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Pinniped Predation on Salmonids in the Washington Portions of the Salish Sea and Outer Coast

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EXECUTIVE SUMMARY

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. Key findings are summarized below.

Pinniped and Salmonid Populations in the Salish Sea

The most common pinnipeds inhabiting the Washington State Salish Sea and outer coastal waters are harbor seals, California sea lions, and Steller sea lions, and all have increased in number substantially since the MMPA was enacted by the US Congress in 1972. Although this report makes no attempt to evaluate whether current population levels are at carrying capacity in Washington State, we acknowledge that historical human harvests of pinnipeds likely kept pinniped population sizes smaller than those currently observed. Unfortunately, pre-MMPA population data are not available to provide reliable baseline comparison levels for present day abundance of pinnipeds.

Salmonids are an important economic and cultural resource for Washington State. Populations of wild Chinook salmon, coho salmon, sockeye salmon, and steelhead have decreased from the 1970s to the present.

Trophic interactions involving pinnipeds and salmonids in the Salish Sea and Outer Coast are numerous and complex. Pinnipeds and salmonids exist within a greater ecological context and food web; many of those trophic interactions have the potential to either mediate the impact of pinniped predation on salmonids or affect the outcome of management actions aimed at reducing pinniped predation on salmon. The increase in pinniped populations in Washington State since the enactment of the MMPA has likely influenced the structure of the entire ecosystem. Given the large number of trophic links between pinnipeds and salmonids and the potential for direct and indirect ecological interactions, it is impossible to predict with certainty the outcomes for salmon and the rest of the food web under scenarios where the pinniped population size is changed.

Pinniped Diet Composition

It is widely understood that harbor seals, Steller sea lions, and California sea lions are predators of all age classes of Pacific salmon. Detailed studies of stomach contents of dead pinnipeds and examination of pinniped scat also suggest substantial variation across locations within Washington State waters and over time with respect to species and age-classes of salmon and the proportion of the pinniped diet they constitute. In specific locations and during certain seasons, pinniped predation on salmon is intense and reduces the number of adult salmon reaching spawning grounds. Diet studies also show that pinnipeds have a broad diet composition, including a variety of species beyond salmonids that include species that are both predators of salmon (e.g., Pacific hake) and prey of salmon (e.g., Pacific herring).

Several modeling approaches have been used in recent years to estimate the number of salmon consumed by pinnipeds in Washington State waters. While all make simplifying assumptions about the nature of pinniped-salmon interactions, all demonstrate that the number of salmon eaten by pinnipeds currently is substantial and has increased steadily since the passage of the MMPA, paralleling pinniped population increases. Although these reconstructions are useful for understanding general trends in predation intensity in Washington State waters, they do not necessarily provide an accurate reflection of specific predation rates on individual salmon populations, nor do they allow an explicit determination of whether pinniped predation is depressing salmon abundances at either the ecosystem level or on individual salmon stocks.

Rate of Pinniped Predation on Salmonids

Due to low abundance of threatened salmonids and large numbers of pinnipeds, even minimal predation can strongly impact salmonid stocks. Rates of pinniped predation on salmonids vary spatially, seasonally, and intra-annually, and by sex of the pinniped.

Certain aspects of the natural and constructed environment can affect pinniped predation on salmon by causing salmon to congregate in certain areas, influencing salmon migration and anti-predation behaviors, or increasing pinniped predation behavior. Salmon aggregate in the marine environment at habitat features that increase biological productivity. Artificial structures can interfere with salmon migration behavior and cause increased vulnerability to predation by compromising or reducing the effectiveness of salmonid anti-predator behaviors.

Several lines of evidence suggest that some individual pinnipeds act as salmon 'specialists', preying heavily on salmonids. It is thought that the population-level generalist diet of harbor seals in the Salish Sea and Steller sea lions along the Outer Coast is actually comprised of a mixture of individual specialists. Importantly, pinnipeds can learn successful foraging habits and change their foraging behavior based on knowledge transmitted by others of their species. Research suggests that the size, behavior, and origin of salmon may also play a role in determining which salmon are consumed by pinnipeds.

There is some evidence of prey buffering, the hypothesis that pinniped consumption of salmonids would be reduced by the increased presence of alternative prey species such as herring. However, it is not known if feeding on abundant alternative prey would increase pinniped populations, potentially intensifying the impact of pinniped predation on salmonids.

