contributing to mortality that may affect SSL population dynamics. We characterized spatial and temporal trends of SSL strandings (n = 1507) in Alaska, Oregon, and Washington, USA, over a 25 yr period. Stranding reports were obtained from the Alaska and Northwest Region's Marine Mammal Stranding Networks. Temporal trends were assessed by identifying seasonal patterns across all years (1990-2015), analyzing sex, age class, body length, and characterizing signs of human interaction including factors contributing to mortality. An apparent increase in strandings occurred after 2000, likely due to increased stranding response effort resulting from increased federal grant awards. Adult males were the most frequently stranded sex and age class in the Alaska (AK) and Northwest (NW) Regions. Clear seasonality trends were evident, with the greatest reported stranding occurrences during the spring and summer. Gunshot wounds and fishery interactions accounted for a large proportion (90%) of human interaction cases. In Alaska, the southeast region had the highest number of strandings. In the NW Region, Oregon had the highest documented strandings. Despite caveats associated with stranding data, our findings suggest rapid timing of continued stranding response is imperative for a better understanding of cause-specific mortality trends and other factors contributing to stranding events.

Goto, Y., Isono, T., Ikuta, S., & Burkanov, V. (2022). Origin and Abundance of Steller Sea Lions (*Eumetopias jubatus*) in Winter Haulout at Benten-Jima Rock Off Cape Soya, Hokkaido, Japan between 2012-2017. *Mammal Study*, 47(2), 87-101. <https://doi.org/10.3106/ms2020-0029>

Benten-Jima Rock, located off Cape Soya, Hokkaido, has been a Steller sea lion (SSL; *Eumetopias jubatus*) winter haulout for decades. The animals usually occupy the site from October to May. Observations have been sporadic, although the population count started to increase in 2005. We have monitored SSL numbers since 2012 using several survey methods, such as observation by direct counting and remote archival cameras. Since these data were not sufficient, owing to blind spots, we started using unmanned aerial vehicle (UAV) surveys in 2016 and corrected the previously collected data. Using these methods, a considerable number of SSLs were observed at Benton-Jima Rock during 2016-2017. The maximum number of SSLs was 3158 on land and 3056 in the water near the site, as counted from UAV images on May 2, 2017. Based on hot brand marks, we found that Benten-Jima Rock hosted SSLs from all ten main rookeries along the Asian coast. The majority (similar to 60%) were from Tuleny Island near the east coast of Sakhalin. The cause of this extraordinary increase in SSL numbers at Benten-Jima Rock remains unclear and requires further monitoring and research.

Hattori, K., Kitakado, T., Isono, T., & Yamamura, O. (2021). Abundance Estimates of Steller Sea Lions (*Eumetopias jubatus*) Off the Western Coast of Hokkaido, Japan. *Mammal Study*, 46(1), 3-16. <https://doi.org/10.3106/ms2020-0030>

Aerial surveys were conducted to estimate the abundance of wintering populations of Steller sea lions (SSLs; *Eumetopias jubatus*) in the Sea of Japan originated from Russian waters using the line transect sampling method during spring from 2005 to 2019. The survey areas covered the continental shelf off the western coast of Hokkaido. A total of 28 196 km survey effort was made through the study period under suitable sighting conditions. The numbers of SSLs in haul-out sites were counted separately. Estimations and model selection for the effective strip width were carried out using the maximum-likelihood method. The abundance estimates of SSLs with the line transect method varied annually, ranging from 284 animals (coefficient of variation [Cu] = 0.732) in 2016 to 6271 (CV = 0.194) in 2014. This large variation in abundance estimates might be attributable to interannual changes in the survey coverage, spatial distribution, haul-out behaviors, and seasonal variation of wintering populations of SSLs in the waters off Hokkaido. This warrants further investigation of seasonal and annual change of distribution to adjust key information on the abundance estimates reported here for use in the conservation and management of this species.

Lowry, M. S., Jaime, E. M., & Moore, J. E. (2021). *Abundance and Distribution of Pinnipeds at the Channel Islands in Southern California, Central and Northern California, and Southern Oregon During Summer 2016-2019*. <https://doi.org/10.25923/6qhf-0z55>

Aerial photographic surveys of the coastline and offshore islands of southern California to southern Oregon were conducted during the summers of 2016 to 2019 to document breeding season abundance and distribution of California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*), and Guadalupe fur seals (*Arctocephalus townsendi*). Surveys also documented summer island-residence at the Channel Islands for northern elephant seals (*Mirounga angustirostris*) and Pacific harbor seals (*Phoca vitulina richardsi*). Age and sex counts were made for California sea lions, Steller sea lions, northern elephant seals, northern fur seals, and Guadalupe fur seals. The entirety of the survey area was a-priori subdivided into distinct regions to document intra-island and coastal distribution. The number of California sea lion pups observed increased from 36,039 in 2016 to 53,646 in 2019. Approximately 3,000 adult Steller sea lions were found in California and southern Oregon, but pup counts were about 2.3 times higher in Oregon. Northern fur seals were found at San Miguel Island (minimum 2,605 pups and 2,925 non-pups) and at the Farallon Islands (minimum 1,138 pups and 1,338 non-pups). Northern elephant seal counts at the Channel Islands ranged from 2,983 to 5,612 individuals. Pacific harbor seal counts at the Channel Islands, which are impacted by tide level, ranged from 1,980 in 2016 to 750 in 2019. One Guadalupe fur seal was found at San Nicolas Island in 2019.

Lowry, M. S., Jaime, E. M., Nehasil, S. E., Betcher, A., & Condit, R. (2020). *Winter Surveys at the Channel Islands and Point Conception Reveal Population Growth of Northern Elephant Seals and Residence Counts of Other Pinnipeds*. <https://doi.org/10.25923/k8c2-a111>

Winter surveys of the Channel Islands and Point Conception were conducted during 2002-2018 to derive estimates of northern elephant seal (*Mirounga angustirostris*) births for estimating population growth rates and abundance, estimate pre-census pup mortality for mid-to-late February surveys, document

breeding season abundance and distribution of elephant seals, and document non-breeding season abundance and distribution of California sea lions (*Zalophus californianus*), Pacific harbor seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), and northern fur seals (*Callorhinus ursinus*). Data were obtained from ground counts conducted at San Clemente Island during 2002-2015 and 2017-2018, and from aerial photographic surveys conducted at all Channel Islands and Point Conception in 2005, 2010, and 2013. Northern elephant seal births were estimated from counts of live plus dead pups, or by applying the 97.5% fecundity rate of Ano Nuevo rookery to counts of adult females or to estimates of the asynchronous population of adult females derived from multiple breeding season surveys conducted at the three largest Channel Islands rookeries during January, February, and March at San Nicolas Island in 2010, and at San Miguel, San Nicolas, and Santa Rosa Islands in 2013. Pre-census pup mortality was estimated for mid-to-late February surveys because they could be applied to previous surveys made during that time and because multiple-surveys are too costly to conduct for the Channel Islands (making it likely that single mid-to-late February surveys will be conducted in the future). Pre-census pup mortality for the mid-to-late-February surveys was higher in 2010 (7.1%) than it was in 2013 (2.7% to 3.6%). Multipliers for estimating pre-census pup mortality from dead pups counted in mid-to-late February surveys ranged from 2.40 to 3.36, with a 2013 mean multiplier of 2.93. Multipliers converted dead pup counts from mid-to-late-February surveys into an estimate of total pre-census pup mortality, then added to the count of live pups to estimate total births. Elephant seal birth estimates indicated that the population at the Channel Islands increased at an average annual rate of 3.1% during 1989-2013 with an abundance of 153,387 (95%CI: 132,509 to 175,506) individuals in 2013. San Miguel, San Nicolas, and Santa Rosa Islands accounted for 99.6% to 99.8% of elephant seal births at the Channel Islands. During 2013 surveys, California sea lions were found at all of the Channel Islands, and Pacific harbor seals were found at all islands except Anacapa and Santa Catalina Islands. Steller sea lions were found at San Miguel, Anacapa, and San Clemente Islands, and northern fur seals were found only at San Miguel Island.

Mizuguchi, D., Kato, K., Okamoto, S., Hattori, K., & Sakurai, Y. (2020). Time-Varying Effect of Sea Ice on the Population Dynamics of Steller Sea Lions (*Eumetopias jubatus*) on Tuleny Island. *Ecological Research*, 35(1), 113-122. <https://doi.org/10.1111/1440-1703.12043>

The population of Steller sea lions (SSLs) on Tuleny Island has been increasing continuously since the 1980s. However, the reasons for this increase have remained unknown. In this study, we investigated whether changes in sea ice distribution affected population dynamics on Tuleny Island by applying a Gompertz density-dependent model in a state-space framework with a time-varying coefficient. We compared results from the time-varying coefficient model with those from two other models that assumed time-constant effects and no effect of sea ice. For both SSL pups and non-pups, only the time-varying coefficient model predicted a significant effect from the timing of sea ice breakup. The SSL population was larger when the sea ice broke up earlier. The sea ice effect was larger at the start of the study period and became insignificant in the late 1980s. Thus, our results suggest that the increase in SSL population on Tuleny Island during the first 20 years could be partly explained by earlier sea ice breakup, which promoted immigration from other rookeries. Because SSLs exhibit strong site-fidelity as the habituation effect, individuals that visited once may have repeatedly returned to visit and breed on the island, regardless of the sea ice conditions in later years. This may explain why the sea ice effect was only significant in the first years of population increase. Negative density dependence was also only predicted by the time-varying coefficient model. Adding the time-varying coefficient to modeling analysis could simultaneously improve predictions of environmental effects and estimations of density dependence.

Muto, M. M., Helker, V. T., Delean, B. J., Angliss, R. P., Boveng, P. L., Breiwick, J. M., . . . Zerbini, A. N. (2020). *Alaska Marine Mammal Stock Assessments, 2019*. <https://doi.org/10.25923/9c3r-xp53>

On 30 April 1994, Public Law 103-238 was enacted allowing significant changes to provisions within the Marine Mammal Protection Act (MMPA). Interactions between marine mammals and commercial fisheries are addressed under three new sections. This new regime replaced the interim exemption that has regulated fisheries-related incidental takes since 1988. Section 117, Stock Assessments, required the establishment of three regional scientific review groups to advise and report on the status of marine mammal stocks within Alaska waters, along the Pacific Coast (including Hawaii), and the Atlantic Coast (including the Gulf of Mexico). This report provides information on the marine mammal stocks of Alaska under the jurisdiction of the National Marine Fisheries Service. Each stock assessment includes, when available, a description of the stock's geographic range; a minimum population estimate; current population trends; current and maximum net productivity rates; optimum sustainable population levels and allowable removal levels; estimates of annual human-caused mortality and serious injury through interactions with commercial, recreational, and subsistence fisheries, takes by subsistence hunters, and other human-caused events (e.g., entanglement in marine debris, ship strikes); and habitat concerns. The commercial fishery interaction data will be used to evaluate the progress of each fishery towards achieving the MMPA's goal of zero fishery-related mortality and serious injury of marine mammals.

Muto, M. M., Helker, V. T., Delean, B. J., Young, N. C., Freed, J. C., Angliss, R. P., . . . Zerbini, A. N. (2021). *Alaska Marine Mammal Stock Assessments, 2020*. <https://doi.org/10.25923/yn3s-n786>

On 30 April 1994, Public Law 103-238 was enacted allowing significant changes to provisions within the Marine Mammal Protection Act (MMPA). Interactions between marine mammals and commercial fisheries are addressed under three new sections. This new regime replaced the interim exemption that had regulated fisheries-related incidental takes since 1988. Section 117, Stock Assessments, required the establishment of three regional scientific review groups to advise and report on the status of marine mammal stocks within Alaska waters, along the Pacific Coast (including Hawaii), and along the Atlantic Coast (including the Gulf of Mexico). This report provides information on the marine mammal stocks of Alaska under the jurisdiction of the National Marine Fisheries Service.

Nordstrom, C., Majewski, S., Miller, A., Ellis, G., Watson, J., & Ross, P. (2020). *Pinnipeds: Population Stable since the 1990s*. Retrieved from <https://oceanwatch.ca/howesound/wp-content/uploads/sites/2/2020/08/OceanWatch-HoweSoundReport2020-SH-Pinnipeds.pdf>

Pinnipeds common to nearshore B.C. waters include harbour seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), and Steller sea lions (*Eumetopias jubatus*). Northern fur seals (*Callorhinus ursinus*) and Elephant seals (*Mirounga angustirostris*) are also common to Pacific Canadian waters, but they are observed much less frequently due to their offshore nature and long dive times, respectively. Recently, lone Guadalupe fur seals (*Arctocephalus townsendi*) have been observed on a handful of occasions, which may be related to warm water pulses driven by climate change. Harbour seals and Steller sea lions, which are the only pinnipeds to currently breed in B.C., have been monitored during the breeding season (late July through August) using standardized breeding season surveys. These surveys began in 1973 when long-standing hunting, culling, and bounty programs ended and have traced the recovery of these populations over the past 45 years. Harbour seals are the only pinniped species with established, predictable haul-outs in Átl'ka7tsem/Txwnéwu7ts/Howe Sound. Haul-outs

are typically located on nearshore islands, islets, reefs, or sandbars. Seals are generalist predators that prey on a variety of fish species as well as various cephalopods (small octopus and to a lesser extent squid). In the Strait of Georgia/Salish Sea, this includes primarily Pacific hake (*Merluccius productus*), herring (*Clupea pallasii*), and pollock (*Gadus sp.*). Seasonally important prey include eulachon (*Thaleichthys pacificus*) in early spring and salmon (primarily chum [*Oncorhynchus keta*]) in the fall. The return of forage fish to Átl'ka7tsem/Txwnéwu7ts/Howe Sound, such as anchovy (*Engraulis mordax*), Pacific sand lance (*Ammodytes hexapterus*), and smelt (*Hypomesus pretiosus*), is also an important source of prey for pinnipeds. The Strait of Georgia has the greatest density of harbour seals in B.C. and has been the area most surveyed since counts began in 1973.2 Trends in seal abundance observed in the Strait of Georgia are thought to be representative of other areas in coastal B.C, and counts in the Strait are important for predicting population trends of harbour seals throughout coastal B.C.1 Átl'ka7tsem/Txwnéwu7ts/Howe Sound is one of five subareas surveyed during a typical Strait of Georgia seal survey (Figure 1), with subareas loosely defined as contiguous areas that can be surveyed during a single tide/time window.

Padubidri, C., Kamilaris, A., Karatsiolis, S., & Kamminga, J. (2021). Counting Sea Lions and Elephants from Aerial Photography Using Deep Learning with Density Maps. *Animal Biotelemetry*, 9, 1-10.
<https://doi.org/10.1186/s40317-021-00247-x>

The ability to automatically count animals is important to design appropriate environmental policies and to monitor their populations in relation to biodiversity and maintain balance among species. Out of all living mammals on Earth, 60% are livestock, 36% humans, and only 4% are animals that live in the wild. In a relatively short period, development of human civilization caused a loss of 83% of wildlife and 50% of plants. The rate of species extinction is accelerating. Traditional wildlife surveys provide rough population estimates. However, emerging technologies, such as aerial photography, allow to perform large-scale surveys in a short period of time with high accuracy. In this paper, we propose the use of computer vision, through deep learning (DL) architecture, together with aerial photography and density maps, to count the population of Steller sea lions and African elephants with high precision. Results We have trained two deep learning models, a basic UNet without any feature extractor (Model-1) and another with the EfficientNet-B5 feature extractor (Model-2). We measured the model's prediction accuracy, using Root Mean Square Error (RMSE) for the predicted and actual animal count. The results showed an RMSE of 1.88 and 0.60 to count Steller sea lions and African elephants, respectively, regardless of complex background, different illumination conditions, heavy overlapping and occlusion of the animals. Conclusions Our proposed solution performed very well in the counting prediction problem, with relatively low training parameters and minimum annotation. The approach adopted, combining DL and density maps, provided better results than state-of-art deep learning models used for counting, indicating that the proposed method has the potential to be used more widely in large-scale wildlife surveying projects and initiatives.

Pelayo-Gonzalez, L., Gonzalez-Rodriguez, E., Ramos-Rodriguez, A., & Hernandez-Camacho, C. J. (2021). California Sea Lion Population Decline at the Southern Limit of Its Distribution During Warm Regimes in the Pacific Ocean. *Regional Studies in Marine Science*, 48.
<https://doi.org/10.1016/j.rsma.2021.102040>

We evaluated the effect of regime shifts on the population dynamics of the California sea lion colony of Santa Margarita Island from 1979-2020. This colony is found at the southern extreme of the California

sea lion's range in the North Pacific Ocean in the temperate-tropical transition zone characterized by high primary productivity where oceanic and lagoon environments converge. It is largely isolated from other colonies. We assessed the influence of sea surface temperature and net primary productivity on sea lion population dynamics using historical abundance data taken from the literature and collected in the field (1979-2015). We also performed a Population Viability Analysis to determine the population trend and predict the probability that the colony could go extinct. Anomalies of sea surface temperature (1981-2020) and net primary productivity (2002-2020) were analyzed. Warm and cold periods were determined using the Regime Shift Detector. Colony size decreased at a rate of 4% per year, a decrease of similar to 75% over 36 years. Four regimes (two cold and two warm) were identified in relation to the sea surface temperature and two regimes (one cold and one warm) in relation to the net primary productivity. The number of births decreased during strong El Niño over tildeo events under both warm and cold regimes. During warm regimes, a lower abundance of sea lions was observed compared to the cold regimes that preceded them. Population declines due to regime shifts have also been observed in several species of pinnipeds that inhabit the North Pacific (e.g., the Steller sea lion). The Santa Margarita Island breeding colony meets the IUCN's quantitative criteria for "Vulnerable" or "Endangered". Our results highlight the importance of a colony-level approach in understanding how populations respond to changes in environmental conditions.

Ryazanov, S. D., & Permyakov, P. A. (2021). Steller Sea Lion (*Eumetopias jubatus*) at Tuleny Island, Russia in Autumn 2018: Abundance, Composition, and Entanglement. *Zoological Science*, 38(4), 311-316. <https://doi.org/10.2108/zs200158>

Steller sea lion (SSL, *Eumetopias jubatus*) inhabits the North Pacific Ocean off both the North American and Asian coasts. The abundance of the species in Asia declined by more than half in the second part of the 20th century. Decline recurred in the second decade of the 21st century after a short period of restoration. In contrast with the total dynamics of SSL in Asia, the reproductive aggregation on Tuleny I. (Sea of Okhotsk) has been growing almost continuously since the beginning of its formation in the late 1980s. Long-term monitoring of SSL at Tuleny I. always covered only summer reproductive seasons. We surveyed Tuleny I. in October 2018, and counted 1058 nonpup sea lions and 396 pups. The majority of tagged animals encountered at the rookery were of local origin. About one-third of the summer non-pup sea lions' number could remain at the rookery until the middle of October, which coincides with the seasonal appearance of sea lions off the coast of Japan. The sex-age structure was characterized by total absence of adult males and reduced proportion of subadult males and juveniles. It contrasts with autumn behavior of SSLs in the rookery of the northern Sea of Okhotsk. We observed that 0.7% of the inspected sea lions were entangled in marine debris. The proportion of entangled animals is lower in comparison with that of the whole population of Tuleny I. due to reduction in the ratios of males and juveniles, which entangle in foreign objects more often than adult females.

Smultea, M. A., Jefferson, T. A., & Lane, R. S. (2022). Marine Mammal Occurrence, Distribution, and Behavior in the Inland Waters of Washington from Aerial Surveys, 2013-2016. *Northwestern Naturalist*, 103(2), 118-135. <https://doi.org/10.1898/nwn21-12>

The inland waters of Washington State are inhabited regularly by 10 species of marine mammals. Updated and comprehensive information regarding marine mammal occurrence, distribution, and behavior in the area is critical when addressing local anthropogenic impact, management, and conservation concerns. We conducted a total of 16,198 km of observation effort during systematic line-

transect surveys from a high-wing, twin-engine airplane throughout Puget Sound in all 4 seasons during 2013 to 2016, and in the Strait of Juan de Fuca and San Juan Islands area during summer 2014 and spring 2015. Ten marine mammal species were confirmed across 5772 groups of an estimated 10,673 individuals sighted, including some seasonal patterns of occurrence. The most commonly sighted species in terms of individuals were Harbor Seals (n = 8012), Harbor Porpoises (n = 2168), California Sea Lions (n = 238) and Steller Sea Lions (n = 77). The most common behavior states documented across species among the total 5670 groups were rest (73%) and medium travel (16%); probable foraging was observed among 13 groups (0.2%) and included Gray Whale foraging pits in tidal mudflats. Potential behavioral reactions to the aircraft were rare (0.3% of total individuals), primarily by Harbor Seals and Harbor Porpoises. Results of these surveys represent the most comprehensive up-to-date information available on marine mammal occurrence, distribution, and behavior across seasons in the Puget Sound region.

Sweeney, K., Birkemeier, B., Luxa, K., & Gelatt, T. (2019). *Results of Steller Sea Lion Surveys in Alaska 2019*. Seattle, WA: National Oceanic and Atmospheric Administration Retrieved from <https://www.fisheries.noaa.gov/resource/data/2019-results-steller-sea-lion-surveys-alaska>

The Marine Mammal Laboratory (MML) conducted aerial surveys to photograph and count Steller sea lion (*Eumetopias jubatus*) pups (~1 month old) and non-pups (adults and juveniles ≥ 1 year old) on known terrestrial rookery and haulout sites (AFSC/MML/AEP 2016) in Alaska in June-July 2019. On odd years, MML focuses their survey effort on the Gulf of Alaska (southeast Alaska towards the western Gulf of Alaska) portion of the Steller sea lion range in Alaska. The occupied aircraft survey team conducted their survey from 24 June to 4 July from southeast Alaska (Dixon Entrance, 132°W) through the western Gulf of Alaska (Sanak Islands, 163°W). On even years, MML focuses their survey effort in the Aleutian Islands (from the western through the eastern Aleutian Islands regions), and sometimes into the western Gulf of Alaska region if not surveyed the previous year. The ship-based survey team on board the R/V Tiġlâx did not conduct visual counts or collect aerial imagery using an unoccupied aircraft system (UAS or drone) during the cruise from 20 June to 2 July. The survey team did travel the Aleutian Islands between Adak Island (176°W) and Attu Island (172°E) focusing on other research priorities.

Sweeney, K., Birkemeier, B., Luxa, K., & Gelatt, T. (2021). *Results of Steller Sea Lion Surveys in Alaska, June-July 2021*. Seattle, WA: National Oceanic and Atmospheric Administration Retrieved from <https://www.fisheries.noaa.gov/resource/data/2019-results-steller-sea-lion-surveys-alaska>

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Sweeney, K. L., Birkemeier, B., Luxa, K., & Gelatt, T. (2023). *Results of the Steller Sea Lion Surveys in Alaska, June–July 2022*. <https://doi.org/10.25923/vsdy-9c87>

The Alaska Fisheries Science Center’s Marine Mammal Laboratory (MML) conducts annual aerial-, boat-, and land-based surveys at known terrestrial rookery and haulout sites in Alaska to collect visual counts and high-resolution imagery from which Steller sea lions are counted. In 2022, MML survey teams collected counts from 97 sites in the Aleutian Islands regions and one site in the western Gulf of Alaska region. We used a newly updated agTrend model that is more precise to model all raw count data through 2022 to estimate counts (as an index of abundance) and annual rates of change.

Warlick, A. J., Johnson, D. S., Gelatt, T. S., & Converse, S. J. (2022). Environmental Drivers of Demography and Potential Factors Limiting the Recovery of an Endangered Marine Top Predator. *Ecosphere*, 13(12). <https://doi.org/10.1002/ecs2.4325>

Understanding what drives changes in wildlife demography is fundamental to the conservation and management of depleted or declining populations, though making inference about the intrinsic and extrinsic factors that influence survival and reproduction remains challenging. Here we use mark-resight data from 2000 to 2018 to examine the effects of environmental variability on age-specific survival and natality for the endangered western distinct population segment (wDPS) of Steller sea lions (*Eumetopias jubatus*) in Alaska, USA. Though this population has been studied extensively over the last four decades, the causes of divergent abundance trends that have been observed across the wDPS range remain unknown. We developed a Bayesian multievent mark-resight model that accounts for female reproductive state uncertainty. Annual survival probabilities for male pups (0.44; 0.36-0.53), female yearlings (0.63; 0.49-0.73), and male yearlings (0.62; 0.51-0.71) born in the western portion of the wDPS range, estimated here for the first time, were lower than those in the eastern portion of the wDPS range, estimated as: male pups (0.69; 0.65-0.74), female yearlings (0.76; 0.71-0.81), and male yearlings (0.71; 0.65-0.78). There was a higher proportion of young female breeders in the western portion of the range, but overall natality was lower (0.69; 0.47-0.96) than in the eastern portion of the range (0.80; 0.74-0.84). Additionally, pup mass had a positive effect on pup survival in the eastern portion of the range and a negative effect in the western portion of the range, potentially due to earlier weaning of heavier pups. Local- and basin-scale oceanographic features such as the Aleutian Low, the Arctic Oscillation Index, the North Pacific Gyre Oscillation, chlorophyll concentration, upwelling, and wind in certain seasons were correlated with vital rates. However, drawing strong inferences from these correlations is challenging given that relationships between ocean conditions and an adaptive top predator in a dynamic ecosystem are exceedingly complex. This study provides the first demographic rate estimates for the western portion of the range where abundance estimates continue to decline. These results will advance efforts to identify factors driving regionally divergent abundance trends, with implications for population-level responses to future climate variability.

Whitlock, S. L., Womble, J. N., & Peterson, J. T. (2020). Modelling Pinniped Abundance and Distribution by Combining Counts at Terrestrial Sites and in-Water Sightings. *Ecological Modelling*, 420, 108965. <https://doi.org/10.1016/j.ecolmodel.2020.108965>

Pinnipeds are commonly monitored using aerial photographic surveys at land- or ice-based sites, where animals come ashore for resting, pupping, molting, and to avoid predators. Although these counts form the basis for monitoring population change over time, they do not provide information regarding where

animals occur in the water, which is often of management and conservation interest. In this study, we developed a hierarchical model that links counts of pinnipeds at terrestrial sites to sightings-at-sea and estimates abundance, spatial distribution, and the proportion of time spent on land (attendance probability). The structure of the model also allows for the inclusion of predictors that may explain variation in ecological and observation processes. We applied the model to Steller sea lions (*Eumetopias jubatus*) in Glacier Bay, Alaska using counts of sea lions from aerial photographic surveys and opportunistic in-water sightings from vessel surveys. Glacier Bay provided an ideal test and application of the model because data are available on attendance probability based on long-term monitoring. We found that occurrence in the water was positively related to proximity to terrestrial sites, as would be expected for a species that engages in central-place foraging. The proportion of sea lions in attendance at terrestrial sites and overall abundance estimates were consistent with reports from the literature and monitoring programs. The model we describe has benefit and utility for park managers who wish to better understand the overlap between pinnipeds and visitors, and the framework that we present has potential for application across a variety of study systems and taxa.

Wood, S. A., Robinson, P. W., Costa, D. P., & Beltran, R. S. (2021). Accuracy and Precision of Citizen Scientist Animal Counts from Drone Imagery. *PLOS One*, 16(2), e0244040.
<https://doi.org/10.1371/journal.pone.0244040>

Repeated counts of animal abundance can reveal changes in local ecosystem health and inform conservation strategies. Unmanned aircraft systems (UAS), also known as drones, are commonly used to photograph animals in remote locations; however, counting animals in images is a laborious task. Crowd-sourcing can reduce the time required to conduct these censuses considerably, but must first be validated against expert counts to measure sources of error. Our objectives were to assess the accuracy and precision of citizen science counts and make recommendations for future citizen science projects. We uploaded drone imagery from Año Nuevo Island (California, USA) to a curated Zooniverse website that instructed citizen scientists to count seals and sea lions. Across 212 days, over 1,500 volunteers counted animals in 90,000 photographs. We quantified the error associated with several descriptive statistics to extract a single citizen science count per photograph from the 15 repeat counts and then compared the resulting citizen science counts to expert counts. Although proportional error was relatively low (9% for sea lions and 5% for seals during the breeding seasons) and improved with repeat sampling, the 12+ volunteers required to reduce error was prohibitively slow, taking on average 6 weeks to estimate animals from a single drone flight covering 25 acres, despite strong public outreach efforts. The single best algorithm was 'Median without the lowest two values', demonstrating that citizen scientists tended to under-estimate the number of animals present. Citizen scientists accurately counted adult seals, but accuracy was lower when sea lions were present during the summer and could be confused for seals. We underscore the importance of validation efforts and careful project design for researchers hoping to combine citizen science with imagery from drones, occupied aircraft, and/or remote cameras.

Section II: Behavior

Hastings, K. K., Johnson, D. S., Pendleton, G. W., Fadely, B. S., & Gelatt, T. S. (2021). Investigating Life-History Traits of Steller Sea Lions with Multistate Hidden Markov Mark–Recapture Models: Age at Weaning and Body Size Effects. *Ecology and Evolution*, *11*(2), 714-734.
<https://doi.org/10.1002/ece3.6878>

The duration of offspring care is critical to female fitness and population resilience by allowing flexibility in life-history strategies in a variable environment. Yet, for many mammals capable of extended periods of maternal care, estimates of the duration of offspring dependency are not available and the relative importance of flexibility of this trait on fitness and population viability has rarely been examined. We used data from 4,447 Steller sea lions *Eumetopias jubatus* from the Gulf of Alaska and multistate hidden Markov mark–recapture models to estimate age-specific weaning probabilities. Maternal care beyond age 1 was common: Weaning was later for animals from Southeast Alaska (SEAK) and Prince William Sound (PWS, weaning probabilities: 0.536–0.648/0.784–0.873 by age 1/2) compared with animals born to the west (0.714–0.855/0.798–0.938). SEAK/PWS animals were also smaller than those born farther west, suggesting a possible link. Females weaned slightly earlier (+0.080 at age 1 and 2) compared with males in SEAK only. Poor survival for weaned versus unweaned yearlings occurred in southern SEAK (female survival probabilities: 0.609 vs. 0.792) and the central Gulf (0.667 vs. 0.901), suggesting poor conditions for juveniles in these areas. First-year survival increased with neonatal body mass (NBM) linearly in the Gulf and nonlinearly in SEAK. The probability of weaning at age 1 increased linearly with NBM for SEAK animals only. Rookeries where juveniles weaned at earlier ages had lower adult female survival, but age at weaning was unrelated to population trends. Our results suggest the time to weaning may be optimized for different habitats based on long-term average conditions (e.g., prey dynamics), that may also shape body size, with limited short-term plasticity. An apparent trade-off of adult survival in favor of juvenile survival and large offspring size in the endangered Gulf of Alaska population requires further study.

Masahiro, S., Miyui, C., Eri, I., Kazuki, T., Koichi, I., & Tomoki, S. (2022). Human Vocal Commands Verify Audio Discrimination Ability in the Steller Sea Lion, *Eumetopias jubatus*. *International Journal of Comparative Psychology*, *35*, 1-10. Retrieved from <https://escholarship.org/uc/item/5fs4b6ht>

We report results of experiments using human vocal commands to investigate how well a Steller sea lion (*Eumetopias jubatus*) can discriminate different sounds. The participant, Hama, a 12-year-old female at Kinosaki Marine World, Japan, was raised by 4 trainers. We investigated Hama's ability to discriminate 10 vocal commands (e.g. Iya-iyaya, Okay etc.) used in daily performances in two experiments: 1, commands given directly to the sea lion by trainers, but out of her sight; and 2, vocal commands given to the sea lion by trainers, but using recorded commands over a loudspeaker. In Experiment 1, Hama was able to discriminate all 10 commands, but her accuracy to discriminate 1 command was significantly lower than others ($p < .05$). In Experiment 2, Hama was able to discriminate all but 1 command; accuracy rates among commands were variable, but the accuracy rate for 1 was significantly lower than the others, and those for 3 commands were significantly higher than others ($p < .05$). These experiments demonstrate that Hama can discriminate between most commands based on their acoustic properties, regardless of which of the 4 trainers spoke them out of her sight or if they were relayed from a recording. This ability suggests that Steller sea lions, *E. jubatus*, might use sound for their own complex communication.

Trites, A. W. (2021). Behavioral Insights into the Decline and Natural History of Steller Sea Lions. In *Ethology and Behavioral Ecology of Otariids and the Odobenid*. (pp. 489-519)
https://doi.org/10.1007/978-3-030-59184-7_23

Two competing hypotheses were proposed to explain why Steller sea lions had declined in the Gulf of Alaska, Bering Sea and Aleutian Islands. One of the theories was that young sea lions were starving because fisheries had reduced the abundance of groundfish—the overfishing hypothesis. The other was that these low-fat species offish had increased in abundance as the sea lion population declined following the 1976–1977 oceanic regime shift, and were compromising sea lion reproductive and survival rates—the junk-food hypothesis. Behavioral ecologists tested these hypotheses by comparing sea lion behaviors in the declining region (Gulf of Alaska and Aleutian Islands) with sea lion behaviors in an increasing region (Southeast Alaska) to determine whether the populations exhibited behavioral differences consistent with food shortages. These studies involved comparing dive depths, dive durations, time spent foraging, and time spent nursing by regions and seasons. Research also focused on weaning—a critical life-history stage—to determine when and how it occurs. Collectively, these observations and measures of behavioral responses revealed that most dependent young begin supplementing their milk diet with fish between April and May, and wean just before the start of the upcoming June breeding season. However, the proportion of young sea lions that wean at 1, 2 or 3 years of age appears to vary by year due to regional and temporal differences in the quantity and quality of prey available to them once weaned. None of the behavioral studies of adult and juvenile Steller sea lions supported the overfishing hypothesis—but were, instead, consistent with the junk-food hypothesis. It appears that lactating females that consume large amounts of low-energy fish (such as walleye pollock and Pacific cod) have a high probability of miscarriage, and will keep their dependent young for an extra one or two years—thereby causing birth rates and population size to decline. In contrast, lactating females that consume larger amounts of fattier fish (such as sand lance and Pacific herring) can successfully wean a pup every year. Plasticity in age at weaning appears to be an evolutionary adaptation to natural shifts in community prey structure in the North Pacific Ocean—and is an adaptation that successfully slows population declines of Steller sea lions until the ocean shifts to an alternative state containing greater proportions of energy-rich fish that allows sea lion numbers to increase again.

Section III: Bibliographies and Encyclopedia Articles

Cheever, E., & Riley, T. (2019). *Steller Sea Lion Thirty Year Review: Bibliography*. Silver Spring, MD: National Oceanic and Atmospheric Administration <https://doi.org/10.25923/m6sy-k402>

The goal of this bibliography is to provide a comprehensive review of the scientific literature published on the Steller sea lion (SSL), *Eumetopias jubatus*, in the past thirty years. The Steller (or northern) sea lion is the largest member of the family Otariidae, the 'eared seals,' which includes all sea lions and fur seals. Steller sea lions were first listed under the Endangered Species Act in 1990. In 1997 NOAA Fisheries recognized two populations, classifying the eastern population as threatened and the western population as endangered. The eastern population has since recovered and is no longer listed, which is a significant achievement under the ESA. The western population remains endangered.

Section IV: Conflicts and Deterrents

Heide, H. A., Niklitschek, E. J., & Sepúlveda, M. (2022). Pinnipeds and Salmon Farming: Threats, Conflicts and Challenges to Co-Existence after 50 Years of Industrial Growth and Expansion. *Reviews in Aquaculture*, 14(2), 528-546. <https://doi.org/10.1111/raq.12611>

In this review, we summarize and discuss the main interactions affecting salmon farming and pinniped populations worldwide. Out of seven pinnipeds commonly engaged in these interactions, only one, *Eumetopias jubatus*, is currently listed, as 'Near Threatened', by the IUCN. This scenario may change as the salmon farming industry is expanding to higher latitudes and climate change is threatening many pinniped populations. Pinniped attacks cause productive and economic losses, equivalent to 1%–12% of gross production costs, due to predation, induced escapes and implementing deterrent measures. Other potential negative effects on the industry remain unassessed: lower fish growth, immunosuppression, diseases transmission, damaging infrastructure and injuring farmworkers. Main direct threats to pinnipeds include intended and unintended killing, which lack independent quantifications and have generated a growing number of ethical, economic and socio-political concerns, as well as trade regulations affecting the industry. Physical perturbation, pollution, nutrification and/or prey subsidies related to this industry may induce behavioural, trophic and social changes, as well as breeding and/or foraging habitat loss/change in impacted areas. Despite their relevance, the magnitude and consequences of these potential impacts have been poorly evaluated and documented, precluding us from assembling accurate assessments on most interactions. Hence, we recommend focusing further research on assessing the effects of these interactions and make a call for implementing and maintaining reliable and independent records of: (i) intended and unintended killings and (ii) demography of affected populations. Implementing an ecosystem approach may be key to reduce negative impacts of salmon farming on pinnipeds and coastal ecosystems.

Herbert, S. S., Hayes, F. E., & Hellie, M. E. (2019). Kleptoparasitism of the Sea Otter (*Enhydra Lutris*) and Steller Sea Lion (*Eumetopias jubatus*) by the Glaucous-Winged Gull (*Larus Glaucescens*) at Seward, Alaska. *Polar Biology*, 42(10), 1935-1941. <https://doi.org/10.1007/s00300-019-02559-4>

Observations of seabirds stealing food (kleptoparasitism) from marine mammals are rarely reported. During 67 hours of observation at Seward, Alaska, where fishers frequently discard scraps of fish, we documented 16 incidents of gulls attempting to kleptoparasitize sea otters (*Enhydra lutris*) and seven incidents of gulls attempting to kleptoparasitize Steller sea lions (*Eumetopias jubatus*). An average of 3.5 +/- 3.5 SD (range 1-13) glaucous-winged gulls (*Larus glaucescens*) and < 0.1 +/- 0.3 SD (range 0-1) black-legged kittiwakes (*Rissa tridactyla*) attacked sea otters with discarded fish scraps, with a success rate of 53% per incident and 16% per individual gull. The gulls ignored sea otters with invertebrate prey. An average of 3.6 +/- 1.7 SD (range 1-7) glaucous-winged gulls and 0.1 +/- 0.4 SD (range 0-1) black-legged kittiwakes attacked sea lions with discarded fish scraps, with a success rate of 29% per incident and 8% per individual gull. Only glaucous-winged gulls succeeded in stealing food, usually comprising fragments of the original item floating on the surface after the victim dived, but twice food was stolen directly from sea otters. To avoid kleptoparasitism, sea otters used five evasive maneuvers (swimming away, diving, rolling, lunging toward gull, and pulling food from gull), whereas sea lions used only two (swimming away and diving). Kleptoparasitism of sea otters and sea lions by gulls is a previously overlooked behavior that merits further study of its potential benefits and costs.

Lucas, S., & Berggren, P. (2023). A Systematic Review of Sensory Deterrents for Bycatch Mitigation of Marine Megafauna. *Reviews in Fish Biology and Fisheries*, 33(1), 1-33.
<https://doi.org/10.1007/s11160-022-09736-5>

Marine megafauna are critical for marine ecosystem health and their removal can cause food webs to collapse. Methods to reduce marine megafauna mortality can result in conflict between scientists, conservationists, fishers and fisheries management due to real or perceived effects on target catch, income and food security. Sensory deterrents have been used in attempts to mitigate bycatch and retain target catch quantity and quality. Here, we completed a systematic review of 116 papers, plus 25 literature reviews published between 1991 and 2022, to investigate potential for sensory deterrents to mitigate bycatch across four marine megafauna taxonomic groups (marine mammals, sea turtles, seabirds and elasmobranchs). Lights on gillnets are the only technology so far to result in significant bycatch reductions across all four taxonomic groups. It is difficult to make generalisations about the efficacy of sensory deterrents and their ability to deliver consistent bycatch reductions. The efficacy of each method is context dependent, varying with species, fishery and environmental characteristics. Further research is recommended for field studies assessing bycatch mitigation in all sensory deterrents, including combinations of deterrents, to assess effects on target and non-target species. The associated issues of habituation, habitat exclusion and foraging around fishing gear are important, although reducing mortality of vulnerable species should remain the highest priority for conservation and preserving ecosystems that fishers depend on. Multiple complementary measures will be required to achieve consistent bycatch reduction targets in many fisheries, of which sensory deterrents could play some part if implemented appropriately.

Schakner, Z. A., & Blumstein, D. T. (2021). The California Sea Lion: Thriving in a Human-Dominated World. In *Ethology and Behavioral Ecology of Otariids and the Odobenid*. C. Campagna & R. Harcourt (Eds.), (pp. 347-365). Cham: Springer International Publishing
https://doi.org/10.1007/978-3-030-59184-7_18

California sea lions offer an important case study of a species that has successfully adapted and thrived in a human-dominated world. The recovery of California sea lion populations over the past four decades is a conservation success story. Unfortunately, their recovery has put them in direct conflict with human activities resulting in new management challenges in the regions where they occur. Here, we review the role of learning in California sea lions and their capacity to tolerate and successfully capture prey from commercial or recreational fishing lines or salmon at dams. Learning underlies tolerance to novel human-related stimuli, locating novel foraging resources, and responding to environmental change. According to modern animal learning theory, there are basic mechanisms, or types of experiences underlying animal learning. The simplest learning process of habituation is non-associative because it involves an individual's experience with a single stimulus, whereas complex associative learning mechanisms elicit changes in behavior as a result of experience with two stimuli or stimulus and response. We focus on these fundamental associative and non-associative learning mechanisms in California sea lions which could be used to manage wildlife-human conflicts involving otariids. For instance, understanding what kinds of stimuli California sea lions respond to and learn from, or how social factors influence learning processes, are all important parameters that can be used by managers for modifying animal behavior. Lessons from both human-tolerant species and those in conflict could inform best practices for ensuring human-wildlife coexistence in a human-dominated environment will be enhanced with lessons from both human-tolerant species as well as those that do not do well with humans.

Tidwell, K. S., Carrothers, B. A., Blumstein, D. T., & Schakner, Z. A. (2021). Steller Sea Lion (*Eumetopias jubatus*) Response to Non-Lethal Hazing at Bonneville Dam. *Frontiers in Conservation Science*, 2, 760866. <https://doi.org/10.3389/fcosc.2021.760866>

Protected Steller sea lions (*Eumetopias jubatus*) aggregate at Bonneville Dam on the Columbia River and prey upon multiple species of endangered salmon ascending the river. Hazing is a non-lethal activity designed to repel sea lions that includes aversive auditory and physical stimuli to deter animals from an area and has been employed with sea lion—fisheries interactions for more than 40 years but sea lion responses to hazing through time is not well-documented. We observed the behavior of Steller sea lions in periods with and without hazing during two spring Chinook salmon passage seasons to evaluate: (1) what effect hazing had on the number of animals present and their foraging behavior, and (2) whether they habituated to hazing. We found that hazing temporarily reduced the number of Steller sea lions, but only when actively hazed. During hazing, Steller sea lions were more likely to move away from hazers on the dam, decreased their foraging, and increased their time investigating the environment. However, these effects were temporary; their behavior returned to initial observation levels once hazing ceased. Furthermore, their responsiveness to hazing declined throughout the season, indicating habituation and raising concern for the application and long-term efficacy of hazing in managing predation on endangered salmon.

Section V: Disease and Parasites

Davies, K., Pagan, C., & Nadler, S. A. (2020). Host Population Expansion and the Genetic Architecture of the Pinniped Hookworm *Uncinaria Lucasi*. *Journal of Parasitology*, 106(3), 383-391.
<https://doi.org/10.1645/19-172>

The long-term fidelity of pinniped hosts to their natal rookery site suggests the genetic architecture of their *Uncinaria spp.* hookworms should be strongly structured by host breeding biology. However, historical events affecting host populations may also shape parasite genetic structure. Sequences of the mitochondrial cytochrome c oxidase 1 (COI) gene of 86 *Uncinaria lucasi* individuals were obtained to assess genetic variation and structure of nematodes from 2 host species (68 hookworms from northern fur seals; 18 hookworms from Steller sea lions) and rookeries from 3 widely separated geographic regions: the western Bering Sea and Sea of Okhotsk, eastern Bering Sea, and the eastern Pacific Ocean. High COI haplotype ($h = 0.96-0.98$) and nucleotide ($\pi = 0.014$) diversity was found. The haplotype network showed a star-shaped pattern with a large number of haplotypes separated by few substitutions. The network did not show separation of *U. lucasi* by geographic region or host species. *Fst* values between *U. lucasi* individuals representing geographic regions showed no differentiation, consistent with the absence of genetic structure. At face value, this lack of genetic structure in *U. lucasi* suggests high gene flow but could also be explained by recent (post-glacial) population expansions of northern fur seals and their hookworms.

Esquible, J. A., Burek-Huntington, K., Atkinson, S., Klink, A. C., Bortz, E., Goldstein, T. A., . . . Tiller, R. (2019). Pathological Findings and Survey for Pathogens Associated with Reproductive Failure in Perinatal Steller Sea Lions *Eumetopias jubatus*. *Diseases of Aquatic Organisms*, 137(2), 131-144.
<https://doi.org/10.3354/dao03421>

Steller sea lions (SSLs) *Eumetopias jubatus* experienced a population decline in the 1960s, leading to the listing of the western stock as endangered and the eastern stock as threatened under the US Endangered Species Act. A decrease of births in the western stock beginning in the late 1960s indicates that reproductive failure may have contributed to the decline. We evaluated the role pathogens play in spontaneous abortions, premature births and neonatal deaths in SSLs. Archived tissues from carcasses ($n = 19$) collected in Alaska from 2002 to 2015 were tested by PCR for *Coxiella burnetii*, *Brucella spp.*, *Chlamydia* and morbilliviruses. Animals examined included 47 % premature pups, 32% aborted fetuses, 11% neonates and 11 % intrauterine fetuses. Gross necropsy and histology findings were summarized in the context of the PCR findings. Tissues were negative for *Chlamydia* and *C. burnetii*. *Brucella spp.* were detected in the lung tissues of 3 animals, including 1 positive for the ST27 strain, the first detection of *Brucella spp.* DNA in SSLs. Phocine distemper virus was detected in 3 animals in 2 skin lesions and 1 placenta by heminested diagnostic qRT-PCR. Both skin and the placental lesions had vesiculoulcerative changes, and 1 skin lesion contained inclusion bodies in syncytia and upon histologic examination, suggesting that the lesions may be associated with an infection reminiscent of phocine distemper virus, the first in SSLs. We highlight the continuing need for disease surveillance programs to improve our understanding of the prevalence and potential population impacts of these infectious disease agents for pinnipeds in Alaskan waters.

Gardner, B. R., Stenos, J., Hufschmid, J., Arnould, J. P. Y., McIntosh, R. R., Tadepalli, M., . . . Stent, A. (2022). An Old Pathogen in a New Environment-Implications of *Coxiella burnetii* in Australian Fur Seals (*Arctocephalus pusillus doriferus*). *Frontiers in Marine Science* 9. <https://doi.org/10.3389/fmars.2022.809075>

The Australian fur seal (*Arctocephalus pusillus doriferus*) has experienced a slower than expected population recovery since the end of the commercial sealing era, with a high third trimester abortion rate. There is currently no known proximate cause. *Coxiella burnetii* (Cb) is a well-known cause of abortion in domestic and wildlife species and an important zoonotic pathogen. It has been recorded from a small number of northern hemisphere marine mammals and may be a potential contributory factor to decreasing populations of northern fur seals (*Callorhinus ursinus*) and Steller sea lions (*Eumetopias jubatus*). It has not been recorded from marine mammals in the southern hemisphere but is well documented in ruminants and wildlife in Australia as a cause of reproductive failure. Third trimester aborted fetuses (n = 46) and full-term placentas (n = 66) from Australian fur seals, were collected on Kanowna Island and Seal Rocks in Bass Strait, south-eastern Australia. Utilizing routine hematoxylin and eosin histopathology, Cb immunohistochemistry and two different qPCR targets-htpAB and com1, Cb was identified. Routine histopathology and immunohistochemistry were insensitive for the detection of Cb. The detected Cb prevalence ranged from 10.6% for com1 up to 40.9% with htpAB. *Coxiella burnetii* was readily detected in full-term placentas but in aborted fetal material only in a single placenta associated with a still birth. The exact significance is currently unclear, but this highlights that Cb is present in Australian fur seals, breeding in Bass Strait. Bass Strait is in one of the world's fastest warming oceanic regions and marine mammals breeding in the area are likely to be key indicators of marine ecosystem stressors. This first description of Cb in a marine mammal from the southern hemisphere, highlights the need to further investigate the potential risks this pathogen poses to Australian fur seals and sympatric marine mammals. Additionally, it is important to determine the zoonotic risk of this pathogen to persons working with, and in proximity of, Australian fur seal breeding colonies.

Gonzalez-Barrio, D., & Ruiz-Fons, F. (2019). *Coxiella burnetii* in Wild Mammals: A Systematic Review. *Transboundary and Emerging Diseases*, 66(2), 662-671. <https://doi.org/10.1111/tbed.13085>

Coxiella burnetii is a multi-host bacterium that causes Q fever in humans, a zoonosis that is emerging worldwide. The ecology of *C. burnetii* in wildlife is still poorly understood and the influence of host, environmental and pathogen factors is almost unknown. This study gathers current published information on different aspects of *C. burnetii* infection in wildlife, even in species with high reservoir potential and a high rate of interaction with livestock and humans, in order to partially fill the existing gap and highlight future needs. Exposure and/or infection by *C. burnetii* has, to date, been reported in 109 wild mammal species. The limited sample size of most of the existing studies could suggest an undervalued prevalence of *C. burnetii* infection. Knowledge on the clinical outcome of *C. burnetii* infection in wildlife is also very limited, but currently includes reproductive failure in waterbuck (*Kobus ellipsiprymnus*), roan antelope (*Hippotragus niger*), dama gazelle (*Nanger dama*) and water buffalo (*Bubalus bubalis*) and placentitis in the Pacific harbor seal (*Phoca vitulina richardsi*), Steller sea lion (*Eumetopias jubatus*) and red deer (*Cervus elaphus*). The currently available serological tests need to be optimised and validated for each wildlife species. Finally, there is a huge gap in the research on *C. burnetii* control in wildlife, despite of the increasing evidence that wildlife is a source of *C. burnetii* for both livestock and humans.

Joblon, M. J., Flower, J. E., Thompson, L. A., Biddle, K. E., Burt, D. A., Zabka, T. S., . . . Tuttle, A. D. (2022). Investigation of the Use of Serum Biomarkers for the Detection of Cardiac Disease in Marine Mammals. *Journal of Zoo and Wildlife Medicine*, 53(2), 373-382. <https://doi.org/10.1638/2021-0152>

Cardiac disease has been extensively documented in marine mammals; however, it remains difficult to diagnose antemortem. Assays measuring cardiac troponin I (cTnI) and N-terminal pro-brain natriuretic peptide (NT-proBNP) are used as sensitive and specific biomarkers of cardiac disease in many species, but have not been widely investigated in marine mammals. This study aimed to provide a set of reference values for cTnI and NT-proBNP in belugas (BW) (*Delphinapterus leucas*), sea otters (SO) (*Enhydra lutris*), Steller sea lions (SSL) (*Eumetopias jubatus*), and California sea lions (CSL) (*Zalophus californianus*) with and without cardiac disease, and to determine if these biomarkers are useful indicators of cardiac disease in these species. First, existing immunoassays for cTnI and NT-proBNP were successfully validated utilizing species-specific heart lysate spiked serum. Cohorts were defined by histopathology as animals with no evidence of cardiac disease ("control"), with confirmed cardiac disease ("disease"), and with concurrent renal and cardiac disease ("renal") for which serum samples were then analyzed. Serum concentration ranges for cTnI (ng/ml) and NT-proBNP (pmol/L) were determined for control and disease cohorts. There was significantly higher cTnI ($P = 0.003$) and NT-proBNP ($P = 0.004$) concentrations in the CSL disease cohort, as well as positive trends in BW, SO, and SSL disease cohorts that did not reach statistical significance. NT-proBNP concentrations were significantly higher in the CSL renal cohort compared with the control ($P < 0.001$) and disease ($P = 0.007$) cohorts. These results suggest that cTnI and NT-proBNP may be clinically useful in the antemortem diagnosis of cardiac disease in CSL, and warrant further investigation in BW, SO, and SL.