Impacts of Pinniped Predation on Salmon Recovery

The evidence summarized above is consistent with the hypothesis that pinniped predation is a plausible explanation for reduced abundance of salmon in Washington State waters and lack of salmon recovery following efforts to protect them. However, this evidence does not support a definitive conclusion that pinnipeds are a primary cause of the lack of salmonid population recovery in these ecosystems. Among the most important sources of uncertainty are: 1) whether pinniped predation appreciably adds to the mortality of salmon or whether pinnipeds are simply killing individuals that would otherwise die before maturing to adulthood (i.e., 'compensatory' mortality), 2) the role of alternative prey (e.g., herring) in either increasing pinniped populations and thus predation rates on salmon or decreasing predation by providing alternative food sources, and 3) whether the indirect effect of pinniped predation on salmon predators such as Pacific hake offsets the direct impact of pinniped predation on salmonids.

Scientific research to improve our understanding of pinniped - salmon ecological interactions (e.g., further characterization of behavior and diet) will resolve some of the uncertainties in our understanding of the role of pinnipeds as predators in salmon food webs. Development and refinement of models to synthesize field observations will be essential in interpreting emerging information from new and ongoing field studies. These focused studies will continue to build the body of knowledge about species interactions. These approaches, however, are not likely to lead to robust conclusions about the role of pinniped predation in the depression of Washington State salmon populations. Providing concrete answers to the question that motivated the WDFW request for this report – Are pinnipeds currently impeding the recovery of salmon? **– will require robust adaptive management approaches that experimentally change pinniped populations at spatial and temporal scales that can meaningfully impact the ecosystem.**

Strategic and appropriately scaled adaptive management of pinniped populations is key to resolving these uncertainties but will require carefully constructed lethal removals and intensive monitoring of salmon. Other approaches are unlikely to lead to fundamentally new insights. Importantly, however, current uncertainties about the salmon-pinniped system should not be perceived as an obstacle to adaptive management, but rather should motivate well-crafted experimental approaches funded with adequate resources.

Such experiments might involve changing the MMPA to allow applications from researchers from Tribal, State, or Federal governments for research permits of the MMPA for more geographically focused manipulations of local pinniped behaviors or abundances or the encouragement of treaty-protected tribal harvests of pinnipeds. Because the MMPA currently imposes severe constraints on the potential scope of such experiments, meaningful management action within the waters of coastal Washington or the Salish Sea is unlikely in the absence of legislative changes to the Act. However, maintaining the status quo of management actions without a more thorough understanding of the role of pinnipeds in this ecosystem could further depress salmon populations that play an important ecological, social, and economic role in the inner and outer coastal ecosystems of Washington State.

INTERPRETATION OF CHARGE AND APPROACH

The Washington State Legislature directed the Washington Department of Fish and Wildlife (WDFW) to request that the Washington State Academy of Sciences (WSAS) conduct a scientific and technical review of the science of pinniped predation on salmonids, with an emphasis on Washington's portion of the Salish Sea and Washington's outer coast. The proviso language indicated that the review should include: "*what is known about pinniped predation of salmonids, and with what level of certainty; where the knowledge gaps are; where additional research is needed; how the science may inform decision makers; and assessment of the scientific and technical aspects of potential management actions*." The impetus for this proviso language was a recommendation from the 2018 Southern Resident Orca Task Force Report, which states:

> *"…coordinate an independent science panel (Washington Academy of Sciences or National Academy of Sciences) to review and evaluate research needed to determine the extent of pinniped predation on Chinook salmon in Puget Sound and Washington's outer coast…"*

The WSAS Committee on Pinniped Predation on Salmonids, hereafter referred to as "the committee," has prepared this summary of the current state of research on pinniped predation on salmonids, the knowledge gaps and uncertainties, and the scientific and technical aspects of potential management actions. Early in the project, WDFW, in coordination with the Northwest Indian Fisheries Commission (NWIFC) and western Washington treaty tribes, provided a set of guiding questions for the committee (Appendix B). The committee sought to address these guiding questions while focusing on the key question at hand: How does pinniped predation impact salmonids? The committee would like to note at the outset, however, that many of the questions lack associated research findings that can provide clear answers and thus cannot be answered with certainty; in these instances, the committee instead describes the extent of the available information and the additional research required to obtain answers.

The committee interpreted the scope of work as including pinniped predation on salmonids in Washington State waters, impacts of pinniped predation on salmon recovery, potential effectiveness of management actions, unknowns and uncertainties, and future directions for research to address gaps in data and information. The committee examined peer-reviewed literature and reports that are not formally peer reviewed (e.g. government and contractor products). In this review, the committee aimed to address the applicability of the science to the management context, outline how current evidence can inform management, and describe the characteristics of research needed to further inform management strategies.

Some topics are not covered in the interpretation of scope. First, the committee acknowledges animal welfare issues concerning potential harvest or management of pinnipeds, but did not interpret this issue to be within the scope of this report review. Second, the committee would like to highlight one of the most uncertain aspects of the science surrounding pinniped predation; the inherent difficulty of making interpretations about an entire ecosystem based on studies of individual predators or specific sites.