Kennedy, S. N. (2019). *Determining the Immune Status of Steller Sea Lions (Eumetopias jubatus): An Environmental Agents of Disease Perspective*. (Doctor of Philosophy), University of Alaska, Fairbanks, AK. Retrieved from <http://hdl.handle.net/11122/10510>

The integrity of the immune system is paramount for preserving overall health for many organisms. Investigating environmental and physiological factors that may be associated with alterations of the immune status in non-traditional sentinel species, like the Steller sea lion (SSL), is a prominent undertaking in eco-immunology research. Changes to immune homeostasis likely impacts the health and survival of SSLs. Recent studies have reported that mercury concentrations in hair in 24 to 36% of newborn SSLs of the Western Aleutian Islands (WAI) exceed thresholds (>30 ppm) for potential adverse effects. Many of these individuals were from WAI rookeries that have historically experienced significant population declines with some slow to recover. Retrospective, and ongoing, analyses of mercury in lanugo coats (natal hair) from young pups of the WAI demonstrate in utero exposure to relatively high levels of mercury during late gestation. Therefore, this dissertation focuses on the notion that dietary acquired mercury could potentially alter immune response in SSLs, especially young pups, and may contribute to the lack of recovery from population declines. In order to gain an understanding of the potential for mercury to adversely affect the immune response of SSLs, selected aspects of immunity were measured (blood cell counts, haptoglobin, immunoglobulins, and cytokines) and investigated within the context of body condition, age, mercury exposure and regional population dynamics. In Chapter Two, the acute phase response protein, haptoglobin, was found to vary significantly with age and region. Individual SSL pups with greater concentrations of mercury had lower predicted concentrations of haptoglobin. In Chapter Three, a colorimetric protein A enzyme-linked immunosorbent assay was modified for enhancing accurate measurement of immunoglobulin

concentrations in SSL serum. This improved methodology was then used in Chapter Four for comparing immunoglobulins in young developing SSL pups and dams as a measure of maternal investment of immunity among different rookeries. Lastly, Luminex multiplex technologies were employed for quantifying cell-signaling proteins (cytokines) in SSL serum to compare associations among rookery pups in Chapter Five. Although mercury concentrations in some individuals exceed adverse effects thresholds that are defined for other mammals, no statistically significant associations were found between immunoglobulins and cytokines relative to mercury concentrations in young developing pups. These thesis chapters provide a powerful baseline and improved methods for ongoing and future assessments of haptoglobin, immunoglobulins, and cytokines (combined with traditional hematologic measures) observed in young developing SSL pups in regions experiencing population decline when compared with rookeries with stable or increasing pup production. Some of these findings, especially for haptoglobin, are indicative of alterations in immune status in young SSL pups born to dams from different natal rookeries with higher mercury exposure. Understanding the cause of the differences in the immune status of young SSLs will require additional assessments of the maternal-fetal interface of immunity and other factors like nutrition, metabolic status, and infectious disease that may shape neonatal immunity leading to the regional differences observed.

Section VI: Foraging and Diving Behavior

Braun, C. D., Arostegui, M. C., Thorrold, S. R., Papastamatiou, Y. P., Gaube, P., Fontes, J., & Afonso, P. (2022). The Functional and Ecological Significance of Deep Diving by Large Marine Predators. *Annual Review of Marine Science*, 14(1), 129-159. <https://doi.org/10.1146/annurev-marine-032521-103517>

Many large marine predators make excursions from surface waters to the deep ocean below 200 m. Moreover, the ability to access meso- and bathypelagic habitats has evolved independently across marine mammals, reptiles, birds, teleost fishes, and elasmobranchs. Theoretical and empirical evidence suggests a number of plausible functional hypotheses for deep-diving behavior. Developing ways to test among these hypotheses will, however, require new ways to quantify animal behavior and biophysical oceanographic processes at coherent spatiotemporal scales. Current knowledge gaps include quantifying ecological links between surface waters and mesopelagic habitats and the value of ecosystem services provided by biomass in the ocean twilight zone. Growing pressure for ocean twilight zone fisheries creates an urgent need to understand the importance of the deep pelagic ocean to large marine predators.

Feddern, M. L. (2021). *Applied Ecosystem Chemistry: Linking Biogeochemical and Physiological Processes to Ecological Interactions*. (Doctor of Philosophy), University of Washington, Seattle, WA. Retrieved from https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/48253/Feddern_washington_0250E_23631.pdf?sequence=1&isAllowed=n

Physical environments are changing globally due to anthropogenic impacts which have the potential to alter ecological interactions. To understand how ecological interactions are changing, long-term datasets are necessary to document ecological baselines from the past that are comparable to current ecological conditions. Stable isotope values can be useful chemical tracers for retrospective analyses which can elucidate changes in biogeochemistry and trophic interactions that influence food webs. My dissertation applies compound-specific stable isotope analysis (CSIA) of amino acids and inorganic nitrogen to understand long-term, regional, ecological responses to physical conditions in the northeast Pacific. I tested the long-term importance of salmon subsidies to Alaskan riparian ecosystems by measuring inorganic nitrogen concentrations, transformation rates, and nitrogen stable isotope values in soil following a 20-year carcass manipulation experiment. Carcass subsidies did not increase soil nitrogen concentrations or transformation rates but the nitrogen stable isotope value of ammonium was significantly enriched in ^{15}N compared to salmon carcasses, indicating the importance of salmon derived nutrients is likely overestimated for some systems. Using museum skull specimens from two species of pinnipeds in the northeast Pacific, harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*), I derived a century of predator stable isotope data. I compared the carbon and nitrogen stable isotope values of source amino acids to regional climate datasets and determined coastal food webs responded to climate regimes, coastal upwelling, and freshwater discharge, yet the strength of responses to individual drivers varied across the northeast Pacific. These findings demonstrate stable isotope data can serve as a tracer of nitrogen resources and phytoplankton dynamics that is specific to resources that are assimilated by food webs. To calculate pinniped trophic position from the historic dataset, I was the first to apply taxa-specific trophic enrichment factors, a system specific beta-value, a temporal lag to account for tissue turnover time, and a multi-trophic amino acid analysis framework within a single study. This approach constrained assumptions regarding

physiological processes and vascular plant contributions to the food web, which can confound stable isotope data interpretation. I analyzed long-term predictors of harbor seal trophic position in Washington and identified delayed responses of harbor seals to both physical ocean conditions (upwelling, sea surface, discharge) and prey availability (Pacific hake, Pacific herring and Chinook salmon). Consideration for dynamic responses of harbor seals to their environment is an important factor for understanding predator-prey interactions as harbor seals respond to multiple ecological factors that are often changing simultaneously and their response occurs at multiple temporal scales. I then analyzed regional and decadal trends in pinniped trophic position in Alaska and identified the largest change in trophic position occurred in recent decades (2000 and 2010) but the direction of the trends diverged based on region and species. Gulf of Alaska pinnipeds are experiencing unique food web conditions in recent decades compared to the past likely in response to climate-induced ecological change in the region. Finally, I constructed a compartment model to explore the effect of stable isotope heterogeneity and consumer isotope incorporation rates on consumer trophic position estimates using both bulk stable isotope analysis and CSIA. Bulk stable isotope analysis produced consistent errors in trophic position estimates by as much as one trophic level that were more pronounced in higher trophic level consumers and CSIA was more accurate than bulk stable isotope analysis. Altogether, these results show CSIA is a useful tracer for elucidating long-term physical forcing mechanisms on food webs and incorporating physiological processes that govern stable isotope fractionation into sampling and analysis design can uncover forcing mechanisms that would otherwise be overlooked.

Feddern, M. L., Ward, E. J., Warlick, A. J., & Holtgrieve, G. W. (2022). Recent Divergent Changes in Alaskan Pinniped Trophic Position Detected Using Compound-Specific Stable Isotope Analysis. *Marine Ecology Progress Series*, 688, 153-166. <https://doi.org/10.3354/meps14014>

Over the past century, Alaskan pinnipeds have experienced dramatic changes in abundance, but these changes have been highly variable across species and regions. In recent decades, changes in atmospheric forcing and sea surface temperature have been particularly pronounced in the Gulf of Alaska and eastern Bering Sea, impacting the food webs in which Alaskan pinnipeds forage. We used compound-specific stable isotope analysis of nitrogen in amino acids to estimate historic and modern trophic positions of harbor seals *Phoca vitulina* and Steller sea lions *Eumetopias jubatus* in the Gulf of Alaska and Bristol Bay. We applied a Bayesian hierarchical framework to determine whether shared trends through time exist across pinnipeds (classified by region and species) on decadal scales. Model results identified both shared trends through time and classification-specific decadal changes in pinniped trophic position. The largest change in trophic position occurred in the 2000s and 2010s and was observed in both Steller sea lions (median: 2.8) and harbor seals (median: 3.1) in the Gulf of Alaska, but not harbor seals in Bristol Bay or Iliamna Lake. Divergent trophic position patterns in the 2000s were identified in the western stock of Steller sea lions, which increased in trophic position, and sympatric harbor seals in the northern Gulf of Alaska, which decreased in trophic position. Our results indicate that these species have been experiencing unique food web conditions in recent decades in the Gulf of Alaska, likely in response to recent climate-induced ecological change in the region.

Fritz, L., Brost, B., Laman, E., Luxa, K., Sweeney, K., Thomason, J., . . . Zeppelin, T. (2019). A Re-Examination of the Relationship between Steller Sea Lion (*Eumetopias jubatus*) Diet and Population Trend Using Data from the Aleutian Islands. *Canadian Journal of Zoology*, 97(12), 1137-1155. <https://doi.org/10.1139/cjz-2018-0329>

Prey diversity and energy density have been linked to each other and to population trends in many studies of bird and mammal diets. We re-examined these relationships in Steller sea lions (*Eumetopias jubatus* (Schreber, 1776)) using data collected from the Aleutian Islands, where there has been a strong longitudinal gradient in population trend. Diet diversity and energy density metrics were similar in the western Aleutians, where sea lion counts declined consistently, and in the easternmost Aleutian area, where population trends improved significantly. We compared traditional deterministic diet diversity metrics with diversity scores based on an occupancy model that accounts for differences in sample size and uncertainty in prey group detection. This analysis indicated that there was no significant change in diet diversity over the 23-year study period or any significant differences across the Aleutian Islands. These results are consistent with prey abundance data from nine groundfish bottom trawl surveys conducted over the same period. While diet studies detail what Steller sea lions eat and provide an estimate of their energy intake, they provide only limited information on the energy expended to obtain their food or the consequences of their diet and foraging ecology on individual or population fitness.

Inglis, S. D. (2019). *Dietary Effects on Protein Turnover in Three Pinniped Species, Eumetopias jubatus, Phoca vitulina, and Leptonychotes Weddellii*. (Doctor of Philosophy Ph.D.), University of Alaska Fairbanks, Fairbanks, AK. Retrieved from <http://hdl.handle.net/11122/10505>

The role of dietary protein in pinniped (seal and sea lion) nutrition is poorly understood. Although these marine mammals derive the majority of their daily energetic needs from lipid, lipids cannot supply essential amino acids which have to come from protein fractions of the diet. Protein regulation is vital for cellular maintenance, molt, fasting metabolism, exercise and development. Proteins are composed of linked amino acids (AA), and net protein turnover is the balance between protein synthesis from component AA, and degradation back to AA. Protein regulation is influenced by dietary intake and quality, as well as physiological and metabolic requirements. In this work, pinniped diet quality was assessed through comparisons of amino acid profiles between maternal milk, blood serum, and seasonal prey of wild juvenile Steller sea lions (*Eumetopias jubatus*) in Southcentral Alaska. Both Pacific herring (*Clupea pallasii*) and walleye pollock (*Gadus chalcogramma*) showed similar patterns to milk in essential and branched chain amino acid content. Serum amino acid profiles suggest the juvenile sea lions were not in protein deficit at the time of capture. Protein metabolism in the blood and urine was assessed through turnover studies using amino acid tracers. The turnover kinetics of ¹⁵N-labelled glycine in the blood amino acid and protein pool, red blood cells, and urine urea were measured in wild adult female Weddell seals (*Leptonychotes weddellii*) in the Antarctic. Labelled glycine moved quickly into serum protein and red blood cells (1-2 hours) and urinary urea (2-4 hours). The turnover rates in the blood amino acid and urine urea pools demonstrated a reduced turnover rate associated with molting. Lastly, whole body protein turnover experiments using a single bolus ¹⁵N-labelled glycine tracer method with endproduct collection of blood, feces and urine were conducted on 2 Cohort groups of captive Alaskan harbor seals over 2 years. Season was found to have the greatest effect on whole body protein turnover, which increased during the winter and decreased in the summer molt. Conversely, protein intake decreased during the winter and increased in the summer molt. This pattern corresponded with an increase in mass and protein synthesis in the winter, while mass decreased and protein degradation rates increased in molting seals. Weaning also influenced the patterns with reduced protein turnover in

newly weaned animals that had recently transitioned from milk to a fish diet. This project presents results on whole body protein turnover rates in nonfasting pinnipeds and reveals that protein turnover is strongly regulated by developmental and seasonal physiological and metabolic demands.

Lander, M. E., Fadely, B. S., Gelatt, T. S., Sterling, J. T., Johnson, D. S., & Pelland, N. A. (2020). Mixing It up in Alaska: Habitat Use of Adult Female Steller Sea Lions Reveals a Variety of Foraging Strategies. *Ecosphere*, 11(2), e03021. <https://doi.org/10.1002/ecs2.3021>

From 2010 to 2015, satellite transmitters were deployed on 16 adult female Steller sea lions (AFSSLs; *Eumetopias jubatus*) in three regions of Alaska because there is limited information regarding the habitat use of this age class during winter and populations have yet to recover in western Alaska. Two approaches were used to assess how static (distance to shore, sea lion site, and continental shelf break, presence on/off the continental shelf, and bathymetric depth and slope), dynamic (proportion of daylight, fraction of lunar illumination, chlorophyll-a, wind speed, sea surface height, eddy kinetic energy, and sea surface temperature), and other (region, distinct population segment, and season) covariates affected the habitat use of AFSSLs. Multimodel inference was first used to examine diving behaviors (mean and maximum dive depths, dive frequency) with respect to covariates using linear mixed-effects models, whereas single model inference was used to examine kernel density estimates (KDEs) of individual monthly utilization distributions ($n = 74$) in western Alaska with respect to environmental covariates using generalized additive models. Additionally, weighted coefficients from these models were examined for the population as a whole, within each individual, between regions, and across monthly scales. Comparisons of foraging behaviors of AFSSLs over time and space revealed pronounced individual variability within overall broader patterns. Response variables of most models were related to various combinations of predictor variables, but distance to shore was the most influential variable across all models. As expected with a non-migratory central place forager, frequency of diving and KDEs were greater on the shelf and near shore, though maximum dive depths increased with distance to shore. Interaction effects (proportion of day light on/off shelf) observed for mean dive depths suggested AFSSLs were feeding on benthic species when in shelf waters near shore, whereas they were likely feeding on vertically migrating prey species while off-shelf. Relationships regarding diving behaviors and KDEs of AFSSLs relative to dynamic oceanographic variables were not as prominent as those observed for static environmental variables, though some signals were apparent at different scales. Overall, static environmental features likely provided more consistent sources of habitat for prey resources, thereby making them more predictable for AFSSLs.

Lewis, Z. K. (2022). *Foraging Ecology of Sexually-Dimorphic Marine Generalist Predators: Describing Stellar Sea Lion Diet Along the Northern Washington Coast*. (Master of Science), Western Washington University, Bellingham, WA. Retrieved from <https://cedar.wvu.edu/wwuet/1129>

Understanding generalist predator impact on prey populations requires an understanding of predator diet composition, foraging ecology and specialization, all of which may vary over spatial and temporal scales. Steller sea lions (*Eumetopias jubatus*) are large, sexually dimorphic, generalist predators that may have different roles in the ecosystem based on sex. However, the variation between individuals within a population, or intrapopulation feeding diversity of Steller sea lions has not been examined. In this study, I describe the diet of Steller sea lions along the northern coast of Washington between December 2020-August 2021 using DNA metabarcoding, hard parts analysis, and qPCR sex determination to examine diet composition and factors influencing intrapopulation feeding diversity. I found that the diet composition

of Steller sea lions along the northwest Washington coast from December 2020-August 2021 was mainly comprised of American shad (*Alosa sapidissima*), Pacific herring (*Clupea pallasii*), big skate (*Raja binoculata*), walleye pollock (*Gadus chalcogrammus*) and starry flounder (*Platichthys stellatus*). I found that intrapopulation feeding diversity, a proxy for individual specialization, is not influenced by season and sex. Further, individuals that exhibited generalist foraging techniques correlated with pelagic prey items such as American shad, Pacific herring, and Pacific salmon (*Oncorhynchus* Spp.), which suggest that Steller sea lions in this region generally exhibit pelagic foraging techniques resulting in consumption of species of conservation concern.

Maniscalco, J. M. (2023). Changes in the Overwintering Diet of Steller Sea Lions (*Eumetopias jubatus*) in Relation to the 2014 – 2016 Northeast Pacific Marine Heatwave. *Global Ecology and Conservation*, 43. <https://doi.org/10.1016/j.gecco.2023.e02427>

Understanding variation in the diets of endangered species during critical time periods in their annual cycle is of utmost importance because of the effects that diet can have on vital rates and population trends. This may be especially true for endangered Steller sea lions during the winter months when prey can be difficult to find, and many adult females are both lactating and pregnant. This study aimed to examine changes in the overwintering diet of Steller sea lions across an extreme climatic event, the northeast Pacific marine heatwave (PMH) that adversely affected this species and broadly impacted many others throughout the trophic spectrum. Diet analysis was conducted from scat samples using hard part remains and qPCR methods. Prior to the peak impact of the PMH, Steller sea lions fed predominantly on epipelagic and mesopelagic fishes such as capelin, walleye pollock and Pacific cod. Following the warm-water peak, capelin was strongly reduced in their diet, and diet diversity increased with greater presence of demersal and benthic prey such as skates, lumpsuckers, snailfish, and polychaetes. These results suggest that sea lions were having a difficult time finding their preferred prey, spending time searching deeper to find alternative prey with poorer energy content following the peak impact of the PMH. These changes in diet corresponded with fewer pups being born and a reduction in overall sea lion numbers in the study area, providing evidence that overwintering prey fields may have a substantial impact on population health.

Olivier, P. A., Andrews, R., Burkanov, V., & Davis, R. W. (2022). Diving Behavior, Foraging Strategies, and Energetics of Female Steller Sea Lions During Early Lactation. *Journal of Experimental Marine Biology and Ecology*, 550. <https://doi.org/10.1016/j.jembe.2022.151707>

Lactating Steller sea lions (SSL; *Eumetopias jubatus*) are income breeders, which balance the energetic cost of provisioning a pup with alternating periods of foraging at sea and nursing onshore during a 12-36 month dependency period. Foraging dives may be benthic or epipelagic, and the diverse diet varies seasonally and geographically. The objective of this study was to use animal-borne video and data recorders (VDRs) to record prey captures and characterize the three-dimensional movements, dive performance, and foraging strategies of female SSL while rearing a pup on Lovushki Island, located in the Kuril Island Archipelago in Far Eastern Russia. Female SSL made short foraging trips (8.7 h) and remained relatively close to the rookery (< 15 km) with an average swim speed of 1.5 m sec⁻¹ and metabolic rate of 3.15 W kg⁻¹, which was 1.8-fold greater than their estimated resting metabolic rate. We identified two types of dives representing shallow (Type 3) and deep (Type 4) benthic foraging, primarily on Atka mackerel (*Pleurogrammus monopterygius*) at night when they rest on the seafloor. The estimated Field Metabolic Rate (FMR; 2.31 W kg⁻¹) for a mean 31.7 h foraging-nursing cycle was only 1.3-fold greater

than their estimated resting metabolic rate, primarily because the females spent 73% of their time onshore nursing the pup. The short foraging trips near the rookery and low FMR indicated abundant prey. On average, female SSL captured 35.4 fish during a foraging trip, which represented an estimated 20.8 kg of prey. This was sufficient to remain in energy balance and provision a pup during early lactation. However, a 10-20% reduction in the size or abundance of prey would result in a 38-76% reduction in milk production, respectively, which would cause reduced growth or death of the pup. These calculations indicate the thin margin for energy balance in SSL during early lactation. Hence, any reduction in the size or abundance of prey could have serious consequences for reproductive success and fitness.

Rand, K., McDermott, S. F., Logerwell, E., Matta, M. E., Levine, M., Bryan, D. R., . . . Loomis, T. (2019). Higher Aggregation of Key Prey Species Associated with Diet and Abundance of the Steller Sea Lion *Eumetopias jubatus* across the Aleutian Islands. *Marine and Coastal Fisheries*, 11(6), 472-486. <https://doi.org/10.1002/mcf2.10096>

The Aleutian Islands ecosystem is a highly dynamic marine environment that supports commercially important fish species, such as Atka Mackerel *Pleurogrammus monopterygius* and Northern Rockfish *Sebastes polyspinis*, and several large marine mammals, including the Steller sea lion (SSL) *Eumetopias jubatus*. To protect SSL foraging behavior and prey, trawl exclusion zones (TEZs) were established around SSL rookeries and haulouts across the Aleutian Islands and are closed to bottom trawling. The Atka Mackerel fishery is concentrated at small, local patches (similar to 37.04 km [similar to 20 nautical miles]) across the Aleutian Islands, often near and adjacent to TEZs. Food web models and fishery stock assessments predict sufficient prey for both the fishery and foraging SSLs at the level of large management areas (each area is similar to 463 km [similar to 250 nautical miles] longitudinally), but little is known about local fish distribution (similar to 37.04 km) in proximity to SSL rookeries and haulouts. We used CPUE to examine the spatial distribution of two SSL prey species (Atka Mackerel and Northern Rockfish) and marine invertebrates (as a proxy for habitat quality) at large (across the Aleutian Islands) and small (similar to 37.04-km) scales. Although Atka Mackerel abundance estimates were similar across the Aleutian Islands, the density of Atka Mackerel differed. In the eastern Aleutian Islands, where SSL population trends have stabilized, Atka Mackerel aggregations were dense. In contrast, in the far western Aleutian Islands, where SSL populations are still in decline, Atka Mackerel distributions were diffuse and Northern Rockfish exhibited a greater density. Results indicated no significant difference in CPUE between areas open to fishing and closed areas (i.e., TEZs) at all study sites for Atka Mackerel and at all but one study site for Northern Rockfish, whereas invertebrate densities were significantly higher inside of TEZs at all study sites. We discuss how fish distributions across the Aleutian Islands may impact the success and behavior of foraging SSLs.

Reed, N. M. (2021). *Home Ranges and Diving Behavior of New Zealand Sea Lions Along the Catlins Coast, South Island, New Zealand*. (Doctor of Philosophy), Texas A&M University, College Station, TX. Retrieved from <https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/193246/REED-DISSERTATION-2021.pdf?sequence=1>

New Zealand sea lions (*Phocarctos hookeri*) were extirpated from the North and South Islands of New Zealand during pre-European native hunting, and their numbers were greatly reduced on the Auckland and Campbell Islands during European commercial sealing. However, they began reoccupying South Island in 1994, and pup production remains low but steady. The home range, at-sea movements, and

diving behavior of females at the breeding colony along the Catlins Coast of South Island have not been studied since its inception in 2006. The goal of the study was to: 1) evaluate the performance of home range models to identify the most accurate model(s) for a semiaquatic distribution, 2) track movements to identify home ranges, and 3) record diving behavior of females to characterize foraging behavior and estimate energy expenditure. To accomplish this study, we attached satellite telemeters and video and data recorders to females along the Catlins Coast during austral winter of 2019. Home ranges were most accurately modeled by separating inshore and offshore habitats and applying adaptive local convex hulls (LOCOH) and fixed kernel density with plug-in bandwidth selection (PKDE), respectively. This method minimized the ranges outside of used habitat, handled boundaries to movement, and performed accurately in cross-validation evaluation. The results showed the importance of home range model selection. Total home ranges were small and restricted to coastal areas. Foraging cycles were frequent, with short times at sea and onshore. Dives were shallow, short in duration, and divided into three types based on variables derived from three-dimensional dive analysis. Dive characteristics indicated a benthic foraging strategy with transit periods between foraging patches. At-sea estimated metabolic rate varied by activity, with an estimated field metabolic rate lower than that of females at the Auckland Islands, possibly indicating differences in energetic expenditure among populations. It appears that females along the Catlins Coast consume nearshore, abundant prey and require less time and smaller home ranges for foraging compared to that for females in the Auckland Islands. Although reoccupation of their historic range on South Island will take decades, suitable habitat for breeding and prey availability along the southeast coast are encouraging.

Rosen, D. A. S. (2021). The Effect of Food Restriction on Growth Rates in Steller Sea Lions, *Eumetopias jubatus*. *Marine Mammal Science*, 37(4), 1524-1530. <https://doi.org/10.1111/mms.12813>

Quantifying the physiological consequences of disturbance (PCoD) is increasingly becoming a standard tool for assessing the effects of ecological changes on individual animals and, subsequently, on their population trajectories. Predicting the effects of changes in prey quality and/or availability has been the focus of several investigations with various marine. For example, there has been a concerted scientific effort to determine whether changes in prey availability or quality have contributed to the 85% decline in Steller sea lion (*Eumetopias jubatus*) populations in Western. While episodes of suboptimal energy intake from prey can have numerous short- and long-term physiological effects, the most rudimentary consequence is a decrease in body mass. One key element to understanding the effects of nutritional stress and recognizing its role in wild populations is quantifying the effect of episodes of decreased food energy intake on the growth rates and body mass of individual. A number of studies have examined specific scenarios involving changes in prey intake on aspects of Steller sea lion physiology and health through experimental manipulations with Steller sea lions under human care. However, an overall predictive model of the fundamental effects of reductions in energy intake on body mass and growth has not been established. This information is critical for bioenergetic modeling efforts to envision the effects of a range of ecological disturbances on individual Steller sea lions and, subsequently, on populations.

Rub, A. M. W., Som, N. A., Henderson, M. J., Sandford, B. P., Van Doornik, D. M., Teel, D. J., . . . Huff, D. D. (2019). Changes in Adult Chinook Salmon (*Oncorhynchus tshawytscha*) Survival within the Lower Columbia River Amid Increasing Pinniped Abundance. *Canadian Journal of Fisheries & Aquatic Sciences*, 76(10), 1862-1873. <https://doi.org/10.1139/cjfas-2018-0290>

Considerable effort towards conservation has contributed to the recovery of historically depleted pinniped populations worldwide. However, in several locations where pinnipeds have increased, they have been blamed for preventing the recovery of commercially valuable fish species through predation. Prompted by increasing pinniped abundance within the Columbia River (CR), USA, over a 6-year period, we used passive integrated transponder tags to measure the survival of adult spring-run Chinook salmon (*Oncorhynchus tshawytscha*) through the estuary and lower CR to Bonneville Dam (river kilometre 234). We estimated 51 751 - 224 705 salmon died annually within this reach from sources other than harvest. Mixed-effects logistic regression modelling identified pinniped predation as the most likely source of this mortality. The odds of survival was estimated to decrease by 32% (95% CI: 6%-51%) for every additional 467 sea lions (*Zalophus californianus* and *Eumetopias jubatus*) present within the CR and to increase by 32% (95% CI: 8%-61%) for every increase of 1.5 in the log of American shad (*Alosa sapidissima*), a potential prey item for sea lions.

Scordino, J. J., Akmajian, A. M., & Edmondson, S. L. (2022). Dietary Niche Overlap and Prey Consumption for the Steller Sea Lion (*Eumetopias jubatus*) and California Sea Lion (*Zalophus californianus*) in Northwest Washington During 2010-2013. *Fishery Bulletin*, 120(1), 39-54. <https://doi.org/10.7755/FB.120.1.4>

The diets of Steller (*Eumetopias jubatus*) and California (*Zalophus californianus*) sea lions in northwest Washington are poorly documented. We hypothesized that these species exploit the same prey in Washington because they are both generalist predators that utilize the same haul-out sites and are similar in behavior and body size. We analyzed 776 samples of scat from Steller sea lions and 263 samples of scat from California sea lions collected throughout each year during 2010-2013. The aim of this analysis was to characterize seasonal and annual diets, estimate biomass of prey consumed, and evaluate dietary niche overlap. Steller and California sea lions ate diverse diets that varied seasonally and annually. Primary prey groups for both sea lion species were Clupeidae, Salmonidae, Sebastidae, Rajidae, Pleuronectiformes, Squalidae, and Merlucciidae. We estimated that Steller sea lions ate 11,327 metric tons (t) (standard deviation [SD] 1600) and that California sea lions ate 9063 t (SD 4098) of prey per year during our study. We found significant dietary niche overlap between California and Steller sea lions that feed in northwest Washington.

Scordino, J. J., Marshall, C., Akmajian, A. M., Shay, D., & James, R. (2022). Consumption of Pacific Salmon (*Oncorhynchus Spp.*) by California Sea Lions (*Zalophus californianus*) and Steller Sea Lions (*Eumetopias jubatus*) in Northwest Washington During 2010-2013. *Fishery Bulletin*, 120(2), 150-161. <https://doi.org/10.7755/fb.120.2.5>

Pacific salmon (*Oncorhynchus Spp.*) are important to the ecology, economy, and cultures of the Pacific Northwest. Many populations of Pacific salmon in the Pacific Northwest are declining because of poor marine survival. We evaluated the role of Steller (*Eumetopias jubatus*) and California (*Zalophus californianus*) sea lions as predators of Pacific salmon. Roughly, half of the 1330 metric tons (t) of Pacific salmon eaten by Steller sea lions per year and of the 1220 t of Pacific salmon eaten by California sea

lions per year in northwest Washington during 2010–2013 were coho salmon (*O. kisutch*). The response of Steller and California sea lions to the large run of pink salmon (*O. gorbuscha*) in 2011 was less than expected. Sea lions of these species rarely ate large (roughly ≥ 50 cm in total length) Chinook salmon (*O. tshawytscha*), indicating that they have limited direct competition for prey with the southern resident distinct population segment of killer whales (*Orcinus orca*). Combined, California and Steller sea lions in northwest Washington consumed a mass of coho salmon similar to that landed by commercial fisheries in Washington State. More work on modeling the effect of the predation of California and Steller sea lions on salmon populations, particularly for coho salmon, is needed to better evaluate the conservation and productivity of Pacific salmon.

Sinclair, E. H., Walker, W. A., & Gearin, P. J. (2019). The Diet of Free-Ranging Male Steller Sea Lions (*Eumetopias jubatus*) in the Eastern Bering Sea: A Retrospective Analysis Based on Stomach Contents of an Endangered Pinniped. *Canadian Journal of Zoology*, 97(3), 195-202.
<https://doi.org/10.1139/cjz-2018-0057>

This study illuminates historical diet and foraging locations of endangered western U.S. stock Steller sea lions (*Eumetopias jubatus* (Schreber, 1776)). Prey were identified from stomachs of 22 males collected in the eastern Bering Sea from the ice edge in March 1985 and nearshore St. Paul Island in September–October 1985 and 1986. Percent frequency of occurrence (PFO) and percent number (PN) were highest for walleye pollock (*Gadus chalcogrammus* Pallas, 1814; PFO 69%, PN 15%, mean length 17 cm), Pacific herring (*Clupea pallasii* Valenciennes in Cuvier and Valenciennes, 1847; PFO 62%, PN 16%, mean length 26 cm), shorthorn sculpin (*Myoxocephalus scorpius* (Linnaeus, 1758); PFO 54%, PN 30%), and Pacific giant octopus (*Enteroctopus dofleini* (Wulker, 1910); PFO 39%, PN 8%, mean weight 31 kg) in spring, and northern rock sole (*Lepidopsetta polyxystra* Orr and Matarese, 2000; PFO 78%, PN 47%, mean length 35 cm), Pacific cod (*Gadus macrocephalus* Tilesius, 1810; PFO 56%, PN 12%, mean length 62 cm), walleye pollock (PFO 44%, PN 7%, mean length 49 cm), and red Irish lord (*Hemilepidotus hemilepidotus* (Tilesius, 1811); PFO 11%, PN 9%) in fall. Species of Cryptacanthidae, Liparidae, and Zoarcidae were highly represented and exclusive to spring collections. Predictable seasonal concentrations and movements of mature prey along frontal boundaries of the continental shelf and ice edge may be critical to male Steller sea lion fitness during the non-breeding season.

Takano, N., Kanaiwa, M., & Kobayashi, M. (2023). Estimation of Feeding Strategies of Spotted Seals (*Phoca largha*) Migrating to Three Regions in Hokkaido, Japan. *Marine Ecology*, 44(2).
<https://doi.org/10.1111/maec.12740>

To understand the current feeding habits of spotted seals, this study estimates feeding strategies based on region, season, growth stage, and sex through the results of stomach content analyses, and compares its findings with feeding habits of the past. As a result of permutational multivariate analysis of variance (PERMANOVA), region, season, growth stage, and sex were detected as significant. Non-metric multidimensional scaling (nMDS), hierarchical cluster analysis, and the growth stages were categorized into age classes: Age 0 to age 4 years were classified as young, and age 5 and older were classified as adult. For the seasons, November and December were classified as winter, and February to May was classified as spring. And clustering with flexible mixture modeling, samples were divided into eight feeding strategies. In Rebun, the feeding strategy consisting of *Octopodidae* species showed a high total energy value and appeared at a high occurrence rate for both young and adult. In Saroma, *Osmeridae* species in winter and *Clupeidae* species in spring showed a high proportion. Both *Osmeridae*

and *Clupeidae* species showed a high proportion in both seasons, all growth stages, and both sexes. In Rausu, adult was particularly dominant in Alaska pollock (*Gadus chalcogramma*) in spring, while young appeared at a high rate in *Ammodytidae* species. The present study has shown that seals have become particularly dependent on fish in all layers of the marine environment. In addition to drastic changes in their environment, the increase in the number of individuals of a competing species that is Steller sea lions in Rebun, and a decrease in fishery resources have made it impossible for spotted seals to take advantage of their high-energy feeding strategy mainly composed of Alaska pollock both Rebun and Rausu. As a result, regional differences in feeding strategies for both Rebun and Rausu have become more clearly differentiated than in the past, and the seals have flexibly changed their feeding strategies to accommodate the availability of prey species in their particular region. This study has succeeded in accurately classifying the feeding strategies of spotted seals in three disparate regions of Hokkaido and has revealed significant temporal and regional differences.

Walters, C. J., McAllister, M. K., & Christensen, V. (2020). Has Steller Sea Lion Predation Impacted Survival of Fraser River Sockeye Salmon? *Fisheries*, 45(11), 597-604.
<https://doi.org/10.1002/fsh.10488>

The commercially, recreationally, and culturally important Fraser River Sockeye Salmon, *Oncorhynchus nerka*, has experienced a productivity decline over the past 3 decades, which along with greater temporal variation in annual abundance (i.e., cyclic dominance) may at least partly be due to Steller sea lion *Eumetopias jubatus* (SSL) predation on returning adult salmon. This assumes that SSLs residing around northern Vancouver Island (British Columbia, Canada) target Sockeye Salmon for just a few weeks during the peak of their run. It is a reasonable enough assumption to warrant immediate priority for field research on SSL behavior and diets during the migration period. We evaluated the plausibility of the assumption with a variety of approaches ranging from simple estimates of maximum SSL consumption to partitioning of observed marine mortality rates and analysis of SSL foraging behavior to show that SSLs could have caused the decline in productivity and abundance of Fraser River Sockeye Salmon.

Section VII: Genetics

Beklemisheva, V. R., Perelman, P. L., Lemskaya, N. A., Proskuryakova, A. A., Serdyukova, N. A., Burkanov, V. N., . . . Graphodatsky, A. S. (2020). Karyotype Evolution in 10 Pinniped Species: Variability of Heterochromatin Versus High Conservatism of Euchromatin as Revealed by Comparative Molecular Cytogenetics. *Genes*, *11*(12). <https://doi.org/10.3390/genes11121485>

Pinnipedia karyotype evolution was studied here using human, domestic dog, and stone marten whole-chromosome painting probes to obtain comparative chromosome maps among species of Odobenidae (*Odobenus rosmarus*), Phocidae (*Phoca vitulina*, *Phoca largha*, *Phoca hispida*, *Pusa sibirica*, *Erignathus barbatus*), and Otariidae (*Eumetopias jubatus*, *Callorhinus ursinus*, *Phocarctos hookeri*, and *Arctocephalus forsteri*). Structural and functional chromosomal features were assessed with telomere repeat and ribosomal-DNA probes and by CBG (C-bands revealed by barium hydroxide treatment followed by Giemsa staining) and CDAG (Chromomycin A3-DAPI after G-banding) methods. We demonstrated diversity of heterochromatin among pinniped karyotypes in terms of localization, size, and nucleotide composition. For the first time, an intrachromosomal rearrangement common for Otariidae and Odobenidae was revealed. We postulate that the order of evolutionarily conserved segments in the analyzed pinnipeds is the same as the order proposed for the ancestral Carnivora karyotype ($2n = 38$). The evolution of conserved genomes of pinnipeds has been accompanied by few fusion events (less than one rearrangement per 10 million years) and by novel intrachromosomal changes including the emergence of new centromeres and pericentric inversion/centromere repositioning. The observed interspecific diversity of pinniped karyotypes driven by constitutive heterochromatin variation likely has played an important role in karyotype evolution of pinnipeds, thereby contributing to the differences of pinnipeds' chromosome sets.

Deeg, C. M., Esenkulova, S., Li, S., Ben, J. G. S., Wallace, C., Schulze, A., & Miller, K. M. (2022). Environmental DNA Survey of the Winter Salmonosphere in the Gulf of Alaska. *Environmental DNA*(18), 37-41. <https://doi.org/10.1002/edn3.404>

Environmental DNA (eDNA) is an emerging field to study the diversity and distribution of aquatic communities without the need to capture individuals. It utilizes sequencing of traces of DNA left behind in the environment by organisms to provide an unbiased account of species composition and distribution in an environment without the need for invasive sampling methods. The International Year of the Salmon (IYS) Gulf of Alaska (GoA) expeditions were launched in 2019 and 2020 to illuminate the factors influencing the survival of Pacific salmon in the open ocean. The winter months, when open-ocean conditions might critically impact ocean survival of first ocean-winter juvenile and subadult salmon, are the least understood but could largely determine stock performance. Despite progress on salmon marine ecology during the winter, questions regarding the health and survival of salmon during this period remain unanswered, particularly in the open ocean. Specifically, the impact of predators and competitors has been notoriously difficult to assess due to the scarcity of data, in part due to the difficulty of catching large highly mobile predators of salmon in trawl surveys. Accordingly, we collected water samples during the GoA expeditions and performed an eDNA survey on the samples with the goal of describing the salmonosphere (i.e., the relative abundance and distribution of Pacific salmon, as well as their prey, competitors, and predators).

Kwan, H. H., Culibrk, L., Taylor, G. A., Leelakumari, S., Tan, R., Jackman, S. D., . . . Jones, S. J. M. (2019). The Genome of the Steller Sea Lion (*Eumetopias jubatus*). *Genes*, 10(7). <https://doi.org/10.3390/genes10070486>

The Steller sea lion is the largest member of the Otariidae family and is found in the coastal waters of the northern Pacific Rim. Here, we present the Steller sea lion genome, determined through DNA sequencing approaches that utilized microfluidic partitioning library construction, as well as nanopore technologies. These methods constructed a highly contiguous assembly with a scaffold N50 length of over 14 megabases, a contig N50 length of over 242 kilobases and a total length of 2.404 gigabases. As a measure of completeness, 95.1% of 4104 highly conserved mammalian genes were found to be complete within the assembly. Further annotation identified 19,668 protein coding genes. The assembled genome sequence and underlying sequence data can be found at the National Center for Biotechnology Information (NCBI) under the BioProject accession number PRJNA475770.

Lopes, F., Oliveira, L. R., Kessler, A., Beux, Y., Crespo, E., Cardenas-Alayza, S., . . . Bonatto, S. L. (2021). Phylogenomic Discordance in the Eared Seals Is Best Explained by Incomplete Lineage Sorting Following Explosive Radiation in the Southern Hemisphere. *Systematic Biology* 70(4), 786-802. <https://doi.org/10.1093/sysbio/syaa099>

The phylogeny and systematics of fur seals and sea lions (Otariidae) have long been studied with diverse data types, including an increasing amount of molecular data. However, only a few phylogenetic relationships have reached acceptance because of strong gene-tree species tree discordance. Divergence times estimates in the group also vary largely between studies. These uncertainties impeded the understanding of the biogeographical history of the group, such as when and how trans-equatorial dispersal and subsequent speciation events occurred. Here, we used high-coverage genome-wide sequencing for 14 of the 15 species of Otariidae to elucidate the phylogeny of the family and its bearing on the taxonomy and biogeographical history. Despite extreme topological discordance among gene trees, we found a fully supported species tree that agrees with the few well-accepted relationships and establishes monophyly of the genus *Arctocephalus*. Our data support a relatively recent trans-hemispheric dispersal at the base of a southern clade, which rapidly diversified into six major lineages between 3 and 2.5 Ma. *Otaria* diverged first, followed by *Phocarctos* and then four major lineages within *Arctocephalus*. However, we found *Zalophus* to be nonmonophyletic, with California (*Zalophus californianus*) and Steller sea lions (*Eumetopias jubatus*) grouping closer than the Galapagos sea lion (*Zalophus wollebaeki*) with evidence for introgression between the two genera. Overall, the high degree of genealogical discordance was best explained by incomplete lineage sorting resulting from quasi-simultaneous speciation within the southern Glade with introgression playing a subordinate role in explaining the incongruence among and within prior phylogenetic studies of the family.

Section VIII: Movements, Distribution, and Habitat Use

Conn, P. B., Hoef, J. M. V., McClintock, B. T., Johnson, D. S., & Brost, B. (2022). A GLMM Approach for Combining Multiple Relative Abundance Surfaces. *Methods in Ecology and Evolution*, 13(10), 2236-2247. <https://doi.org/10.1111/2041-210x.13948>

Spatio-temporal maps of organismal density or relative abundance are fundamental to many applications in conservation and ecology. There are often a number of data sources to inform species maps, including citizen science monitoring programs, remote sensing, geolocation data from satellite-tagged animals and formal scientific surveys. In these cases, it may be desirable to come up with a single map integrating all data sources. We introduce a novel two-step method for combining inference about relative abundance maps using multiple data sources. Log-scale relative abundance surfaces are first estimated from individual data sets, and resultant surfaces are then treated as 'data' within a generalized linear mixed model framework with a spatially autocorrelated mean process. We also introduce generalizations allowing data misalignment and predictive processes to decrease computational burden. Using simulation, we show that our approach frequently outperforms other approaches, including basing inference on a single surface, or taking a simple arithmetic mean (although the arithmetic mean performs well when there are few surfaces). We then demonstrate our method using citizen science and satellite-tracking data of Steller sea lions in Alaska. In this case, relative abundance surfaces consisted of an effort-adjusted map developed from platform-of-opportunity sightings and a utilization distribution developed from geolocation records. The resulting combined surface represented a compromise between single-data source predictions. Our approach should be useful for ecologists seeking to reconcile alternative species distribution maps, particularly when individual surfaces are prone to bias, when there is no obvious common currency (e.g. point process), or when computational demands preclude a fully integrated analysis.

Gallo-Reynoso, J. P., Figueroa-Caranza, A. L. r., Barba-Acuna, I. D., Borjes-Flores, D., & Perez-Cossio, I. J. (2020). Steller Sea Lions (*Eumetopias jubatus*) Along the Western Coast of Mexico. *Aquatic Mammals*, 46(4), 411-416. <https://doi.org/10.1578/AM.46.4.2020.411>

Reports on the occasional presence of pinniped species along the Mexican Pacific coast, well beyond their known distribution range, are remarkable for implying long-distance swimming by these individuals. The pinniped species in those reports include the California sea lion (*Zalophus californianus*), Guadalupe fur seals (*Arctocephalus townsendi*), Pacific harbor seals (*Phoca vitulina*), elephant seals (*Mirounga* sp.), Galápagos sea lions (*Zalophus wollebaeki*) and fur seals (*Arctocephalus galapagoensis*), South American sea lions (*Otaria byronia*) and fur seals (*Arctocephalus australis*), and Steller sea lions (*Eumetopias jubatus*). The extralimital presence of these pinnipeds has been discussed by many authors and has been related to changes in sea surface temperature driven by climatic–oceanographic events such as El Niño, La Niña, or the Pacific decadal oscillation. Such climatic–oceanographic events produce changes in sea surface temperature - either increasing or reducing it - that affect the direction, strength, or depth of ocean currents in the northeast tropical and temperature Pacific. This leads to drastic changes in the availability of prey species, likely resulting in prey shortages in some instances, which might prompt the long-distance displacement of pinnipeds searching for prey. These individual movements are likely related to population recovery and expansion, one example being the population recovery and expansion one example being the population growth of the Guadalupe fur seal and their occupation of former rookery islands such as the San Benito Archipelago. Another example is the recovery of the Steller sea lion population at the northernmost area of its range.

Grishin, S. Y., Belousov, A. B., Belousova, M. G., Auer, A., & Kozyrev, I. A. (2021). The 2019 Explosive Eruption of Raikoke Volcanic Island, Kuriles: Pyroclastic Deposits and Their Impact on the Relief and Ecosystems. *Journal of Volcanology and Seismology*, 15(6), 387-398.
<https://doi.org/10.1134/S074204632105002X>

A short-lived but violent explosive eruption occurred on the small volcanic island Raikoke in June 2019 (central Kuril Islands). The culmination of the eruption lasted 3.5 h and the ash cloud rose to a height of 13 km. An analysis of a sequence of satellite images in combination with ground-based observations gave information on the pyroclastic deposits of the eruption and allowed us to estimate the associated impact on the island ecosystems. We found that this eruption had a phreatomagmatic, sub-Plinian to Plinian character. The phreatomagmatic mechanism of the eruption occurred due to interaction between the rising basaltic andesite magma and ground waters, which were mostly represented by sea water that percolated through the permeable rocks of the volcanic island. The eruption produced numerous pyroclastic flows. The hot deposits of the pyroclastic flows and tephra covered the entire island, destroying the vegetation and the habitat of birds and sea mammals. Much of the pyroclasts was deposited in the form of fans of pyroclastic flows at the base of the volcanic slopes, considerably displacing the shoreline seaward. As a result, the island area increased by 15%. The pyroclastic deposits were intensely eroded and redeposited during the first year after the eruption, making new areas of the island coast. The recovery of Raikoke's ecosystems will be enhanced by erosion of the pyroclastic deposits and gradual resettling of birds, which would bring new plant species to the island. The succession would be accelerated by areas of survived vegetation. Overall, we see periodic dramatic disruptions in the island ecosystems caused by violent explosive eruptions with subsequent rapid recovery that with high probability will be interrupted by new eruption.

Hoef, J. M. V., Johnson, D., Angliss, R., & Higham, M. (2021). Species Density Models from Opportunistic Citizen Science Data. *Methods in Ecology and Evolution*, 12(10), 1911-1925.
<https://doi.org/10.1111/2041-210x.13679>

With the advent of technology for data gathering and storage, opportunistic citizen science data are proliferating. Species distribution models (SDMs) aim to use species occurrence or abundance for ecological insights, prediction and management. We analysed a massive opportunistic dataset with over 100,000 records of incidental shipboard observations of marine mammals. Our overall goal was to create maps of species density from massive opportunistic data by using spatial regression for count data with an effort offset. We illustrate the method with two marine mammals in the Gulf of Alaska and Bering Sea. We counted the total number of animals in 11,424 hexagons based on presence-only data. To decrease bias, we first estimated a spatial density surface for ship-days, which was our proxy variable for effort. We used spatial considerations to create pseudo-absences, and left some hexagons as missing values. Next, we created SDMs that used modelled effort to create pseudo-absences, and included the effort surface as an offset in a second stage analysis of two example species, northern fur seals and Steller sea lions. For both effort and species counts, we used spatial count regression with random effects that had a multivariate normal distribution with a conditional autoregressive (CAR) covariance matrix, providing 2.5 million Markov chain Monte Carlo (MCMC) samples (1,000 were retained) from the posterior distribution. We used a novel MCMC scheme that maintained sparse precision matrices for observed and missing data when batch sampling from the multivariate normal distribution. We also used a truncated normal distribution to stabilize estimates, and used a look-up table for sampling the autocorrelation parameter. These innovations allowed us to draw several million samples in just a few hours. From the posterior distributions of the SDMs, we computed two functions of interest. We

normalized the SDMs and then applied an overall abundance estimate obtained from the literature to derive spatially explicit abundance estimates, especially within subsetted areas. We also created ‘certain hotspots’ that scaled local abundance by standard deviation and using thresholds. Hexagons with values above a threshold were deemed as hotspots with enough evidence to be certain about them.

Lewis, S., Fritz, L. W., & Sweeney, K. M. (2019). *Spatial Delineation of Western Distinct Population Segment Steller Sea Lion Rookeries and Major Haulouts in Alaska*.
<https://doi.org/10.25923/t77t-9m26>

Since the early 1970s, the National Marine Fisheries Service (NMFS) has identified Steller sea lion rookery and haulout locations in Alaska from the air, ships, and on land, and obtained their locations using LORAN coordinates and nautical charts. Over the last 20 years, coordinates collected at sites along with satellite imagery have allowed scientists to more accurately update and pinpoint rookery and haulout sites. NMFS conducts aerial surveys to count sea lions hauled out at these sites during the summer breeding season, which allow biologists to use today’s GPS technology and detailed satellite imagery to update historical site locations. This report updates the locations of all rookeries and major haulouts used by western Distinct Population Segment (WDPS) Steller sea lions in Alaska. In addition, we summarize the process used to update coordinates and delineate site extent. Older, less precise geolocation data for many of these sites have been previously identified in Federal regulations: 50 CFR § 224.103 (Special prohibitions relating to endangered Steller sea lion protection); 50 CFR § 226.202 (Critical Habitat for Steller sea lions); and the 50 CFR § 679.22 fishery restriction regulations. Since some of these regulations were developed with less accurate (than present) techniques for identifying geolocations of sites, the 2008 Recovery Plan for Steller sea lions includes a threats-based recovery criteria to correct erroneous locations for rookeries and major haulout sites designated as critical habitat and rookeries listed in the ESA special prohibitions regulation. The work documented in this memo provides such updated location data. Steller sea lion rookeries (N=51 in Alaska) as described in this report are sites where there is at least one count of 50 WDPS newborn pups, since 1973. Major haulouts (N=139) as described in this report are sites that are not rookeries, and have had significant historical counts of WDPS Steller sea lions: at least one count of 200 or more during the breeding season or at least 100 during the non-breeding season, since 1973. To classify major haulout sites for WDPS Steller sea lions in southeast Alaska, historical counts were used to calculate the proportion of Steller sea lions at these sites that were from the WDPS. See March 2008 Steller Sea Lion Recovery Plan.

Michelot, T., Gloaguen, P., Blackwell, P. G., & Étienne, M. P. (2019). The Langevin Diffusion as a Continuous-Time Model of Animal Movement and Habitat Selection. *Methods in Ecology and Evolution*, 10(11), 1894-1907. <https://doi.org/10.1111/2041-210x.13275>

The utilization distribution of an animal describes the relative probability of space use. It is natural to think of it as the long-term consequence of the animal's short-term movement decisions: it is the accumulation of small displacements which, over time, gives rise to global patterns of space use. However, many estimation methods for the utilization distribution either assume the independence of observed locations and ignore the underlying movement (e.g. kernel density estimation), or are based on simple Brownian motion movement rules (e.g. Brownian bridges). We introduce a new continuous-time model of animal movement, based on the Langevin diffusion. This stochastic process has an explicit stationary distribution, conceptually analogous to the idea of the utilization distribution, and thus

provides an intuitive framework to integrate movement and space use. We model the stationary (utilization) distribution with a resource selection function to link the movement to spatial covariates, and allow inference about habitat preferences of animals. Standard approximation techniques can be used to derive the pseudo-likelihood of the Langevin diffusion movement model, and to estimate habitat preference and movement parameters from tracking data. We investigate the performance of the method on simulated data, and discuss its sensitivity to the time scale of the sampling. We present an example of its application to tracking data of Steller sea lions *Eumetopias jubatus*. Due to its continuous-time formulation, this method can be applied to irregular telemetry data. The movement model is specified using a habitat-dependent utilization distribution, and it provides a rigorous framework to estimate long-term habitat selection from correlated movement data. The Langevin movement model can be written as a linear model, which allows for very fast inference. Standard tools such as residuals can be used for model checking.

Platto, S., Zhou, J., Wang, Y., & Wang, H. (2021). First Confirmed Sighting of Steller Sea Lion (*Eumetopias jubatus*) in China since 1990. *Aquatic Mammals*, 47(2), 216-226.
<https://doi.org/10.1578/AM.47.2.2021.216>

Steller sea lions (*Eumetopias jubatus*) have a wide distribution range in the North Pacific Ocean that extends from California to Alaska (Bering Strait) in the northwest, and from the western Bering Sea along the Asian coast to Sakalin and Hokkaido Islands in the northeast. The distribution of these pinnipeds throughout Asia is not uniform, occurring year-round in some regions and seasonally in others. The Steller sea lion is not a migratory species, but individuals do disperse during different times of the year. Young animals up to 4 years of age tend to disperse further than adults. When young individuals approach the age when they begin to breed, they will generally stay in the vicinity of the breeding grounds. As a general rule, adult Steller sea lions return to their birthplace to breed. The breeding season extends from late May to early July throughout the distribution range in the Pacific regions. Males establish their territories during Mid-May on grounds usually used by females during the birthing period.

Rhodes-Reese, M., Clay, D., Cunningham, C., Moriles-Miller, J., Reese, C., Roman, J., . . . Pearson, H. C. (2021). Examining the Role of Marine Mammals and Seabirds in Southeast Alaska's Marine Ecosystem Dynamics. *Frontiers in Marine Science*. <https://doi.org/10.3389/fmars.2021.720277>

Primary producers are the foundation of marine food webs and require reliable nutrient sources to maintain their important role with ecosystems. While marine mammals and seabirds can play critical roles in marine nutrient cycling, their contributions are often overlooked. The fjord systems of Southeast Alaska support a high diversity of marine mammals and seabirds in addition to some of the most valuable fisheries in the US. Nonetheless, there is still relatively little known about nutrient sources and fluxes in this region which is a critical component of fisheries management. The goal of our study was to advance knowledge of the role of mammals and seabirds in marine nutrient cycling and to understand how changing marine mammal and seabird populations may alter ecosystem dynamics. We analyzed nutrient levels in marine mammal scat, seabird guano, and seawater samples collected in Berners Bay, Southeast Alaska, to determine the influence of marine mammals and seabirds on nearshore nutrient concentrations. Utilizing qualitative network models (QNMs), we then examined how a simulated Berners Bay ecosystem would respond to an increase in marine mammals, seabirds, and nutrients. Researchers are increasingly utilizing QNMs as a first step in the development of ecosystem-based

fisheries management plans as their adaptable nature is well suited to address rapidly changing climatic conditions. Our direct nutrient measurements and QNM results indicate that marine mammals and seabirds have the potential to provide substantial contributions to marine nutrient concentrations in the region and that these valuable ecosystem services should not be overlooked.

Rojek, N. A., & Williams, J. C. (2019). Present-Day Assemblage of Birds and Mammals in the Islands of Four Mountains, Eastern Aleutians, Alaska. *Quaternary Research*, 91(3), 1059-1074.
<https://doi.org/10.1017/qua.2018.36>

We compiled present-day observations and survey data of the avian and mammal fauna in the Islands of Four Mountains, Alaska, which primarily consist of marine-adapted species, to provide insight into the prehistoric fauna found in the archaeological record. We documented 63 bird species, mainly seabirds (67%). The majority (71%) of the estimated number of breeding birds are ledge nesters, predominately murre, and most (68%) spend the majority of their lives in the offshore environment. We lack good estimates for burrow and crevice nesters, which were impacted by and are still recovering from a period of arctic fox farming in the twentieth century. Marine mammals, predominately Steller sea lion, harbor seal, and sea otter, primarily use accessible land as haul-outs and are found in low numbers compared with the rest of the Aleutians. Red fox, the only land mammal, presently only reside on Chuginadak Island. While the present-day fauna is similar to the fauna recorded in the archaeological record, we found no indication of nesting by ancient murrelets and northern fulmars in the Island of Four Mountains, whereas both species were present in midden sites on Carlisle and Chuginadak Islands, with the possibility of prehistoric breeding colonies on Carlisle Island.

Sheffield, G., & Jemison, L. (2021). *Community Report: Steller Sea Lion Distribution and Counts in the Bering Strait*. Retrieved from <https://repository.library.noaa.gov/view/noaa/48503>

Steller sea lions, a marine resource utilized for subsistence purposes by Alaska Natives and a top predator in the Bering Sea ecosystem, are extending their seasonal use in the Bering Strait region and expanding their range northward. These shifts are happening at the same time ecosystem-wide changes are ongoing in the northern Bering Sea since 2017, as a result of recent unprecedented low sea ice coverage. The lack of sea ice has reduced sea ice algae growth and reduced the annually replenished cold briny water that served as a thermal barrier separating the previously-distinct southern and northern ecosystems of the Bering Sea. Massive northward shifts of large, predatory, commercially viable fish populations (e.g., Alaska pollock, Pacific cod) from the southern Bering Sea are currently dominating the Bering Strait region and are re-configuring the marine food web of the northern Bering Sea.

Tsuzuku, N., & Kohno, N. (2020). The Oldest Record of the Steller Sea Lion *Eumetopias jubatus* (Schreber, 1776) from the Early Pleistocene of the North Pacific. *PeerJ*, 8.
<https://doi.org/10.7717/peerj.9709>

The extant genera of fur seals and sea lions of the family *Otariidae* (Carnivora: Pinnipedia) are thought to have emerged in the Pliocene or the early Pleistocene in the North Pacific. Among them, the Steller sea lion (*Eumetopias jubatus*) is the largest and distributed both in the western and eastern North Pacific. In contrast to the limited distribution of the current population around the Japanese Islands that

is now only along the coast of Hokkaido, their fossil records have been known from the middle and late Pleistocene of Honshu Island. One such important fossil specimen has been recorded from the upper lower Pleistocene Omma Formation (ca. 1.36-0.83 Ma) in Kanazawa, Ishikawa Prefecture, Japan, which now bears the institutional number GKZ-N 00001. Because GKZ-N 00001 is the earliest fossil having been identified as a species of the sea lion genus *Eumetopias*, it is of importance to elucidate the evolutionary history of that genus. The morphometric comparisons were made among 51 mandibles of fur seals and sea lions with GKZ-N 00001. As results of bivariate analyses and PCA based on 39 measurements for external morphologies with internal structures by CT scan data, there is almost no difference between GKZ-N 00001 and extant male individuals of *E. jubatus*. In this regard, GKZ-N 00001 is identified specifically as the Steller sea lion *E. jubatus*. Consequently, it is recognized as the oldest Steller sea lion in the North Pacific. About 0.8 Ma, the distribution of the Steller sea lion had been already established at least in the Japan Sea side of the western North Pacific.

Section IX: Physiology

Castellini, J. M., Rea, L. D., Avery, J. P., & O'Hara, T. M. (2022). Total Mercury, Total Selenium, and Monomethylmercury Relationships in Multiple Age Cohorts and Tissues of Steller Sea Lions (*Eumetopias jubatus*). *Environmental Toxicology and Chemistry*, 41(6), 1477-1489. <https://doi.org/10.1002/etc.5329>

Steller sea lion (*Eumetopias jubatus*) tissue mercury concentrations increasingly above thresholds of concern occur in regions of Alaska where lack of population recovery is noted. Selenium-monomethylmercury interactions may mitigate toxicosis but may also result in functional selenium deficiency, impacting essential selenium-dependent processes. Physiologically driven differences in tissue concentrations (organotropism) of total mercury ([THg]), total selenium ([TSe]), and monomethylmercury ([MeHg+]) confound interpretation for various age cohorts. Archived tissues from Alaska Steller sea lions (2002-2016) were used to compare [THg], [MeHg+], and [TSe] across age cohorts and tissue types. Liver [THg] ranged from 0.05 to 63.7 $\mu\text{g/g}$. Fetal and pup livers had significantly lower [THg] and [TSe], higher percentage MeHg+, and greater range of molar TSe:THg than subadult and adult livers. Molar Se:MeHg+ ratios, including Se in excess of nonmethylmercury, were dependent on [MeHg+] in fetuses and pups. While [THg] varied significantly by muscle type (heart vs. skeletal) and anatomical location, concentrations were strongly correlated. Biomagnification and/or bioaccumulation of THg in liver of older animals confounded comparison with other tissues; however, in fetal and pup liver [THg] correlated with other tissues. In contrast, liver [MeHg+] correlated with other tissues across all age classes. Fetal and pup tissues, which reflect in utero exposure and are subject to limited bioaccumulation, are ideal for assessing mercury exposure related to dam diet, including intertissue comparison, and represent key cohorts of concern. Evaluating [MeHg+] and [TSe] in tissues from multiple age cohorts allows better intertissue comparison, providing insight into time courses, routes of exposure, and potential for adverse effects.

Crawford, S. G. (2021). *Fasting Status of Steller Sea Lion Pups*. (Master of Science M.S.), University of Alaska Fairbanks, Fairbanks, AK. Retrieved from <http://hdl.handle.net/11122/12913>

Following population declines in species of concern, wildlife managers often seek to identify underlying causes to understand and predict population dynamics for better future management. Often, physiological and/or behavioral metrics are measurable markers of decline, and these are often detectable well before declines are measurable through population surveys. During the 1970's, 80's, and 90's Steller sea lion (SSL; *Eumetopias jubatus*) populations in the western portion of their breeding range declined by ~85%. Though declines in most regions have since stabilized or exhibited modest recovery, some subpopulations breeding in the Aleutian Islands continue to decline. In contrast, SSL subpopulations in eastern regions of their range have steadily grown since the 1970s. Prior studies on the maternal attendance behaviors of SSL have noted differences in the timing of parturition, the duration of the perinatal period, foraging trip duration of nursing females, and the duration of periods dams spend ashore tending their pups. Variability in these metrics has been associated with year, location, the dam's age and parity, environmental oscillations (i.e. El Niño Southern Oscillation), and pup age over the lactation period. This study utilized prior findings of predictable changes in metabolite concentrations while pups fasted during their mother's foraging trips as a new approach for assessing maternal attendance patterns. The distributions of fasting phase categories, assigned based on the relative concentrations of plasma β -hydroxybutyrate and blood urea nitrogen, were compared across 12 subpopulations extending from eastern Russia along the coastal northern Pacific into southeastern

Alaska from blood samples of 1528 SSL pups. Fasting phase categories were merged into Short and Long fasting durations to compare pups sparing critical proteins (relying on lipid reserves) to those with plasma profiles indicative of metabolic protein reliance (muscle & organ breakdown), respectively. Notably the subpopulations with the maximal (western Aleutian Islands) and minimal (eastern Aleutian Islands) observed proportions of Long fasting pups were in the same broad Aleutian Island region. Three metapopulations had significantly greater proportions of Long fasting pups: the western and central Aleutian Islands and the southern portion of southeastern Alaska. Due to contrasting population trends among these metapopulations, we suggest that both density-dependent and density-independent factors contributed to extended fasting durations in SSL pups.

Gastaldi, A., Bishop, A., & Rea, L. D. (2023). How Small Can You Go? Using a Direct Mercury Analyzer to Measure Mercury in Vibrissae of Steller Sea Lions. *Marine Mammal Science*.
<https://doi.org/10.1111/mms.13003>

Mercury is a global pollutant that has known negative impacts on human and wildlife health and has been shown to biomagnify through marine food webs. Most of the mercury found in upper trophic level predators comes from dietary sources, and it bioaccumulates over the course of their lifetime. Many investigations of food web dynamics and dietary sources of mercury in wildlife populations have relied on measuring stable isotopes of carbon and nitrogen in tissues that reflect a brief period, such as blood, muscle, or fur in animals that molt annually. However, it is becoming more common for researchers to utilize slow-growing keratinized tissues to understand seasonal and long-term changes in marine mammal foraging behavior. Longitudinal sampling of stable isotopes has been shown to be effective in teeth, baleen, claws, and vibrissae (i.e., whiskers). Stable isotope measurements from slow-growing keratinized tissues not only provide greater temporal resolution of foraging and diet, but they can also be paired with other bioindicators of physiological state or health to understand more complex food-web dynamics in marine systems. For example, carbon and nitrogen stable isotope measurements have been paired with measurements of reproductive and stress hormones from claws of bearded (*Erignathus barbatus*) and ringed (*Pusa hispida*) seals to understand the connection between seasonal changes in diet, reproduction, and stress. Longitudinal sampling of stable isotopes has been successfully paired with sampling of mercury in baleen from two populations of bowhead whales (*Balaena mysticetus*), which demonstrated they forage year-round, though they consume more mercury during the summer months.

Hanke, F. D., Reichmuth, C., & Cook, P. (2021). The Sensory World of Otariids. In *Ethology and Behavioral Ecology of Otariids and the Odobenid*. C. Campagna & R. Harcourt (Eds.), (pp. 305-321). Cham: Springer International Publishing https://doi.org/10.1007/978-3-030-59184-7_16

Otariids face many unique challenges with respect to lifestyle and habitat. They need to find suitable foraging areas in the open ocean, detect and capture moving prey in near darkness, identify suitable mating partners in traditional terrestrial breeding areas, and relocate their pups following extended separations. Above all, otariids have to cope with the different physical properties of air and water. This chapter illustrates how the challenges of amphibious living have shaped the sensory systems considered to be the 'antennae' through which otariids gather information about the surrounding world. Our current understanding of the sensory capabilities of otariids comes from studies of both structure (anatomy, neurobiology) and function (sensitivity, performance) of specific sensory modalities. This information helps us to describe what the senses are specialized for and to identify the particular

biological tasks they are probably involved in. However, future studies need to explicitly link the senses, behavior, and ecology. Altogether, this knowledge will be informative to behavioral ecologists in their attempts to determine why an otariid behaves the way it does.

Hooker, S. K., Andrews, R. D., Arnould, J. P. Y., Bester, M. N., Davis, R. W., Insley, S. J., . . . McKnight, J. C. (2021). Fur Seals Do, but Sea Lions Don't — Cross Taxa Insights into Exhalation During Ascent from Dives. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 376(1830), 20200219. <https://doi.org/10.1098/rstb.2020.0219>

Management of gases during diving is not well understood across marine mammal species. Prior to diving, phocid (true) seals generally exhale, a behaviour thought to assist with the prevention of decompression sickness. Otariid seals (fur seals and sea lions) have a greater reliance on their lung oxygen stores, and inhale prior to diving. One otariid, the Antarctic fur seal (*Arctocephalus gazella*), then exhales during the final 50–85% of the return to the surface, which may prevent another gas management issue: shallow-water blackout. Here, we compare data collected from animal attached tags (video cameras, hydrophones and conductivity sensors) deployed on a suite of otariid seal species to examine the ubiquity of ascent exhalations for this group. We find evidence for ascent exhalations across four fur seal species, but that such exhalations are absent for three sea lion species. Fur seals and sea lions are no longer genetically separated into distinct subfamilies, but are morphologically distinguished by the thick underfur layer of fur seals. Together with their smaller size and energetic dives, we suggest their air-filled fur might underlie the need to perform these exhalations, although whether to reduce buoyancy and ascent speed, for the avoidance of shallow-water blackout or to prevent other cardiovascular management issues in their diving remains unclear. This article is part of the theme issue 'Measuring physiology in freelifving animals (Part I)'.

Isono, T., Kobayashi, Y., Burkanov, V. N., & Yamamura, O. (2019). Aging Steller Sea Lions by Growth Layer Groups in Teeth. *Wildlife Society Bulletin*, 43(2), 238-243. <https://doi.org/10.1002/wsb.965>

Accurate age determination of individuals is crucial in estimating age structure in populations as well as age-specific rates of reproduction and survival. We examined growth layer groups (GLGs) in the canine, incisor, and postcanine teeth of Steller sea lions (*Eumetopias jubatus*) to find the optimal method to determine their age using 18 known-age animals, from data collected in Hokkaido, Japan, 1995-2011. After checking to determine if the pulp cavity was open, nearly closed, or closed, teeth were sectioned and stained. Occlusion of the canine pulp cavity occurred at older ages than with the incisor and postcanine teeth. Initially, the number of GLGs in both dentin and cementum was compared with actual ages to confirm the age determination method. Dentin GLGs appeared clearly in all of the canines, incisors, and postcanines. The number of GLGs was consistent with the actual age, with the exception of teeth with a closed pulp cavity. With respect to cementum, appearance of GLGs was rather obscure and no GLG was detectable at ages of 0 and 1 year. Thus, the number of GLGs in cementum could be assigned as age when the value 1 year was added. We examined the accuracy and precision of the tested methods using an independent reader, who did not know the actual ages. By conducting readings 3 times, we used coefficient of variation (CV) to determine precision. The most precise CV was obtained in dentin canine (6.7%). Accuracy was calculated as proportion of estimates without error. The greatest accuracy in dentin was observed in canines (0.83, n = 18), whereas that of cementum was in postcanines (0.36, n = 11). We concluded that canine dentin provided the most precise and accurate ages for Steller

sea lions. Once closure of the pulp cavity in canines has occurred at the age of 15-16 years in males and 11-12 years in females, we recommend postcanine cementum be used.

Kennedy, S. N., Keogh, M., Levin, M., Castellini, J. M., Lian, M., Fadely, B. S., . . . Hara, T. M. O. (2021). Regional Variations and Relationships among Cytokine Profiles, White Blood Cell Counts, and Blood Mercury Concentrations in Steller Sea Lion (*Eumetopias jubatus*) Pups. *Science of the Total Environment*, 775. <https://doi.org/10.1016/j.scitotenv.2020.144894>

The Steller sea lion (SSL) population west of 144 degrees W longitude experienced a significant population decline. While there appears to be a stable or increasing population trend in rookeries in the Gulf of Alaska (GOA) and Southeast Alaska (SEA), some rookeries within the Aleutian Islands (AI) have failed to recover. Previous studies found regional differences in whole blood total mercury concentrations ([THg]) showing more than 20% of AI pups had [THg] above critical thresholds for increased risk of immunological effects and other adverse outcomes. Measurements of immune cell-signaling proteins can be used to evaluate the immune status of marine mammals in relation to [THg]. We compared serum cytokine and chemokine concentrations in pups among regions (AI, eastern GOA, SEA), and examined associations among cytokines, chemokines, white blood cell (WBC) counts, and [THg]. Considering liver is an important target organ for mercury and immune protein synthesis we additionally examined the relationship of [THg] with liver-related enzymes serum aspartate (AST) and alanine aminotransferase (ALT). We observed regional differences in cytokine and chemokine measurements and immune protein associations. There was a positive association between total WBC counts and [THg] in AI pups, whereas a negative association between lymphocytes and [THg] in SEA pups. These findings may indicate regional variation in proliferation and differentiation of hematopoietic cells, differences in immune system development, and/or a difference in antigenic stimuli. No associations between [THg] and cytokines, chemokines, AST or ALT were found. Observed regional differences in cytokine and chemokine milieu during gestational and early development in SSL pups could lead to an imbalance in cell differentiation that could impact immunological resiliency in juvenile and adult life stages. We report concentration ranges of a suite of cytokines and chemokines which may prove to be a useful metric for ecotoxicology and risk assessment studies in SSLs and other wildlife.

Keogh, M. J., Charapata, P., Fadely, B. S., Zeppelin, T., Rea, L., Waite, J. N., . . . Wooller, M. J. (2021). Whiskers as a Novel Tissue for Tracking Reproductive and Stress-Related Hormones in North Pacific Otariid Pinnipeds. *Conservation Physiology*, 9(1), coaa134. <https://doi.org/10.1093/conphys/coaa134>

Keratinized tissues, including whiskers, are ideal for acquiring a record of physiological parameters. Most tissues provide a snapshot of physiological status; however, whiskers may support longitudinal sampling for reproductive and stress-related hormones, if hormones are incorporated as whiskers grow and concentrations change with physiological state. Whiskers from female Steller sea lions (*Eumetopias jubatus*) and northern fur seals (*Callorhinus ursinus*) were serially sectioned and pulverized and steroid hormones were extracted. Standard methods were used to validate enzyme immunoassay kits for cortisol, progesterone, 17beta-estradiol and testosterone. All hormones were measurable in whisker segments from both species with progesterone concentrations showing cyclical patterns, which appear to signify previous pregnancies or luteal phases. Yearly progesterone concentrations were greater in years a pup was produced compared with years when no pup was observed. Free-ranging female Steller sea lions had reproductive rates between 0 and 1.0 (0.53 +/- 0.33, n = 12) using a yearly progesterone

concentration of 30 pg/mg or greater to classify a reproductive year as producing a pup and below 30 pg/mg as non-reproductive. Cortisol concentrations were greater near the root and rapidly declined, lacking any obvious patterns, throughout the rest of the whisker. Progesterone and testosterone concentrations were able to help determine sex of unknown individuals. Immunohistochemistry revealed that steroid hormones most likely do not leach out of whiskers based on the deposition patterns of progesterone and cortisol being present throughout the whisker length. Overall, measuring steroid hormones in whiskers can reveal individual reproductive histories over multiple years in sea lions and fur seals. Cyclical patterns of delta(15)N were useful for identifying periods of up to ~10 years of growth within whiskers, and measuring both stable isotopes and hormones may be useful for differentiating periods of active gestation from diapause and potentially track multi-year reproductive histories of female otariids.

Keogh, M. J., Gastaldi, A., Charapata, P., Melin, S., & Fadely, B. S. (2020). Stress-Related and Reproductive Hormones in Hair from Three North Pacific Otariid Species: Steller Sea Lions, California Sea Lions and Northern Fur Seals. *Conservation Physiology*, 8(1), coaa069. <https://doi.org/10.1093/conphys/coaa069>

Assessing the physiological impact of stressors in pinnipeds is logistically challenging, and many hormones are altered by capture and handling, limiting the utility of metabolically active tissues. Hair is increasingly being used to investigate stress-related and reproductive hormones in wildlife populations due to less-invasive collection methods, being metabolically inert once grown and containing multiple biomarkers of ecological interest. We validated enzyme immunoassays for measuring aldosterone, cortisol, corticosterone, and testosterone in lanugo (natal hair grown in utero) samples collected from Steller sea lions (*Eumetopias jubatus*), California sea lions (*Zalophus californianus*), and northern fur seals (*Callorhinus ursinus*). We applied laboratory validation methods including recovery of added mass, parallelism and dilution linearity. We found no effects due to differences in alcohol- versus detergent-based cleaning methods. Further, there were no significant differences in hormone concentrations in hair samples collected immediately after the molt and the subsequent samples collected over 1 year, indicating steroid hormones are stable once deposited into pinniped hair. We found no sex differences in any hormone concentrations, likely due to the lanugo being grown in utero and influenced by maternal hormone concentrations. For Steller sea lion and California sea lion pups, we found hormone concentrations significantly differed between rookeries, which warrants future research. Hair provides a novel tissue to explore the intrinsic or extrinsic drivers behind hormone measurements in otariids, which can be paired with multiple health-related metrics to further investigate possible drivers of physiological stress.

Keogh, M. J., Taras, B., Beckmen, K. B., Burek-Huntington, K. A., Ylitalo, G. M., Fadely, B. S., . . . Pitcher, K. W. (2019). Organochlorine Contaminant Concentrations in Blubber of Young Steller Sea Lion (*Eumetopias jubatus*) Are Influenced by Region, Age, Sex, and Lipid Stores. *Science of the Total Environment*, 698, 134183. <https://doi.org/10.1016/j.scitotenv.2019.134183>

Contaminant exposure is particularly important for species and populations of conservation concern, such as the Steller sea lion (*Eumetopias jubatus*). We used blubber samples (n = 120) to determine organochlorine concentrations, including polychlorinated biphenyls (PCBs) and dichloro-diphenyl-trichloroethane (DDTs), and blood samples (n = 107) to estimate total body lipids based on the hydrogen isotope dilution method. We assessed the influence of age, sex, condition, and geographic area on

contaminant concentrations in blubber and contaminant body load. The concentration of Σ PCBs was highest in pups (<6 months) from the Aleutian Islands, and the concentrations in males were higher than females in all regions. The Σ PCBs and Σ DDTs concentrations and loads decreased with increasing mass in pups, however, there were no regional or sex differences in contaminant load. Within each of the five age classes, the concentrations of Σ PCBs and Σ DDTs decreased with increasing mass, but overall these OCs increased with age. Further, accounting for the lipid content, a potential proxy for energy balance, in the animal load reduced or removed the regional and sex effects present in age models for contaminants. We propose, that adjusting OCs concentration by the lipid content of the blubber sample alone may not fully account for the variability in OC concentrations associated with differences in condition or energy states between young Steller sea lions.

Keogh, M. J., Taras, B. D., Eischens, C., Kennish, J. M., Fadely, B. S., & Rea, L. D. (2019). Variation in Milk, Serum, and Blubber Fatty Acids in Young, Free-Ranging Steller Sea Lions. *Marine Mammal Science*, 35(3), 909-933. <https://doi.org/10.1111/mms.12574>

We determined the fatty acid signatures in milk, serum, and blubber samples collected from young free-ranging Steller sea lions (*Eumetopias jubatus*) and investigated the partitioning of fatty acids among these matrices. We assessed the relationship of fatty acids in each matrix with region, age, season, sex, and body condition to gain information needed to determine the most appropriate type of samples to collect and analyze to address future research questions. The variability of fatty acid composition was almost entirely explained by sample type, highlighting the importance of selecting a matrix consistent with the study objectives. Regional differences in fatty acid composition were found in all sample types and these differences varied among matrices. The proportion of fatty acids in milk and serum were influenced by season of capture whereas blubber samples were more affected by age of the pup. The influence of season on the fatty acid signatures in milk and serum highlights the use of these samples over blubber in studies investigating seasonal changes in diet. Further, our findings suggest that the use of milk samples collected from the stomachs of pups may be a viable alternative to directly collecting milk from adult females.

Kot, C. C. S., Arzi, B., Evenhuis, J. V., Kass, P. H., & Verstraete, F. J. M. (2022). Dental and Temporomandibular Joint Pathology of the Steller Sea Lion (*Eumetopias jubatus*). *Journal of Comparative Pathology*, 199, 23-36. <https://doi.org/10.1016/j.jcpa.2022.09.002>

Skulls from 112 Steller sea lions (*Eumetopias jubatus*) were examined according to predefined criteria. Of the specimens, 73 (65.2%) were from males, 29 (25.9%) from females and 10 (8.9%) were of unknown sex, with 50 adults (44.6%), 61 young adults (54.5%) and one of unknown age (0.9%). The number of teeth evaluated was 3,521. Adults had more acquired tooth loss than young adults ($P < 0.0001$). A total of 1,660 teeth (47.1%) from 111 specimens (99.1%) had evidence of attrition or abrasion. Adults displayed more attrition or abrasion than young adults ($P < 0.0001$). A total of 241 teeth (6.8%) from 47 specimens (42%) had tooth fractures. Adults had more fractured teeth than young adults ($P < 0.0001$). Bony changes consistent with periodontitis affected 36.7% of teeth. Adults had more teeth affected by periodontitis than young adults ($P < 0.0001$). Temporomandibular joint osteoarthritis lesions were found in 54 specimens (48.2%) with more in adults than in young adults ($P < 0.0001$). Although the significance of our findings is unknown, the occurrence and severity of these lesions may play an important role in the morbidity and mortality of Steller sea lions.

Legacki, E., Sattler, R., & Conley, A. (2022). Longitudinal Patterns in Progesterone Metabolites in Pregnant and Non-Pregnant Steller Sea Lions (*Eumetopias jubatus*). *General and Comparative Endocrinology*, 326, 114069-114069. <https://doi.org/10.1016/j.ygcen.2022.114069>

Similar to the several pinniped and a few terrestrial carnivore species, the Steller sea lion has a seasonal synchronized mating scheme enabled by a female reproductive cycle that includes embryonic diapause, delayed implantation, and pseudopregnancy (a state in which the corpus luteum produces progesterone for approximately as long as in pregnant females). Due to this, circulating systemic progesterone concentrations cannot be used to differentiate pregnant and nonpregnant females during early gestation. With the use of advanced measurement technologies such as liquid chromatography tandem mass spectrometry (LC-MS/MS) additional steroid hormones are measurable which can provide additional information on the endocrine pathways throughout gestation. Our objectives were to further characterize endocrine patterns in female Steller sea lion pregnancy by 1) quantifying longitudinal profiles of hormone metabolites in pregnant and non-pregnant female sera, and 2) evaluating hormone profiles to identify pregnant animals within the early stage of gestation. Three gestation stages were delineated based on what is believed to be the period of implantation (September-October): EARLY (August- November), MID (December-February), and LATE (March to May). Five steroids, Progesterone (P4), 5alpha-dihydroprogesterone (DHP), 17alphaOH-progesterone (17OHP), 20alphaOH-progesterone (20OHP), and androstenedione (A4), were detected in both pregnant and non-pregnant animals. A significant difference in P4 concentrations was measured between EARLY and MID gestation ($p \leq 0.01$) in both pregnant and non-pregnant animals. During MID gestation there was a significant difference ($p \leq 0.05$) between pregnant and non-pregnant animals in all pregnancies measured. Significant patterns of correlation between P4 and 17OHP and between P4 and DHP were detected during EARLY and MID gestation in non-pregnant animals. While those significant correlations also exist in EARLY pregnant animals, this pattern was lost by MID gestation. This loss of correlation suggests a potential shift in progesterone metabolism from ovarian to alternative tissue (e.g. fetal gonads or adrenal glands) by MID gestation in Steller sea lions. We were unable to identifying a steroid hormone biomarker capable of differentiating pseudopregnancy from pregnant animals and conclude that such a biomarker likely falls outside of the traditional progesterone metabolic pathway.

Levin, M., Jasperse, L., Desforges, J. P., O'Hara, T., Rea, L., Castellini, J. M., . . . Keogh, M. (2020). Methyl Mercury (MeHg) in Vitro Exposure Alters Mitogen-Induced Lymphocyte Proliferation and Cytokine Expression in Steller Sea Lion (*Eumetopias jubatus*) Pups. *Science of the Total Environment*, 725, 138308. <https://doi.org/10.1016/j.scitotenv.2020.138308>

Steller sea lions (*Eumetopias jubatus*, SSLs) are managed as two distinct population segments within U.S. waters: the endangered western distinct population segment and the recently delisted eastern distinct population segment. Recent studies reported concentrations of mercury in several tissues collected from young SSLs in the Aleutian Islands that were at or above concentrations found to negatively impact health in other fish-eating mammals. However, there are limited studies which have investigated the range of mercury concentrations that may negatively influence the SSL immune system. This study assessed relationships between methyl mercury (MeHg(+)) concentrations and two immune functions, lymphocyte proliferation and cytokine expression. Peripheral blood mononuclear cells (PBMCs) were isolated and cryopreserved from pups on three rookeries within the western distinct population segment: Chiswell Island, Ulak, and Agattu Islands. Lymphocyte proliferation and cytokine expression were assessed in vitro using thawed PBMCs with exposure to MeHg(+) (unexposed control, 0.001, 0.01, and 0.1 mug/ml). Lymphocyte proliferation was measured without and with stimulation with a T cell

mitogen (ConA) and B cell mitogen (LPS) and the concentration of cytokines was measured in the cell culture supernatant (with and without ConA or LPS). Spontaneous lymphocyte proliferation was significantly increased at 0.01 and 0.1 mug/ml. T lymphocyte proliferation was significantly increased at 0.001 mug/ml and 0.1 mug/ml, while B lymphocyte proliferation was decreased at 0.1 mug/ml. Cytokine concentrations for INFgamma, IL-10, IL-6, and TNFalpha were reduced at 0.1 mug/ml upon either T or B cell mitogen stimulation, with the exception for IL-10, where 0.1 mug/ml reduced IL-10 concentration compared to unstimulated cells. These data suggest immune functions were affected by MeHg(+) exposure requiring in vivo follow up investigations. The observed modulation of immune functions is of concern as any toxicant-induced modulation may adversely affect the health of individuals, particularly younger animals undergoing periods of critical development.

Li, G., Suzuki, H., Takei, J., Saito, M., Goto, N., Uchida, K., . . . Kato, Y. (2022). Immunohistochemical Analysis Using Monoclonal Antibody Pmab-269 against Steller Sea Lion Podoplanin. *Monoclonal antibodies in immunodiagnosis and immunotherapy*, 41(1), 39-44.
<https://doi.org/10.1089/mab.2021.0055>

Monoclonal antibodies (mAbs) that specifically target podoplanin (PDPN), a marker for type I alveolar cells, are required for immunohistochemical analyses. Anti-PDPN mAbs are available for many species, including human, mouse, rat, rabbit, dog, cat, bovine, pig, Tasmanian devil, alpaca, tiger, whale, goat, horse, bear, sheep, and California sea lion PDPNs. However, no anti-Steller sea lion PDPN (stePDPN) antibody has been developed. Immunohistochemical analysis showed that an anti-California sea lion PDPN mAb (PMab-269) reacted with type I alveolar cells from the Steller sea lion lung, renal glomeruli and Bowman's capsules from kidney, and lymphatic endothelial cells from the colon, indicating that PMab-269 is useful for detecting stePDPN.

Lian, M., Castellini, J. M., Kuhn, T., Rea, L., Bishop, L., Keogh, M., . . . O'Hara, T. (2020). Assessing Oxidative Stress in Steller Sea Lions (*Eumetopias jubatus*): Associations with Mercury and Selenium Concentrations. *Comparative Biochemistry and Physiology, Part C*, 235, 108786.
<https://doi.org/10.1016/j.cbpc.2020.108786>

Selenium (Se) bioavailability is required for synthesis and function of essential Se-dependent antioxidants, including the enzyme glutathione peroxidase (GPx). Strong interactions between monomethyl mercury and Se impair the critical antioxidant role of Se. Approximately 20% of Steller sea lion (*Eumetopias jubatus*, SSL) pups sampled in the western Aleutian Islands, Alaska, had total Hg concentrations ([THg]) measured in hair and whole blood above thresholds of concern for adverse physiologic effects in pinnipeds. Importantly, low molar ratios of TSe:THg, in some cases < 1 in several tissues (hair, liver, pelt, muscle, spleen, intestine, heart, lungs, brain) were documented for one SSL pup with [THg] above threshold of concern, which may lead to antioxidant deficiency. Our aim with this study was to evaluate the relationship between circulating [THg], [MeHg(+)], [TSe] and TSe:THg molar ratio status relative to oxidative stress and antioxidants measured during general anesthesia in free-ranging SSL. We captured, anesthetized and sampled newborn SSL pups at rookeries located in the Aleutian Islands or Gulf of Alaska. Biomarkers analyzed for oxidative stress included 4-hydroxynonenal and thiobarbituric acid reactive substances (4-HNE and TBARS, respectively, lipid peroxidation), protein carbonyl content (PCC, protein oxidation), and GPx activity as a key indicator for Se-dependent antioxidant defense levels. We found a negative association between TBARS and [TSe], and SSL with low

[TSe] had higher concentrations of 4-HNE than those with intermediate [TSe]. These results suggest that SSL with lower [TSe] experience increased lipid peroxidation potentially associated with [THg] status.

Milne, A. O. (2019). *Active Touch Sensing in Pinnipeds*. (Doctor of Philosophy), Manchester Metropolitan University, Manchester, United Kingdom. Retrieved from <https://e-space.mmu.ac.uk/624791/>

Active touch sensing in humans is characterised by making purposive movements with their fingertips. These movements are task-specific to maximise the relevant information gathered from an object. In whisker-touch sensing, previous research has suggested that whisker movements are purposive, but no one has ever examined task-specific whisker movements in any animal. Pinnipeds are whisker specialists, with long, mobile, sensitive whiskers and diverse whisker morphologies. The aim of this PhD is to investigate active touch sensing in Pinnipeds (seals, sea lions and walrus), by: i) describing whisker morphology; ii) comparing and quantifying whisker movements; and iii) characterising task-dependency of whisker movements during texture, size and luminance discrimination tasks. Pinnipeds with long, numerous whiskers, such as California sea lions (*Zalophus californianus*) and Stellar sea lions (*Eumetopias jubatus*) have larger infraorbital foramen (IOF) sizes and therefore, more sensitive whiskers. The IOF being a small hole in the skull, allowing the infraorbital nerve (ION) to pass through, which supplies sensation to the whiskers. Comparing whisker movements in Harbor seals (*Phoca vitulina*), California sea lions and Pacific walrus (*Odobenidae rosmarus*), showed these species all protracted their whiskers forwards and oriented their head towards a moving fish stimulus. However, California sea lions moved their whiskers more than the other species, and independently of the head. Due to the movement capabilities and sensitivity of whiskers in California sea lions, this species was used to investigate whether whiskers can be moved in a task-specific way. Results suggested that California sea lions make task-specific movements, by feeling around the edge of different-sized shapes, and focussing and spreading their whiskers on the centre of different-textured shapes. Therefore, California sea lion whiskers are controlled like a true active touch sensory system, similar to human fingertips. I suggest that active touch sensing is likely to efficiently guide foraging and prey capture in dark, murky waters in these animals. Moreover, the complexity of California sea lion whisker movements and their subsequent behaviours makes them a good candidate from which to further investigate animal decision-making, perception and cognition.

Purdy, A. S. (2019). *Post-Dive Gas Recovery and the Transition between Metabolic States as Physiological Limits to Diving in Steller Sea Lions (Eumetopias jubatus)*. (Master of Science Text), The University of British Columbia, Vancouver, Canada. Retrieved from <https://open.library.ubc.ca/collections/24/items/1.0378507>

Marine mammal diving behaviour is influenced by multiple physiological processes, both at depth and at the surface. To date, the majority of research in diving physiology has focused solely on how quickly marine mammals utilize their O₂ during a dive, as seen in the numerous studies of the aerobic dive limit (ADL) and calculated aerobic dive limit (cADL). In this thesis I investigated other physiological limits, namely how long it takes for marine mammals to recover after a dive, and how these animals transition between aerobic and anaerobic metabolism at depth. Specifically, I 1) determined how post-dive rates of O₂ and CO₂ gas exchange are affected by dive behaviour, and 2) measured how lactate accumulates with increased dive time, and examined how this indicator of metabolic transition affected post-dive recovery times. To measure gas exchange, I used flow-through respirometry to determine the time required for Steller sea lions (*Eumetopias jubatus*) to reach within 5% of stable rates of O₂ uptake and

CO₂ excretion following a dive. These times were interpreted as the O₂ and CO₂ recovery times, respectively. CO₂ recovery time was longer and became more extended with increasing dive time when compared to O₂, requiring an extra 44 sec per minute submerged for CO₂ as opposed to 33 sec per minute submerged for O₂. This indicates that recovery time was limited by CO₂ as opposed to O₂, and this difference became greater with increased dive time. Contrary to traditional models, plasma lactate concentration was present even after short dives, and increased linearly with dive duration. Neither O₂ nor CO₂ recovery rates were affected by levels of blood lactate. This indicates that anaerobic metabolism may be used long before the body's total O₂ -stores have been consumed. These results support the idea that there is not a distinct threshold between aerobic and anaerobic pathways, but rather a progressive transition, which casts doubt on the usual interpretations of the ADL and cADL. My thesis challenges long-held assertions in diving physiology, and underlines the need to further examine how CO₂ and lactate accumulation may act as limits to diving behaviour.

Rea, L. D., Castellini, J. M., Avery, J. P., Fadely, B. S., Burkanov, V. N., Rehberg, M. J., & O'Hara, T. M. (2020). Regional Variations and Drivers of Mercury and Selenium Concentrations in Steller Sea Lions. *Science of the Total Environment*, 744, 140787. <https://doi.org/10.1016/j.scitotenv.2020.140787>

Mercury (Hg) can be neurotoxic to mammals and impact reproduction, whereas selenium (Se) is an important antioxidant known to ameliorate some adverse effects of Hg. Total Hg concentrations ([THg]) were measured in lanugo (pelage grown in utero) of 812 Steller sea lion (*Eumetopias jubatus*) pups across Alaska and Russia to assess fetal exposure during late gestation. The molar ratio of total Se to THg (TSe:THg) was determined in whole blood collected from 291 pups. Stable isotope ratios of carbon and nitrogen were measured in sections of vibrissae (whiskers, n = 498) and in lanugo (n = 480) of pups grown during late gestation to track diet variations among adult females that can drive Hg and Se exposure during this critical fetal development period. Lanugo [THg] ranged from 1.4 to 73.7 µg/g dry weight with the lowest median [THg] in Southeast Alaska. Pups from the Western Aleutian Islands had higher median lanugo [THg] than pups from other metapopulations in Alaska. Over 25% of pups in the Western Aleutian Islands had [THg] above published risk thresholds (20 µg/g) for other mammals. Whole blood molar TSe:THg was significantly lower in the Western Aleutian Islands and in some parts of the Central Aleutian Islands with higher molar ratios found in the Eastern Aleutian Islands and Central Gulf of Alaska. This suggests a limitation on potential protective functions of Se in the western regions with the highest relative [THg]. The Central Aleutian Island pups with [THg] over 20 µg/g had higher delta(15)N ratios than pups with lower [THg] suggesting dams consuming higher trophic level prey is a key driver for Hg exposure. However, regional differences likely reflect variability in diet of the dam during gestation and in Hg food web dynamics between oceanic regimes east and west of key passes in the Aleutian Islands.

Rea, L. D., Castellini, J. M., Avery, J. P., Fadely, B. S., Burkanov, V. N., Rehberg, M. J., & O'Hara, T. M. (2022). Corrigendum to "Regional Variations and Drivers of Mercury and Selenium Concentrations in Steller Sea Lions" [Sci. Total Environ. 744 (2020) 140787]. *Science of the Total Environment*, 831, 154887. <https://doi.org/10.1016/j.scitotenv.2022.154887>

The authors regret that the printed version of the above article contained an omission of detail regarding methods. The correct and final version follows. The authors would like to apologise for any inconvenience caused. In our original submission we included analysis of whole blood [TSe] and molar

TSe:THg collected from Steller sea lion pups (SSL) over several years (2011–2015) from a number of rookeries from the Central Gulf of Alaska and the Eastern, Central, and Western Aleutian Islands (EAI, CAI, and WAI, respectively). The chemical and data analyses were conducted in batches over several years. Unfortunately, when the manuscript was written we unintentionally overlooked that we had applied a correction factor to some data when describing the methods. We present the following addendum to the manuscript to correct that omission and so the data can be understood within that context. We also present further analysis, removing all adjusted data, to confirm our original conclusions with respect to regional differences in SSL whole blood [TSe] and molar TSe:THg.

Rea, L., Ylitalo, G., Crawford, S., Taras, B., Fadely, B., Rehberg, M. J., & O'Hara, T. (2023). One Health, Spatial, and Cumulative Organochlorines and Mercury Exposure Assessment in Steller Sea Lions of Alaska: Emphasizing Pups. *SSRN*. <https://doi.org/10.2139/ssrn.4073277>

Steller sea lion (SSL) contaminants research is an important North Pacific Ocean sentinel approach for examining conservation concerns and food webs. Some SSL rookeries not recovering from population declines (e.g., Western Aleutian Islands; WAI) have relatively higher organochlorine (OCs) and total mercury (THg) tissue concentrations. We assess some drivers (e.g., lipids, location) of OCs and THg cumulative exposure. Pups had significantly higher mean whole blood concentrations of summed chlordanes (Σ CHLDs), DDTs (Σ DDTs) and polychlorinated biphenyls (Σ PCBs) than adult females; some pups had Σ PCBs > 8,600 ng/g lw (threshold of concern). Lipid classes proportions were significant factors for whole blood OC concentrations. Adult female blubber Σ DDT and summed hexachlorocyclohexane concentrations positively correlated with δ 15 N values (trophic level). Top models for Σ DDTs, Σ PCBs, and Σ CHLDs identified regional effects, with each class greater in WAI SSL pups. Young pup whole blood PCB concentrations were significantly affected by δ 15 N, and location as well for PCBs 138 and 153. Concurrently higher exposure to multiple contaminants was documented, with many significant, relative to thresholds, indicating numerous pups (most WAI) with elevated blood concentrations for THg, PCBs, or both. We conclude contaminant exposure of WAI SSLs is of concern requiring cumulative exposure perspectives and risk assessment.

Sattler, R., Bishop, A., & Polasek, L. (2020). Cortisol Levels for Pregnant and Non-Pregnant Steller Sea Lions (*Eumetopias jubatus*) in Human Care. *Aquatic Mammals*, 46(2), 146-151. <https://doi.org/10.1578/Am.46.2.2020.146>

While a considerable amount of research has gone into investigating stress responses in wild populations or in controlled laboratory experiments, animals housed in artificial habitats, such as those in zoos and aquaria, are exposed to a myriad of potentially stress-inducing stimuli, yet little is known about stress responses in these environments. Stressful stimuli may be abiotic (i.e., artificial lighting, unnatural sounds, odors, or temperatures) or confinement-specific (i.e., maintenance in abnormal social groups, restrictions on movement and breeding behaviors, and accessible retreat space). An acute stress response can result in behavioral alterations in locomotion, increased alertness, and vigilance or physiological symptoms such as increased breathing, heart rate, and release of glucocorticoid isomers. Additionally, many zoo and aquarium animals are involved in research and undergo routine veterinary health exams, both of which often require repeat sampling, potentially further compounding a stress load. The capture and restraint techniques used in these sampling events can have different impacts on individual serum or plasma cortisol levels—measures that are commonly used as an index of acute stress response in mammals in relation to capture and handling. Steller sea lions (*Eumetopias jubatus*)

are the largest of the otariid pinnipeds, and there are currently fewer than 20 individuals in human care in North America. Though several of these individuals have participated in extensive research on energetics and nutrition under a collaboration between the Vancouver Aquarium and the University of British Columbia and on reproductive physiology at the Alaska SeaLife Center partnering with the University of Alaska Fairbanks, there is little information on baseline cortisol levels associated with research activities, breeding, or pregnancy. Therefore, having reference information, even from a small sample, can be valuable for the continued care, directed research, and health of marine mammals under human care.

Shero, M. R., Reiser, P. J., Simonitis, L., & Burns, J. M. (2019). Links between Muscle Phenotype and Life History: Differentiation of Myosin Heavy Chain Composition and Muscle Biochemistry in Precocial and Altricial Pinniped Pups. *Journal of Comparative Physiology B*, 189(6), 717-734. <https://doi.org/10.1007/s00360-019-01240-w>

In marine mammals, muscular development has been identified as a rate-limiting factor in achieving adult dive capacities. This study investigates the rate that myosin heavy chain (MHC) composition matures in a postural and locomotor skeletal muscle for four pinniped species with different lactation lengths: hooded seals, *Cystophora cristata*; harp seals, *Pagophilus groenlandicus*; northern fur seals, *Callorhinus ursinus*, and Steller sea lions, *Eumetopias jubatus*. The ontogeny of MHC isoform expression was compared with developmental rates of myoglobin concentrations, and aerobic (citrate synthase, beta-hydroxyacyl-CoA dehydrogenase) and anaerobic (lactate dehydrogenase) enzyme activities. Within taxonomic families, species with shorter lactation periods had more mature muscles biochemically at birth, and fiber types differentiated earlier during ontogeny (*Phocidae*: hooded > harp seals, *Otariidae*: northern fur seals > Steller sea lions). Northern fur seal neonates had the most phenotypically-mature muscles in this study, with no immature MHC isoforms. The relationship between muscle biochemistry and MHC composition became more pronounced with age, and developed to reflect swimming mode and activity levels. In adults, phocids had more slow-twitch oxidative protein in their primary locomotor muscle, the Longissimus dorsi (LD), than otariids which likely reflects oxygen-sparing strategies for the phocids' longer dives. Conversely, northern fur seal muscles had higher proportions of fast-twitch MHCs in the Pectoralis and LD, likely indicative of this species' smaller size and higher mass-specific metabolic rates. Thus, muscle phenotype is linked with species life history, and a mismatch between muscle biochemistry and MHC composition at weaning has important implications for the first year of independent foraging in pinniped pups.

Storlund, R. (2019). *Evaluating Cardiac Form and Function in Marine Mammals*. (Master of Science), The University of British Columbia, Vancouver, Canada. Retrieved from <https://open.library.ubc.ca/collections/24/items/1.0376806>

The hearts of marine mammals frequently sustain marked changes in heart rate and vascular resistance when diving. However, it is not known how marine mammal hearts facilitate these changes. I examined cardiac function and electrical activity of marine mammal hearts to understand how they might differ from terrestrial mammals. I measured electrocardiographic parameters in 8 Steller sea lions, 5 northern fur seals, and 1 walrus—and echocardiographic function in all 8 Steller sea lions. I also compiled electrocardiographic parameters from 17 species of marine mammals (including my measurements) for comparison with 50 species of terrestrial mammals. I found that atrial and ventricular depolarization are slower in marine mammals after accounting for differences in body mass—and that the left ventricle of

Steller sea lions contracts less than expected for a mammal of that size. These differences in cardiac timing and function may reflect specialized adaptations for diving. Electrocardiographic measurements of Steller sea lions, northern fur seals, and a walrus also varied between species and among the individuals of each species. For example, sinus arrhythmias occurred in 5 out of 8 individual Steller sea lions, but not in northern fur seals or the walrus. Mean electrical axes were also unique to each individual and varied greatly. Measurements ranged from -124° to 80° —with 3 of the Steller sea lions having extreme right axis deviation (-111° to -124°). Echocardiographic measurements showed that left ventricular form was similar between Steller sea lions and terrestrial mammals, except that Steller sea lions have larger aortic roots and larger left ventricular end-systolic dimensions than terrestrial mammals. Overall, my results show that marine mammals have functionally similar hearts to terrestrial mammals with a number of notable differences that likely support anatomical adaptations to diving.

Storlund, R. L., Rosen, D. A. S., Margiocco, M., Haulena, M., & Trites, A. W. (2021). Cardiac Examinations of Anesthetized Steller Sea Lions (*Eumetopias jubatus*), Northern Fur Seals (*Callorhinus ursinus*), and a Walrus (*Odobenus Rosmarus*). *Journal of Zoo and Wildlife Medicine*, 52(2), 507-519.
<https://doi.org/10.1638/2020-0054>

Pinniped hearts have been well described via dissection, but in vivo measurements of cardiac structure, function, and electrophysiology are lacking. Electrocardiograms (ECGs) were recorded under anesthesia from eight Steller sea lions (*Eumetopias jubatus*), five northern fur seals (*Callorhinus ursinus*), and one walrus (*Odobenus rosmarus*) to investigate cardiac electrophysiology in pinnipeds. In addition, echocardiograms were performed on all eight anesthetized Steller sea lions to evaluate in vivo cardiac structure and function. Measured and calculated ECG parameters included P-wave, PQ, QRS, and QT interval durations, P-, R-, and T-wave amplitudes, P- and T-wave polarities, and the mean electrical axis (MEA). Measured and calculated echocardiographic parameters included left ventricular internal diameter, interventricular septum thickness, and left ventricular posterior wall thickness in systole and diastole (using M-mode), left atrium and aortic root dimensions (using 2D), and maximum aortic and pulmonary flow velocities (using pulsed-wave spectral Doppler). ECG measurements were similar to those reported for other pinniped species, but there was considerable variation in the MEAs of Steller sea lions and northern fur seals. Echocardiographic measurements were similar to those reported for southern sea lions (*Otaria liavenscens*), including five out of eight Steller sea lions having a left atrial to aortic root ratio <1 , which may indicate that they have an enlarged aortic root compared to awake terrestrial mammals. Isoflurane anesthesia likely affected some of the measurements as evidenced by the reduced fractional shortening found in Steller sea lions compared to awake terrestrial mammals. The values reported are useful reference points for assessing cardiac health in pinnipeds under human care.

Valenzuela-Toro, A. M., Mehta, R., Pyenson, N. D., Costa, D. P., & Koch, P. L. (2023). Feeding Morphology and Body Size Shape Resource Partitioning in an Eared Seal Community. *Biology letters*, 19(3).
<https://doi.org/10.1098/rsbl.2022.0534>

Body size and feeding morphology influence how animals partition themselves within communities. We tested the relationships among sex, body size, skull morphology and foraging in sympatric otariids (eared seals) from the eastern North Pacific Ocean, the most diverse otariid community in the world. We recorded skull measurements and stable carbon ($\delta C-13$) and nitrogen ($\delta N-15$) isotope values (proxies for foraging) from museum specimens in four sympatric species: California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*) and

Guadalupe fur seals (*Arctocephalus townsendi*). Species and sexes had statistical differences in size, skull morphology and foraging significantly affecting the delta C-13 values. Sea lions had higher delta C-13 values than fur seals, and males of all species had higher values than females. The delta N-15 values were correlated with species and feeding morphology; individuals with stronger bite forces had higher delta N-15 values. We also found a significant community-wide correlation between skull length (indicator of body length), and foraging, with larger individuals having nearshore habitat preferences, and consuming higher trophic level prey than smaller individuals. Still, there was no consistent association between these traits at the intraspecific level, indicating that other factors might account for foraging variability.

Wolsan, M., Suzuki, S., Asahara, M., & Motokawa, M. (2019). Dental Integration and Modularity in Pinnipeds. *Scientific Reports*, 9, 4184-4184. <https://doi.org/10.1038/s41598-019-40956-1>

Morphological integration and modularity are important for understanding phenotypic evolution because they constrain variation subjected to selection and enable independent evolution of functional and developmental units. We report dental integration and modularity in representative otariid (*Eumetopias jubatus*, *Callorhinus ursinus*) and phocid (*Phoca largha*, *Histiophoca fasciata*) species of Pinnipedia. This is the first study of integration and modularity in a secondarily simplified dentition with simple occlusion. Integration was stronger in both otariid species than in either phocid species and related positively to dental occlusion and negatively to both modularity and tooth-size variability across all the species. The canines and third upper incisor were most strongly integrated, comprising a module that likely serves as occlusal guides for the postcanines. There was no or weak modularity among tooth classes. The reported integration is stronger than or similar to that in mammals with complex dentition and refined occlusion. We hypothesise that this strong integration is driven by dental occlusion, and that it is enabled by reduction of modularity that constrains overall integration in complex dentitions. We propose that modularity was reduced in pinnipeds during the transition to aquatic life in association with the origin of pierce-feeding and loss of mastication caused by underwater feeding.

Yoshida, M., Miyoshi, K., Tajima, T., Wada, A., Ueda, H., & Kooriyama, T. (2022). Anatomical Features of Ossa Cordis in the Steller Sea Lion. *Journal of Veterinary Medical Science*, 84(5), 660-665. <https://doi.org/10.1292/jvms.21-0261>

Irregular triangular cartilage or bone fragments are sometimes found in the fibrous triangle of the heart. Ossa cordis and/or cartilago cordis has been demonstrated in various terrestrial animal species. Regarding marine mammals, sperm whales lack heart bones, and there have been no studies on bones or cartilage in pinniped hearts. Therefore, we examined the ossa cordis and/or cartilago cordis of the Steller sea lion. Eleven Steller sea lion hearts were examined morphologically and histologically. Before dissection, some hearts were imaged by CT to confirm the presence of ossa cordis or cartilago cordis. As a result, ossa cordis-like fragments were confirmed in four adults and one pup. All of the fragments were found at the right fiber triangle, and one adult had ossified tissue, including adipose tissue in the bone marrow cavity. The ossa cordis probably support the aorta because they surround the aorta as in other terrestrial animals. Steller sea lions can dive to a few hundred meters, but they need to rest on land frequently. Hence, their ossa cordis help maintain heart function during the tachycardia that occurs upon repeated surfacing and movements on land after diving in water.

Section X: Predation

Bishop, A. M., Brown, C. L., Sattler, R., & Horning, M. (2020). An Integrative Method for Characterizing Marine Habitat Features Associated with Predation: A Case Study on Juvenile Steller Sea Lions (*Eumetopias jubatus*). *Frontiers in Marine Science* 7. <https://doi.org/10.3389/fmars.2020.576716>

Characterizing the habitat associated with predation events can inform on predator-prey dynamics. Despite being evaluated extensively in terrestrial systems, quantifying and characterizing the role predation plays in upper trophic marine ecosystems is challenging due to the cryptic nature of pelagic predators and the difficulty of observing predatory behavior. We developed a multi-step method to characterize habitat associated with predation that integrates data from post-mortem pop-up style mortality transmitters, and data from traditional external tracking devices, both of which use the Argos satellite system. In our case study with juvenile Steller sea lions (SSL, *Eumetopias jubatus*) in the Gulf of Alaska, 20 mortality events were previously described, of which 18 were attributed to predation. The locations of 13 of these at-sea predation events with post-mortem tracking data were estimated, with spatial uncertainty calculated using movement-based approaches of backwards step-length and state-space modeling. We then generated a Mortality Occurrence Probability Distribution (MOPD), resampled points within the MOPD based on isopleth weighting, and extracted habitat variables (i.e., slope, depth, distance to haulout-rookery) associated with these locations. This final dataset represented "case" points (n = 115) in terms of predation and was compared to the habitat associated with "control" points (n = 1000), locations within juvenile SSL distribution in this region (i.e., population home range), in a resource-selection function (GAM). Predation events were associated with habitats characterized by greater depths and moderate distances from SSL haulouts and rookeries. This information enabled us to generate a risk-map for juvenile SSL in the Gulf of Alaska, spatially representing areas of high predation probability. Our study provides important information about threats to this vulnerable age-class, and establishes a novel approach to characterizing risk in marine ecosystems that can be applied to other management and ecosystem concerns.

Bishop, A. M., Dubel, A. K., Sattler, R., Brown, C. L., & Horning, M. (2019). Wanted Dead or Alive: Characterizing Likelihood of Juvenile Steller Sea Lion Predation from Diving and Space Use Patterns. *Endangered Species Research*, 40, 357-367. <https://doi.org/10.3354/esr00999>

Understanding linkages between behaviors and mortality risk is critical for managing populations. Juveniles constitute a particularly vulnerable life stage, with growing evidence that within stages, individual strategies may be associated with greater predation risk and mortality. These forms of predator-prey dynamics are rarely explored in marine environments due to difficulties in confirming vital status of individuals, and the lack of data sets that link mortality to behavior. We analyzed 2 concurrently collected data sets for juvenile Steller sea lions *Eumetopias jubatus* in the Gulf of Alaska to examine associations between mortality and specific behavioral patterns. Forty-five juvenile Steller sea lions were instrumented with external satellite tags and internally implanted vital rate transmitters (LHX tags). From 2005 through 2018, 25 juveniles remained alive and 20 died (18 confirmed predation). Using a binomial generalized linear mixed-effects model, we tested whether the probability of individual mortality was associated with seasonally specific dive patterns (time wet, dive depth) or horizontal movement patterns (home range size, average trip distance). Additionally, in 3 cases, external tags were transmitting until death. To examine links between fine-scale ante-mortem behavioral patterns and predation susceptibility, we compared dive patterns recorded during the last 3 d of data transmissions (both for animals which survived and for those which died) to dive patterns recorded during other

periods at sea. Results suggest individuals that spent more time dry or dove shallower had a greater mortality probability, which could reflect foraging tactics of predators. This study highlights the effectiveness of combining multiple telemetry systems for exploring the vulnerability of individuals to the consumptive effects of predators.

National Marine Fisheries Service. (2020). *Environmental Assessment: Reducing Predation Impacts on at-Risk Fish by California and Steller Sea Lions in the Columbia River Basin*. Retrieved from <https://repository.library.noaa.gov/view/noaa/26094>

The National Marine Fisheries Service (NMFS) has prepared this Environmental Assessment (EA) in accordance with the National Environmental Policy Act (NEPA). This document considers the environmental consequences of alternative actions related to an application by certain States and Tribes to remove California sea lions (*Zalophus californianus*) and Steller sea lions (*Eumetopias jubatus*: Eastern stock) (hereafter called sea lions) in the Columbia River and certain tributaries. The purpose of the application is to reduce sea lion predation impacts on at-risk fish species listed as threatened or endangered under the Endangered Species Act (ESA) in the Columbia River Basin, and species of lamprey or sturgeon that are not listed as endangered or threatened but are listed as a species of concern.

Rub, A. M. W., & Sandford, B. P. (2020). Evidence of a 'Dinner Bell' Effect from Acoustic Transmitters in Adult Chinook Salmon. *Marine Ecology Progress Series*, 641, 1-11. <https://doi.org/10.3354/meps13323>

The 'dinner bell' hypothesis posits that marine mammals hear or otherwise sense soundwaves produced by acoustic transmitters and use the signal to selectively prey on fish carrying them. A dual tagging study conducted during 2010 and 2011 supports this hypothesis. Results from this study revealed a significant difference in the survival of fish marked with passive integrated transponder (PIT) tags and those marked with active acoustic transmitters. Our objective had been to use both types of tags to study behavior and survival of migrating adult spring Chinook salmon *Oncorhynchus tshawytscha* at 2 different spatial scales. We tagged fish as they entered the Columbia River, USA, and monitored their survival and progress over a 193 km reach to Bonneville Dam (river km 234), its lowest impoundment. In 2010, estimated survival was 0.34 (95% CI, 0.62-0.86) for PIT-tagged fish but only 0.30 (0.15-0.45) for acoustic-tagged fish. Therefore, in 2011, we included archival tags and a sham acoustic transmitter group to help identify causes of the survival discrepancy. Survival was 0.35 (0.54-0.97) for sham transmitter fish and 0.73 (0.60-0.86) for PIT fish, but only 0.10 (0.00-0.24) for active acoustic transmitter fish. Our study area was replete with harbor seals *Phoca vitulina*, California sea lions *Zalophus californianus*, and Steller sea lions *Eumetopias jubatus* during both years. We suspect the most likely cause of survival differences between tag treatment groups was pinniped predation. Using temperature data from archival tags, we found evidence of such predation and support for a 'dinner bell' effect from acoustic transmitter tags.

Washington State Academy of Sciences. (2022). *Pinniped Predation on Salmonids in the Washington Portions of the Salish Sea and Outer Coast*. Washington State Academy of Sciences, Seattle, WA. Retrieved from <https://washacad.org/wp-content/uploads/2022/11/Pinniped-Predation-on-Salmonids-in-the-Washington-Portions-of-the-Salish-Sea-and-Outer-Coast-1.pdf>

Populations of harbor seals, Steller sea lions, and California sea lions (hereafter ‘pinnipeds’) have increased substantially in the Salish Sea and coastal waters of Washington State following implementation of the US Marine Mammal Protection Act (MMPA) in 1972. During this period, many populations of Pacific salmon in Washington waters, which are at depressed levels and several of which are federally listed under the US Endangered Species Act, have declined in abundance or have failed to recover and continued to exist at low abundance. Because pinnipeds are abundant and widely known to be predators of both juvenile and adult Pacific salmon, these marine predators have been implicated as a primary factor contributing to continued depressed populations of salmon in Washington State. The Washington Department of Fish and Wildlife asked the Washington State Academy of Sciences to examine the scientific basis for the concern that recovery of salmon populations in Washington State’s Salish Sea and outer coastal waters has been impeded by pinniped predation. This report is a summary of the WSAS committee’s findings, following critical review of the existing literature on this topic and from information provided by scientists, managers, tribal representatives, and other participants in workshops. The report is organized to provide a review of existing evidence about pinniped and salmonid populations in the Salish Sea, pinniped predation on salmonids, and the impacts of pinniped predation on salmon recovery.

Section XI: Program, Co-Management, and Method Assessment

Canadian Science Advisory Secretariat. (2020). *Status of Steller Sea Lions (Eumetopias jubatus) in Canada*. Retrieved from <https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40951753.pdf>

Fisheries and Oceans Canada (DFO) has conducted 13 province-wide aerial surveys since the early 1970s to monitor the Steller sea lion population in B.C. Surveys are timed to coincide with the end of the breeding season so as to provide an estimate of pup production, as well as counts of juveniles and adults (non-pups). During the most recent survey in 2013, a total of 28,452 sea lions were counted in B.C. This included 6,317 pups and 22,135 non-pups (10,969 on rookeries and 11,166 on non-breeding haulout sites). This compares to a total of 23,514 sea lions counted in 2010, including 5,485 pups and 18,029 non-pups. The counts from aerial surveys represent minimum abundance because some pups may have died and older animals foraging at sea would be missed. An estimate of the total population size during the 2013 breeding season of 39,200 (95% CI of 33,600 to 44,800) was obtained by applying a correction factor based on telemetry data to account for animals that were at sea and missed during surveys. There is evidence for a continued increasing trend from the 2010 estimate of 32,500 (95% CI 28,200-36,800) although the Confidence Intervals (CI) overlap. Both pups and non-pups have increased since early 1970s, and population growth appears to be increasing at an accelerating rate. Between 2010 and 2013, the population growth rate for Steller sea lions in B.C. pups was 5.64% and non-pups 4.55%. However, there is uncertainty around the degree of immigration from neighboring US rookeries and the contribution to the abundance and growth of the B.C. population. The number of rookeries and year-round haulout sites has increased in B.C. waters since the species was first protected in 1970. In addition to the recovery of the previously eradicated rookeries on the Sea Otter Group by 2006, new rookeries have been established since that time at Garcin Rocks, Gosling Rocks and off Bonilla Island. Abundance of Steller sea lions has also increased in recent years at neighboring rookeries in SE Alaska, Washington and Oregon, as has the number of rookeries and year-round haulouts. The most recent winter surveys in 2009-2010 indicated that an estimated 48,500 (95% CI 38,100 to 58,900) Steller sea lions winter in the coastal waters of B.C. The increase in abundance during the non-breeding season appears to be due to a net influx of animals from rookeries outside of B.C.

Malek, J. C., & Cornish, V. R. (2019). *Co-Management of Marine Mammals in Alaska: A Case Study-Based Review*. M. M. Commission Bethesda, MD. Retrieved from <https://mn-ucsb-1.dataone.org/knb/d1/mn/v2/object/d5bad2d3-4e0c-4069-8e2d-6716e2eab8b0>

Co-management of subsistence use of marine mammals in Alaska is a key provision of the Marine Mammal Protection Act (MMPA). Under authority of Section 119 of the MMPA, the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) may enter into cooperative agreements with Alaska Native organizations (ANOs) to conserve marine mammals and provide co-management of subsistence use by Alaska Natives. Of the agreements established under Section 119, some have been more effective than others, and there is general agreement that co-management relationships can be improved. The Marine Mammal Commission (MMC) undertook this review in response to concerns MMC heard from ANOs, NMFS, and FWS that the comanagement process continues to experience serious challenges, despite a similar review MMC completed in 2008. The goal of this review was to strengthen co-management relationships and support co-management to improve the conservation of marine mammals in a region where they are of critical cultural, ecological, social, nutritional, and economic importance. The objectives of the review were to: Develop a “working”

definition of co-management, Identify important characteristics of, and major impediments to, effective co-management through: - a review of selected co-management and cooperative agreements, and - discussions with federal agency and Alaska Native co-management partners and community members, and provide recommendations for improving co-management relationships that account for the constraints on available resources, including funding . With the help of a Steering Committee comprised of ANO representatives and federal resource managers with co-management experience, we developed a working definition of comanagement as a first step, given the lack of a formal definition in the statute and inconsistencies in how co-management partners appeared to view what was meant by co-management. The Steering Committee agreed, however, that the definition should be used primarily for the purpose of the review, with broader use beyond the review to be determined by the individual ANOs and federal agencies as appropriate. The Steering Committee also helped us to select three 'case study' ANOs that currently hold Section 119 agreements for review: the Aleut Marine Mammal Commission, the Aleut Community of St Paul Island, and the Eskimo Walrus Commission. The case study approach was used given the large number of ANOs in Alaska and the limited timeframe and funding available for the review. In an effort to address the diverse nature of marine mammal co-management in Alaska, the three case studies were selected to reflect diversity in terms of geographic regions covered, the number of communities represented, the number of marine mammal species comanaged, and the federal agency partner (NMFS or FWS). We conducted interviews with 16 federal agency staff, 10 current and former ANO members involved in at least one of the case study agreements, and focus groups with 44 participants in seven coastal communities that were members of one or more of the selected case study agreements (north to south: Utqiagvik, Nome, Gambell, Savoonga, St. Paul Island, Atka, and Akutan). Findings based on the interviews and focus groups fell into seven overarching categories: key elements of co-management; partner roles and expectations; communication; organizational structure and accountability; leadership training and transitioning; agency practices and decision-making processes; and challenges of subsistence hunting and harvesting and the future of co-management. We also heard that limited funding can be an impediment to effectively carrying out co-management responsibilities, particularly for ANOs. Based on our findings, and in coordination with our Steering Committee, we developed the following recommendations (main bullets) and action items⁴ (sub-bullets) that federal agencies, ANOs, and communities/marine mammal resource users can take to strengthen co-management. Recognizing that sufficient funding is important for successful co-management, but also understanding that funding levels are unlikely to improve in the near future, we focused our recommendations on issues that can be addressed using the resources currently available to comanagement partners. Additionally, due to our case-study approach, our findings may not be reflective of all ANOs and not all recommendations and corresponding actions will be appropriate for all groups. Co-management partners should clearly define and mutually agree upon their respective roles, responsibilities, and accountability mechanisms, and should be more transparent regarding partner limitations, through actions such as: o Federal agency and ANO leadership specifying the roles, responsibilities, goals, and expectations of all co-management staff and participants, and including this information in revisions to co-management agreements o Federal agencies outlining major decision-making processes (e.g., ESA listings) and any limitations for including ANO perspectives (e.g., indigenous knowledge) in decisionmaking. Communities/resource users working with ANOs to understand the roles and responsibilities of ANO members, and helping hold members accountable for fulfilling their responsibilities Co-management partners and stakeholders should work cooperatively to strengthen communication, trust, and respect within and among partners, through actions such as: o Federal agency and ANO partners participating in cross-cultural awareness and communication training to help strengthen partner relationships and share expectations. o perly training and providing experience for federal agency field staff to communicate and collaborate with Alaska Native groups o Federal agency staff coordinating with ANOs to understand preferred timing, formats, and mechanisms for

communicating with different communities. Federal agency staff spending more time working in communities to enhance communication, trust, and respect with ANO members and resource users o Federal agency decision-makers being fully informed of co-management activities and concerns, and regularly engaging with ANO members and other community representatives. ANOs stating expectations for timely and effective communication between ANO members and their communities o ANOs informing communities of the communication responsibilities of their ANO members to enlist the help of communities in holding members accountable for timely and sufficient communication o ANO leadership ensuring that newly elected community leaders are informed about ANO missions and the expectations of appointed community representatives. Communities coordinating with ANOs on the preferred method of communication for sharing co-management information. New generations of Alaska Natives and new federal agency staff should be exposed to and provided opportunities to engage in a range of co-management activities, through actions such as: Federal agency and ANO partners forming a joint working group to identify and explore opportunities for training youth in skills related to co-management and leadership. Federal agency and ANO partners creating internal job shadow and volunteer opportunities, and promoting youth and new staff participation in these and other opportunities o Federal agencies and ANOs developing co-management history, curriculum, and training tools for use by both new ANO leadership and federal agency staff o ANOs pursuing funding for Alaska Native youth involvement in co-management related activities, such as internships and fellowships, through their yearly co-management funding requests and non-federal funding opportunities (e.g., grants from foundations). Communities supporting Alaska Native youth involvement in opportunities related to comanagement and leadership. The effectiveness and efficiency of co-management (ANO) structures should be assessed and alternative structural models should be considered as appropriate, through actions such as: Federal agencies investigating how alternative structural models would affect comanagement partner relationships. ANOs working together to consider the overall structure of co-management, how well it promotes shared goals, and how it may be improved o ANOs and agencies working to explore how different structures may affect their comanagement relationship In early 2019, we traveled back to most of the participating communities⁵ and also met with federal agency staff to share the review findings and recommendations and gather feedback that was incorporated into this report. Returning to the communities and agencies was an important step in making sure Alaska Native community members, ANOs, and agency staff were informed of the final outcomes of the study and able to see how their input was incorporated into the report. Our approach to identifying the key elements and major impediments to co-management involved working with all parties—federal agency partners, ANOs, and marine mammal hunters/harvesters and resource users in coastal communities. That integrated approach would not have been possible without the guidance and support of our Steering Committee members and advisors, who also helped ensure that the review was conducted thoughtfully and respectfully. We would also like to thank the review participants for meeting with us and sharing their experiences and perspectives on co-management. MMC is willing to facilitate further discussions, as appropriate, regarding how the findings and recommendations from this report can be used by ANOs, agencies, and communities to continue to enhance co-management and conservation of marine mammals in Alaska.

Marsh, H., Ahuanari, L., del Aguila, V., Haami, B., Laureano, M., Loban, F., . . . Neelin, M. (2022). Elders' Voices: Examples of Contemporary Indigenous Knowledge of Marine Mammals. In *Marine Mammals: The Evolving Human Factor*. (pp. 337-374) https://doi.org/10.1007/978-3-030-98100-6_11

The legal and moral imperatives for incorporating indigenous knowledge into natural resource management are now widely recognized. Many consider the integration of indigenous knowledge to be an essential component of successful solutions for conserving resources valued by indigenous peoples, including marine mammals. The effective integration of indigenous knowledge requires an understanding of what it is. Indigenous elders from five very different parts of the world briefly explain their knowledge of local marine mammals including: ika-moana (large whales) of Aotearoa, New Zealand; dhangal (dugongs) of Torres Strait between northern Australia and Papua New Guinea; river dolphins and manatees of Amazonia; beluga whales, Atlantic walrus, bearded seals and harp seals of the Nunavik region of north Quebec in the Canadian Arctic; and sea otters, spotted or larga seals, northern fur seals and Steller sea lions of the Commander Islands, Russia. These accounts illustrate the complexity and temporal dynamism of indigenous knowledge. To help identify the themes in these accounts, we used an extension of Houde's typology of indigenous knowledge, which we envisaged as a hexagon with worldview at the core and cosmology, factual observations, management systems, past and present uses, ethics and values, and culture and identity on its faces. We hope that this chapter will help marine mammal scientists who work in research partnerships with indigenous peoples, to build trust, respect, and mutual understanding of each other's knowledge systems. This understanding should help marine mammal scientists to work successfully across the "cultural interface to achieve true progress in marine mammal conservation and coexistence."

Matsuda, H. (2021). Beyond Dichotomy in the Protection and Management of Marine Mammals. In *Ecological Risk Management*. (pp. 201-211) https://doi.org/10.1007/978-981-33-6934-4_13

Marine mammals are natural resources and some are considered as pest animals. The main factors driving the relationship between humans and marine mammals changed from the mid-twentieth century to the early twenty-first century. This is the result of changes in their extinction risk, resource demand, and animal welfare for wildlife. In this chapter, we selected Steller sea lions to investigate changes in Japanese marine mammal policies. Japan's policy of Steller sea lion has changed from resource utilization in the mid-twentieth century to conservation in the second half of the twentieth century and pest control since 2014. Japanese environmental groups have played an important role in building consensus on these policy changes. We call for a comprehensive policy that implements a balanced approach to address the three different roles of marine mammals: natural resources, pest animals, and targets of animal welfare. We also discuss the importance of stakeholder involvement in aiming for population management that is neither overfishing nor full protection.

Matsuda, H., & Makino, M. (2021). Marine Comanagement Plan of Shiretoko World Heritage Site. In *Ecological Risk Management*. (pp. 255-270) https://doi.org/10.1007/978-981-33-6934-4_16

Shiretoko was inscribed as a Natural World Heritage site in 2005. It has an outstanding universal value as a connection between the terrestrial and marine ecosystems. However, coastal fisheries are operated throughout the area, and it was required that the protection of the area was strengthened during the nomination process. World Heritage areas are protected by the national laws of each country and are

not under international control. Japanese coastal fisheries are based on comanagement of fisheries cooperative associations (FCA) aiming at sustainable fisheries. The fishers expanded the seasonal fishing-ban areas of walleye pollock (*Gadus chalcogrammus*), and Shiretoko became a World Heritage Site. In this way, Shiretoko became a case of a new world heritage, where the protection of nature was not guaranteed by the government but rather the initiative of the local stakeholders to protect it. Unlike other chapters, this chapter does not include explanation of mathematical techniques for ecological risk management. We discuss the importance of comanagement and decision-making by the local stakeholders in ecological risk management.

Mercurieff, M., Philemonoff, A., & Divine, L. (2022). Tuman Alaġux^ Agliisaax^Tan (Take Care of the Ocean): A New Vision for Indigenous Co-Management in Marine Waters of the US. *Parks Stewardship Forum*, 38(2). <https://doi.org/10.5070/p538257517>

The Pribilof Islands are among the most unique and important places in the world. These islands provide vital breeding and feeding habitat for more than half of the world's population of laaquadan (as they are called in Unangam Tunuu, Native language of the community), or northern fur seals, as well as important habitat for qawan, or Steller sea lions, and isugġin, or harbor seals. More than three million san, or seabirds, flock to the islands during the summer months. By virtue of their position straddling the continental shelf and deeper ocean waters of the Bering Sea, the islands play a central role in creating the productive ocean zone that supports some of the world's largest and most profitable commercial fisheries. This irreplaceable region has experienced centuries of anthropogenic disturbances that have steadily shifted the ecosystem away from its natural stability. Today, the Aleut Community of St. Paul Island Tribal Government (ACSPI) is taking steps to restore and sustain Unangaġ ways of life, mitigate the impacts of climate change in the region, and enact economic policies that eliminate waste and reduce the overuse of resources in the marine environment. Here we provide a case study of our efforts towards using existing US regulations to secure protections for our marine environment.

National Marine Fisheries Service. (2020). *Western Distinct Population Segment Steller Sea Lion 5-Year Review: Summary and Evaluation*. Juneau, AK: National Oceanic and Atmospheric Administration Retrieved from <https://www.fisheries.noaa.gov/resource/document/western-distinct-population-segment-steller-sea-lion-5-year-review-summary-and>

This review was authored by Kim Raum-Suryan and Dr. Lisa Rotterman of the Alaska Regional Office in consultation with Dr. Tom Gelatt, Dr. Brian Fadely, Dr. Michelle Lander, Kathryn Sweeney, Beth Sinclair, and other NOAA Fisheries Alaska Fisheries Science Center (AFSC) staff. Primary sources of information are the many published papers, reports, and technical memoranda that have become available since the listing of the western distinct population segment (WDPS) Steller sea lion in 1997. These sources were augmented with recently-collected and analyzed Steller sea lion count data from AFSC and the lead Russian research coordinator, Dr. Vladimir Burkanov. We also considered information submitted through public comments. This document was reviewed by five external peer reviewers.

Sneddon, L., & Dunn, K. (2019). *Toward Integrated Management in Baynes Sound: A Comparative Analysis*. World Wildlife Fund Canada W. W. Fund Retrieved from <https://wwf.ca/wp-content/uploads/2020/11/Toward-Integrated-Management-in-Baynes-Sound.pdf>

This report assesses the current degree of integration among existing management plans for Baynes Sound/Lambert Channel, located on the eastern shore of Vancouver Island in British Columbia. The marine region is a source of significant ecological productivity as well as economic activity. It is the highest ranked cumulative and spawning area for herring in the Strait of Georgia and is a critical feeding and overwintering area for waterbirds. Baynes Sound also supports the highest density of intertidal shellfish aquaculture in British Columbia, producing over half of all the shellfish cultured in the province. The purpose of this report was to comparatively assess each of the existing management plans to determine the current degree of integration and to identify opportunities to advance an integrated approach to management of the Baynes Sound/Lambert Channel ecosystem. Prior to the analysis, a review of peer-reviewed literature was conducted to identify the key principles of ecosystem-based management. These principles, which related to spatial and temporal scales, management of human activity and ecosystem-level management, helped to provide a framework for the assessment. There were 29 documents selected in total, which included plans produced by various types of government (local, municipal, provincial, First Nations and federal) in various stages of implementation. A content analysis was used to comparatively assess the management plans, and management content was extracted using a coding system, based on key principles of ecosystem-based management, and comparatively examined via a semi-quantitative analysis. Grouped management summaries initially provide an overview of regional context as well as the current state of management. There are many governing bodies involved in Baynes Sound/Lambert Channel and although each has a distinct management role, there are overlapping boundaries, responsibilities and management considerations. Following this section, the results of the assessment are displayed in a comparative chart, which summarizes the purpose of each of the plans, the spatial and temporal scales, species-specific management as well as ecosystem-level management objectives. Following the tabular presentation, results are examined in further detail to identify the opportunities and challenges for further integration of management moving forward. The results of the analysis indicate that the existing management plans have all been developed independently, and largely are not integrated. However, several common management elements emerged and were discussed as opportunities for improving integrated management going forward. The most prevalent of these opportunities stems from a near-universal interest in ecosystem-level health found in the plans. Many of the opportunity areas identified have strong management connections to each other, across sectors, spatial zones, and species, further strengthening the foundation for improved integration. The results also highlighted challenges for the further integration of management in the region, including the complexities of governance and the need for a shared vision for the region. As a region of significant ecological productivity and economic activity, the sustainable management and development of Baynes Sound/Lambert Channel suggests an integrated approach. Though this report identified the strongest opportunities for improving integrated management, a comprehensive integrated and ecosystem-based approach to management in Baynes Sound would weave management efforts across spatial zones, species, time and activities for the long-term benefit of all.

Stocking, J. J., & Wiles, G. J. (2021). *Washington State Periodic Status Review for the Steller Sea Lion*. Olympia, WA: Washington Department of Fish and Wildlife Retrieved from <https://wdfw.wa.gov/sites/default/files/publications/02253/wdfw02253.pdf>

The Steller sea lion (*Eumetopias jubatus*) was delisted from state threatened status in 2015. This document reviews the post-delisting status of the Steller sea lion in Washington, as required in WAC 220-610-110. Steller sea lions are dietary generalists that prey on a broad variety of fish and cephalopods, including both benthic and pelagic species. They move long distances to track abundant prey, resulting in patchy seasonal distributions. Haulouts for resting and rookeries for breeding and pupping are typically located on islands and offshore rocks and often used year after year. Many adult females do not breed annually, resulting in lower productivity than most other pinnipeds. Steller sea lions in Washington belong to the eastern distinct population segment (DPS), one of two DPSs comprising the species. The eastern DPS ranges along the west coast of North America from Southeast Alaska to central California (i.e., east of 144°W longitude) and has been steadily increasing in Washington and range-wide. From 1987 to 2017, non-pup counts and pup counts in the eastern DPS increased at average annual rates of 3.22% and 4.25%, respectively, with the overall population growing from an estimated 18,313 animals in 1979 to at least 71,562 animals in 2019. Steller sea lion abundance in Washington has also grown, with numbers of non-pups at four sites surveyed during summer increasing at an average rate of 9.12% from 1987-2017 and year-round surveys during 2010-2018 estimating a 7.9% increase. Small but increasing numbers of pups have been born at several sites since 1992, with a recently established rookery complex producing more than 200 pups in 2020. Steller sea lions experience several stressors associated with climate change effects and anthropogenic activities. Recently, increasing numbers of Steller sea lions have travelled up the Columbia River to forage on prey concentrated at the Bonneville Dam. This shift has resulted in a request to NOAA Fisheries by state and tribal managers for authority to lethally remove animals at the dam to protect imperiled salmon stocks. Based on sustained population growth and the lack of significant threats, it seems likely that Steller sea lion numbers in Washington will continue to increase for the foreseeable future. For that reason, WDFW recommends that the Washington Fish and Wildlife Commission maintain the delisted status of Steller sea lions in Washington.

Section XII: Threats

Allyn, E. M., & Scordino, J. J. (2020). Entanglement Rates and Haulout Abundance Trends of Steller (*Eumetopias jubatus*) and California (*Zalophus californianus*) Sea Lions on the North Coast of Washington State. *PLOS One*, 15(8). <https://doi.org/10.1371/journal.pone.0237178>

Entanglements affect marine mammal species around the globe, and for some, those impacts are great enough to cause population declines. This study aimed to document rates and causes of entanglement and trends in local haulout abundance for Steller and California sea lions on the north coast of Washington from 2010-2018. We conducted small boat surveys to count sea lions and document entangled individuals. Rates of entanglement and entangling material occurrence were compared with records of stranded individuals on the Washington and Oregon coast and with packing bands recorded during beach debris surveys. The rate of entanglement for California sea lions was 2.13%, almost entirely composed of adult males, with a peak rate during June and July potentially due to some entangled individuals not migrating to their breeding grounds. For Steller sea lions, the rate of entanglement was 0.41%, composed of 77% adults (32.4% male, 63.3% female), 17.1% juveniles, 5.9% unknown age, and no pups. Steller sea lions exhibited a 7.9% +/- 3.2 rate of increase in abundance at the study haulouts, which was similar to that seen in California sea lions (7.8% +/- 4.2); both increases were greater than the population growth rates observed range-wide despite high rates of entanglement. Most entanglements for both species were classified as packing bands, followed by entanglement scars. Salmon flashers were also prevalent and only occurred from June-September during the local ocean salmon troll fishery. Packing band occurrence in beach debris surveys correlated with packing band entanglements observed on haulouts. However, no packing band entanglements were observed in the stranding record and the rate of stranded animals exhibiting evidence of entanglement was lower than expected, indicating that entanglement survival is higher than previously assumed. Future studies tracking individual entanglement outcomes are needed to develop effective, targeted management strategies.

Carretta, J. V., Delean, B., Helker, V., Muto, M. M., Greenman, J., Wilkinson, K., . . . Jannot, J. (2020). *Sources of Human-Related Injury and Mortality for U.S. Pacific West Coast Marine Mammal Stock Assessments, 2014 - 2018*. <https://doi.org/10.25923/j73c-6q78>

The Marine Mammal Protection Act (MMPA) requires the National Marine Fisheries Service (NMFS) to document human-caused mortality, non-serious injury (NSI), and serious injury (SI) of marine mammals, as part of marine mammal stock assessments and to evaluate human-caused injury and mortality levels in the context of potential biological removal (PBR) levels under the MMPA. NMFS defines SI as "any injury that will likely result in mortality". While documenting mortality is straightforward, distinguishing NSI from SI requires data on injury severity and animal condition, often from challenging environments where thorough examination of animals is not always possible. NMFS updated its SI designation and reporting process in 2012, using guidance from previous SI workshops, expert opinion, and analysis of historical injury cases to develop new criteria for distinguishing SI from NSI. This report contains human-caused injury and mortality records of pinnipeds and cetaceans that occur in U.S. west coast waters for the period 2014-2018, for those species evaluated in Pacific region marine mammal stock assessment reports (SARs). Mortality records, while included in this report, were not a part of the SI/NSI status evaluation that included only live and/or injured animals. Subsistence and directed takes (i.e., gray whales taken by Russian natives) are not reported here but are reported in SARs published by NMFS. Previous serious injury and mortality records, including cases from 2007 through 2017, are published in

previous reports. Sources of injury data include strandings, disentanglement networks, the public, researchers, and fishery observer programs. Stranding data include records of injured marine mammals at sea and ashore. Injury sources include, but are not limited to, vessel strikes, gillnet entanglement, pot and trap gear entanglement, shootings, marine debris entanglement, research-related injuries/deaths, hook and line fishery interactions, and entrapment in power plant water intakes. Most records originate from stranding networks in California, Oregon, and Washington, though a few Alaska records of Eastern North Pacific gray whales (*Eschrichtius robustus*) and northern elephant seals (*Mirounga angustirostris*) are included, because these populations are assessed in the Pacific region SARs. Other marine mammals, such as Steller sea lions (*Eumetopias jubatus*), occur in California, Oregon, and Washington waters, but they are assessed in Alaska region SARs and are not included in this report. Injury determinations for Pacific region species/stocks in the central Pacific from Hawaii westward are also included in separate reports.

Carretta, J. V., Greenman, J., Wilkinson, K., Freed, J., Saez, L., Lawson, D., . . . Jannot, J. (2021). *Sources of Human-Related Injury and Mortality for U.S. Pacific West Coast Marine Mammal Stock Assessments, 2015 - 2019*. <https://doi.org/10.25923/cwre-v564>

The Marine Mammal Protection Act (MMPA) requires the National Marine Fisheries Service (NMFS) to document human-caused mortality, non-serious injury (NSI), and serious injury (SI) of marine mammals, as part of marine mammal stock assessments and to evaluate human-caused injury and mortality levels in the context of potential biological removal (PBR) levels under the MMPA. NMFS defines SI as "any injury that will likely result in mortality." While documenting mortality is straightforward, distinguishing NSI from SI requires data on injury severity and animal condition, often from challenging environments where thorough examination of animals is not always possible. NMFS updated its SI designation and reporting process in 2012, using guidance from previous SI, expert opinion, and analysis of historical injury cases to develop new criteria for distinguishing SI from NSI. This report contains human-caused injury and mortality records of pinnipeds and cetaceans that occur in U.S. west coast waters for the period 2015-2019, for those species evaluated in Pacific region marine mammal stock assessment reports (SARs). Mortality records, while included in this report, were not a part of the SI/NSI status evaluation that included only live and/or injured animals. Subsistence and directed takes (i.e., gray whales taken by Russian natives) are not included here but are reported in SARs published by NMFS. Previous serious injury and mortality records, including cases from 2007 through 2018, are published in previous reports. Sources of injury data include strandings, disentanglement networks, the public, researchers, and fishery observer programs. Stranding data include records of injured marine mammals at sea and ashore. Injury sources include, but are not limited to, vessel strikes, gillnet entanglement, pot and trap gear entanglement, shootings, marine debris entanglement, research-related injuries/deaths, hook and line fishery interactions, and entrapment in power plant water intakes. Most records originate from stranding networks in California, Oregon, and Washington, though a few Alaska records of Eastern North Pacific gray whales (*Eschrichtius robustus*) and northern elephant seals (*Mirounga angustirostris*) are included, because these populations are assessed in the Pacific region SARs. Other marine mammals, such as Steller sea lions (*Eumetopias jubatus*), occur in California, Oregon, and Washington waters, but they are assessed in Alaska region SARs and are not included in this report. Two stocks of Northern fur seal overlap in U.S. West Coast waters seasonally from December through May; the Eastern North Pacific stock (assessed in Alaska region SARs) and the California stock (assessed in Pacific region SARs) and interactions that occur during that time period are assigned to both stocks. Injury determinations for Pacific region species/stocks in the central Pacific from Hawaii westward are also included in separate reports.

Carretta, J. V., Helker, V., Muto, M. M., Greenman, J., Wilkinson, K., Lawson, D., . . . Jannot, J. (2019). *Sources of Human-Related Injury and Mortality for U.S. Pacific West Coast Marine Mammal Stock Assessments, 2013 - 2017*. <https://doi.org/10.25923/j6bk-xt87>

The Marine Mammal Protection Act (MMPA) requires the National Marine Fisheries Service (NMFS) to document human-caused mortality, non-serious injury (NSI), and serious injury (SI) of marine mammals, as part of marine mammal stock assessments and to evaluate human-caused injury and mortality levels in the context of potential biological removal (PBR) levels under the MMPA. NMFS defines SI as "any injury that will likely result in mortality". While documenting mortality is straightforward, distinguishing NSI from SI requires data on injury severity and animal condition, often from challenging environments where thorough examination of animals is not always possible. NMFS updated its SI designation and reporting process in 2012, using guidance from previous SI workshops, expert opinion, and analysis of historical injury cases to develop new criteria for distinguishing SI from NSI. This report contains human-caused injury and mortality records of pinnipeds and cetaceans that occur in U.S. west coast waters for the period 2013-2017, for those species evaluated in Pacific region marine mammal stock assessment reports (SARs). Mortality records, while included in this report, were not a part of the SI/NSI status evaluation that included only live animals. Subsistence and directed takes (i.e., gray whales taken by Russian natives) are not reported here but are reported in SARs published by NMFS. Previous serious injury and mortality records, including cases from 2007 through 2016, are published in previous reports. Sources of injury data include strandings, disentanglement networks, the public, researchers, and fishery observer programs. Stranding data include records of injured marine mammals at sea and ashore. Injury sources include, but are not limited to, vessel strikes, gillnet entanglement, pot and trap gear entanglement, shootings, marine debris entanglement, research-related injuries/deaths, hook and line fishery interactions, and entrapment in power plant water intakes. Most records originate from stranding networks in California, Oregon, and Washington, though a few Alaska records of Eastern North Pacific gray whales (*Eschrichtius robustus*) are included, because this population is assessed in the Pacific region SARs and occurs along the U.S. west coast. Other marine mammals, such as Steller sea lions (*Eumetopias jubatus*), occur in California, Oregon, and Washington waters, but they are assessed in Alaska region SARs and are not included in this report. Injury determinations for Pacific region species/stocks in the central Pacific from Hawaii westward are also included in separate reports.

Ferdinando, P. (2019). *Assessment of Heavy Metals in Subsistence-Harvested Alaskan Marine Mammal Body Tissues and Vibrissae*. (Master of Science), Nova Southeastern University, Fort Lauderdale, FL. Retrieved from https://nsuworks.nova.edu/occ_stuetd/504/

The coastal, indigenous communities around Alaska have subsisted on marine animals for generations, often focusing on large apex predators such as seals, sea lions, and whales. Three species of pinnipeds (harbor seal, Steller sea lion, northern fur seal) and the northern sea otter have all undergone significant population declines since the 1970s, some regions more than others. Archived vibrissae (whiskers) and body tissues from these four species were available from the Bering Sea and throughout the Gulf of Alaska from the 1990s and early 2000s. Tissues from these species are exceedingly difficult to obtain; thus, the archived tissues provided a finite and irreplaceable resource of data. Analysis of these archived tissues indicates which species, tissues, and gender bioaccumulate metals more readily. In this study twelve heavy metals (arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, vanadium, zinc) were analyzed in vibrissae from the four select species, and in body tissues from harbor seals and Steller sea lions. The samples were collected from three regions (southeastern, southcentral, and southwestern Alaska) during the 1990s through early 2000s. Significant differences of

heavy metal concentrations in vibrissae were detected among elements ($p(110) = 454.81$, $p(66) = 310.88$, p

Freed, J. C., Young, N. C., Delean, B. J., Helker, V. T., Muto, M. M., Savage, K. M., . . . Jannot, J. E. (2021). *Human-Caused Mortality and Injury of NMFS-Managed Alaska Marine Mammal Stocks, 2015-2019*. (NMFS-AFSC-424). <https://doi.org/10.25923/65g0-5d98>

Section 117 of the Marine Mammal Protection Act (MMPA) requires the National Marine Fisheries Service (NMFS) to estimate human-caused marine mammal mortality and serious injury. Data from documented interactions between human activities and pinnipeds or cetaceans belonging to stocks which appear in the Alaska Marine Mammal Stock Assessment Reports (SARs) were compiled for the 5-year period from 2015 through 2019. A total of 934 unique interactions with evidence of human-caused mortality or injury are summarized in this report. Details for all reported human-marine mammal interactions (approximately 3,500) were first assessed for evidence of human-caused injury or mortality of the marine mammal; injuries and mortalities that could not be attributed with high confidence to human causes were excluded from further analysis. Injury severity determinations were then made for those injuries considered with high confidence to be human-caused. Injury determination details, including the injury cause, type, severity (nonserious, serious, or prorated serious), and criteria supporting the determination are presented in Appendix Table 1.1. Records of human-caused mortality, assigned to cause, are also included in this report and presented in Appendix Table 1.1. Mortality or injury values were assigned to each interaction for comparison with the potential biological removal (PBR) levels, calculated under the MMPA, for each stock in the Alaska SARs. The mortality and injury values included in this report are derived solely from documented interactions. Not all human-caused mortality and injury of marine mammals is documented so this report represents a minimum count of human-caused mortality and injury of Alaska marine mammal stocks.

Gundersen, D., Josefchak, D., Duffield, D. A., D'Alessandro, D. N., & Rice, J. M. (2021). Organochlorine Exposure and Health Effects in Stranded Steller Sea Lions (*Eumetopias jubatus*) and Pacific Harbor Seals (*Phoca vitulina richardii*) from Oregon and Southern Washington Coasts. *Marine Mammal Science*, 37(3), 949-961. <https://doi.org/10.1111/mms.12785>

Organochlorine (OC) pesticides and polychlorinated biphenyls (PCBs) have been detected in a variety of marine mammal species at levels associated with adverse health effects. Little is known about OC levels and impacts on health in pinnipeds with different life histories. We determined the health and levels of 18 OC pesticides and 16 PCB congeners in blubber samples from 20 Steller sea lions and 39 Pacific harbor seals stranded from Oregon and Southern Washington. The most commonly detected OC at the highest concentration was *p,p'*-dichlorodiphenyldichloroethylene (DDE). PCBs were detected in all samples as well. Hypothesis testing indicated that diseased Steller sea lions (males and females combined) had higher contaminant concentrations than healthy Steller sea lions, and diseased Pacific harbor seals had higher concentrations of total OCs than healthy animals. Differences were also noted between diseased and healthy animals when looking at individual sexes of each species. Diseased Steller sea lions had higher mean contaminant levels than diseased harbor seals and healthy Steller sea lions had higher mean contaminant concentrations than healthy Pacific harbor seals. These results show that species differences exist in both contaminant loads and sensitivity to contaminants, which may be due to differences in life histories and physiology.

Hewson, S., & Watson, M. (2020). *Reducing Impacts from Shipping in Scott Islands Marine National Wildlife Area: Pacific Case Study*. World Wildlife Fund Canada. Retrieved from <https://wwf.ca/wp-content/uploads/2021/02/WWF-MPA-10-Scott-Islands-v5.pdf>

The Scott Islands marine National Wildlife Area was established in 2018 to protect the 11,546 square kilometres (km²) of ocean surrounding the Scott Islands archipelago at the northwestern end of Vancouver Island, British Columbia. Planning for designation of this area has been underway for decades as it supports the largest and most diverse seabird nesting colonies in Pacific Canada. It is the first marine National Wildlife Area (mNWA) designated by Environment and Climate Change Canada (ECCC) under the Canada Wildlife Act. Vessel traffic within the Scott Islands mNWA is frequent and mostly includes traffic from cargo and cruise ships, as well as some oil tanker traffic and towing vessels. Concerns about the potential risks from shipping to ecological components of the mNWA were raised during the development process. At present, though the Regulations establish some measures to reduce the risk of predator introduction to the islands, they still largely permit shipping and other vessel traffic to continue as before. Many important species that use the mNWA, including seabird colonies and a number of at-risk species listed under the Species at Risk Act (SARA) – several species of migratory birds, sea lions, killer whales, humpback whales and sea otters – have noted vulnerabilities to impacts of oil discharges, spills and disturbance from vessels (both above and underwater). These potential impacts and risks are described in this Case Study. Recommendations to address these threats are made within the context of the Scott Islands mNWA and its legal framework.

Kuzin, A. E., & Trukhin, A. M. (2022). Entanglement of Steller Sea Lions (*Eumetopias jubatus*) in Man-Made Marine Debris on Tyuleniy Island, Sea of Okhotsk. *Marine Pollution Bulletin*, 177. <https://doi.org/10.1016/j.marpolbul.2022.113521>

The present report provides data on entanglement of Steller sea lions (SSL) in marine debris on Tyuleniy Island, Sea of Okhotsk. The frequency of entanglement depending on the material, sex, and age of animals was estimated. A total of 133 SSL were recorded as having debris on their bodies, or an average of 22.2 individuals per year. The relative rate of entanglement over the observation years ranged from 1.48 to 1.97% of their total number. The entangled individuals were both males and females of all ages, but young males constituted the largest proportion among them (5.2%). The entangled SSL most frequently (43.2%) had neck collars (the material is not defined) and, less frequently, packaging bands (23.4%), nets (17.7%), and other debris. Most of marine litter found on SSL is associated with commercial fishing activities. On Tyuleniy Island, the rate of SSL entanglement is higher than in the eastern part of the species' range.

Meier, S. (2020). *Summary of Current Mitigation Measures for Marine Mammals During in-Water Pile Installation, and Supporting Rationale for a Pinniped-Specific Exclusion Zone*. Retrieved from <https://iaac-aeic.gc.ca/050/documents/p80038/137132E.pdf>

During the environmental assessment of the LNG Canada Export Terminal, LNG Canada Development Inc. (LNGC) committed to monitoring and mitigating potential adverse effects to marine mammals, including pinnipeds (seals and sea lions), from underwater noise during construction activities. The federal decision statement, provincial environmental assessment certificate (EAC #15-01), marine Fisheries Act authorization (15-HPAC-00585) and Canadian Environmental Protection Act 1999 disposal at sea permit (4543-2-03675 and 4543-2-03724), establish the requirements for the implementation of a

marine mammal monitoring program and specify mitigation measures for the protection of marine mammals during construction-related activities. Experience during the first season of marine construction has shown that the blanket exclusion zone for the protection of marine mammals should not be applicable to pinnipeds (i.e., harbour seals and Steller sea lions). Stantec Consulting Ltd. (Stantec) has prepared this memorandum to provide the rationale for a pinniped-specific exclusion zone during construction of the LNGC Project. This memo will summarize the LNGC marine mammal assessment conclusions from the environmental assessment certificate (EAC) application, the development of the marine monitoring plan (MMP), the current mitigation measures being implemented during in-water impact pile installation (including the rationale for pinniped-specific exclusion zones), and recent in-field sound verification measurements during Project impact pile installation. See Appendix A for a literature review of the life history, distribution, abundance and conservation status of harbour seals and Steller sea lions in BC. See Appendix B for a summary of best management practices and mitigation measures for pinnipeds in Canada. See Appendix C for the regulatory context of the LNGC marine mammal exclusion zone (MMEZ).

Raum-Suryan, K. L., & Suryan, R. M. (2022). Entanglement of Steller Sea Lions in Marine Debris and Fishing Gear on the Central Oregon Coast from 2005–2009. *Oceans*, 3(3), 319-330.
<https://doi.org/10.3390/oceans3030022>

Entanglement in marine debris and fishing gear is an increasing problem for the world's pinnipeds and a contributing factor in Steller sea lion (*Eumetopias jubatus*) injury and mortality. From 2005–2009, we surveyed (n = 389 days) two haul-outs on the central Oregon coast containing a combined median of 402 animals (range 33–1240, or ca. 1–19% of the Oregon coast population). We recorded 72 individuals entangled in marine debris (n = 70) or with ingested salmon hook-and-line fishing gear (n = 2). Of the identifiable neck entanglements, black rubber bands were the most common neck-entangling material (62%), followed by plastic packing bands (36%), nets (1.2%), yellow rubber bands (0.4%), and a flying disc (0.4%). The estimated prevalence of entanglement for individuals in Oregon was 0.34%. Juveniles were the most frequently entangled age class (60%), followed by adult females (28%), and subadult males (12%). Supply chain and industry-based solutions are needed to prevent entangling debris from entering the ocean, along with eliminating, modifying, or cutting entangling loops of synthetic material.

Shook, J. E., & Johnson, C. B. (2019). *Seal Monitoring at Ugak Island, Pacific Spaceport Complex Alaska, Kodiak Island - 2018 Annual Report*. Retrieved from https://media.fisheries.noaa.gov/dam-migration/alaskaaerospace_2017rule_2018monrep_opr1.pdf

Rocket launches began in 1998 at the Kodiak Launch Complex (now Pacific Spaceport Complex Alaska [PSCA]) operated by Alaska Aerospace Development Corporation (now Alaska Aerospace Corporation or AAC) at Narrow Cape on Kodiak Island, Alaska (ENRI 1999). Several species of marine mammals occur in the area of Narrow Cape seasonally or year-round (ENRI 1995), but only 2 species use land-based haulouts in that area—Steller sea lions (*Eumetopias jubatus*) and harbor seals (*Phoca vitulina*). Disturbance of haulouts by rocket launches is a major concern of the National Marine Fisheries Service (NMFS), the agency responsible for management of sea lions and harbor seals. Sea lions and harbor seals may flush from haulouts into the water when frightened; during flushing events, young may get trampled or separated from their mothers. Marine mammals in the Kodiak area, other than sea otters (*Enhydra lutris*), are managed by NMFS under the Marine Mammal Protection Act (MMPA; 16 U.S.C. 1361 et seq.). Marine mammals that are listed as threatened or endangered are also managed under the

Endangered Species Act (ESA) of 1973, as amended (PL 93-205; 16 U.S.C. 1531–1544). Both the MMPA and ESA prohibit the taking of species they manage—activities that may result in disturbance, harassment, injury, or killing—without specific authorization. In 2006, NMFS issued a final rule that regulated the types of effects rocket launches could have on marine mammals and authorized the incidental take by harassment of Steller sea lions and adult harbor seals, and incidental take by harassment or mortality of harbor seal pups, during rocket launches. An annual Letter of Authorization (LOA) was issued each year which prescribed the specific monitoring and reporting requirements and authorized incidental take with restrictions for the year in which it was issued. See the five-year summary report for further details. The current LOA is valid from 11 May 2017 to 25 April 2022 and authorizes incidental take of marine mammals for up to 9 launches per year. AAC is authorized to incidentally take 315 harbor seals per year by Level B harassment. Steller sea lions have not been using Ugak Island regularly for haulouts and are no longer a focus of the monitoring. The LOA stipulates that AAC must designate technical experts, approved in advance by NMFS Office of Protected Resources, to:

1. Install time-lapse photography systems designed to monitor pinniped abundance and detect pinniped responses to rocket launches at each of the pinniped haulout locations around Ugak Island. The number of camera systems, equipment capabilities, placement of the systems to be used, and the daily photo frequency shall be determined through a cooperative effort between AAC, NMFS Office of Protected Resources, and the technical experts;
2. Ensure that the time-lapsed photography systems shall be in place and operating in locations that allow for visual monitoring of all pinniped haulouts during launches;
3. Relocate the time-lapsed photography systems in cooperation with NMFS after 5 launches if the system is not accurately capturing all pinniped haulouts and total pinniped abundance during the launches;
4. Monitor and review the effectiveness of these systems, comparing the results to aerial surveys for pinniped presence, abundance, behavior, and re-occupation time from the data obtained from the time-lapsed photography systems for the first 5 launches and report results to NMFS Office of Protected Resources within 90 days (after the fifth launch); and
5. Conduct a study in coordination with NMFS Office of Protected Resources to evaluate the effectiveness of the time-lapsed photography systems (specifically, the accuracy of the photography systems compared with the aerial count surveys).

The results of this study shall determine the need to continue aerial surveys. The study shall be conducted through a minimum of 5 launches. In addition, AAC shall conduct one pre-launch and one post-launch aerial survey for each launch to obtain data on pinniped presence, abundance, and behavior at all pinniped haulouts. If no launches occur during a year, the LOA directs AAC to conduct quarterly aerial surveys, ideally during midday and coinciding with low tide. Results shall be reported to NMFS as part of the year-end summary reports. This report serves as the year-end summary report for 2018 and includes results of the preand post-launch aerial surveys and comparison of the results using the time-lapse photography systems. No quarterly aerial surveys were conducted in 2018. A final 5-year report must be submitted to NMFS at least 90 days prior to expiration of regulations if new regulations are sought or 180 days after expiration of regulations. The primary study area for marine mammal monitoring during 2017–2022 at the PSCA was established in the 2017 final rule and focuses on the shoreline and rocks within 500 m of Ugak Island (5–8 km from the launch pads; Figure 1). The objective of marine mammal monitoring during rocket launches is to record the abundance and distribution of harbor seals on Ugak Island and to evaluate the effect of rocket noise on seal occupation at haulout sites, as stipulated in the 2017 final rule and annual LOA.

Suryan, R. M., Arimitsu, M. L., Coletti, H. A., Hopcroft, R. R., Lindeberg, M. R., Barbeaux, S. J., . . . Zador, S. G. (2021). Ecosystem Response Persists after a Prolonged Marine Heatwave. *Scientific Reports*, 11(1), 6235. <https://doi.org/10.1038/s41598-021-83818-5>

Some of the longest and most comprehensive marine ecosystem monitoring programs were established in the Gulf of Alaska following the environmental disaster of the Exxon Valdez oil spill over 30 years ago. These monitoring programs have been successful in assessing recovery from oil spill impacts, and their continuation decades later has now provided an unparalleled assessment of ecosystem responses to another newly emerging global threat, marine heatwaves. The 2014-2016 northeast Pacific marine heatwave (PMH) in the Gulf of Alaska was the longest lasting heatwave globally over the past decade, with some cooling, but also continued warm conditions through 2019. Our analysis of 187 time series from primary production to commercial fisheries and nearshore intertidal to offshore oceanic domains demonstrate abrupt changes across trophic levels, with many responses persisting up to at least 5 years after the onset of the heatwave. Furthermore, our suite of metrics showed novel community-level groupings relative to at least a decade prior to the heatwave. Given anticipated increases in marine heatwaves under current climate projections, it remains uncertain when or if the Gulf of Alaska ecosystem will return to a pre-PMH state.