There is an urgent need for better understanding of how the entire ecosystem operates and can be managed to protect salmon, and it is unlikely that a collection of smaller-scale studies can lead to such an understanding. There are substantial uncertainties and challenges in generalizing predation patterns across the region and acquiring specific details needed to make management decisions.

In this report, the committee identifies gaps and uncertainties in the existing knowledge around pinniped predation on salmonids and suggests areas for future research to support more informed decision-making around the management of pinniped predation. The committee notes that with sufficient resources and time, some of these gaps can be addressed. However, we highlight areas of system-level research and management interventions that are more likely to move us closer to understanding the problems and solutions in Washington State.

Committee Process

The committee met virtually on December 17, 2021, January 31, 2022, February 22, 2022, April 21, 2022, May 5, 2022, July 5, 2022, August 4, 2022, and September 30, 2022. These meetings each lasted about two hours and were the key touchpoints for the committee to discuss and deliberate on the issues identified during the drafting of this report.

The committee also hosted two workshops to engage with scientists and stakeholders involved in work related to pinniped predation. The committee hosted an online workshop on February 9, 2022, where members of the scientific community (state/tribal/federal/academic, etc.) shared relevant published and unpublished research, data, and context for existing and current studies. The committee hosted another workshop on March 14, 2022, for stakeholders to share additional research, context, and information about current efforts with the committee. In total, nearly 200 scientists and stakeholders participated in these workshops. Summaries of both workshops are available at the WSAS website (washacad.org/portfolio-items/pinniped-predation/). As an interim product, the committee also created a bibliography listing relevant research papers identified by the committee as well as through the scientific and stakeholder workshops. The final version of this extensive reference list is included at the end of this report.

The committee also heard from the National Oceanographic and Atmospheric Administration's National Marine Fisheries Service West Coast Region about management options under the Marine Mammal Protection Act in a meeting on August 11, 2022. In addition, the committee hosted a meeting with WDFW and tribal co-managers on September 9, 2022, to clarify management questions. The committee also met on October 13, 2022, with invited members of the scientific community, including tribal and non-tribal managers and stewards, who have used non-lethal deterrents during research and management for the committee to gather specific knowledge on the efficacy of pinniped deterrents (participant list in Appendix C).

This report has been written as a consensus view of the committee based on its deliberations. The report has undergone peer review from members of the WSAS Board of Directors.

DEFINITIONS

The following definitions are used throughout this report. These definitions are specific to this report and may differ from uses in other contexts.

Stock: A group of salmon of the same species that spawn in the same geographic area

Haulout: An area of land used by pinnipeds for resting between foraging periods

Carrying capacity: The maximum size of a species' population that can be supported sustainably in a given environment.

Salish Sea: Inland marine waters of Washington State, including Puget Sound and the Strait of Juan de Fuca; extends into the Strait of Georgia in Canadian waters as well. We use Salish Sea to refer to broadly applicable processes or findings and more specific place names (e.g., Puget Sound, Hood Canal, or the Strait of Juan de Fuca) when studies are spatially dependent or where inference should not be drawn beyond the study area.

Estuaries: The confluence sites of fresh and salt water at river mouths.

Predation rate: How many salmon are eaten by pinnipeds per unit of time.

Additive mortality: Mortality in direct association with commensurate increases in total population mortality

Compensatory mortality: Mortality that does not result in a commensurate increase in total population mortality because of a decrease in mortality rate from other sources.

Specialist individuals: Individual animals that use a smaller subset of resources than the population as a whole; in this case, individual pinnipeds whose foraging behavior specifically targets salmon.

Generalist individuals: Individual animals that use a wider range of resources than used on average by the population.

I. PINNIPED AND SALMONID POPULATIONS IN THE SALISH SEA AND OUTER COAST OF WASHINGTON

The following descriptions of pinniped and salmonid populations and their trophic interactions within the larger food web in Washington's portion of the Salish Sea and Washington's outer coast are provided as context for this report's discussion of pinniped predation on salmonids.

Pinniped Populations

Pinnipeds in Washington waters that prey upon Pacific salmon include harbor seals, Steller sea lions, and California sea lions. Over time, population sizes of all three of these resident species have increased.

Table 1. Population estimates, body weight, and primary prey families for the principal pinniped predators of Pacific salmon in Washington State waters

Pinniped	**Population estimate in Washington waters**	**Body Weight** *(Wynne 1993)*	**Primary prey families include**
Harbor seal	US Salish Sea, 2013-2016: ~10,900 *(Jefferson et al. 2021)* Washington's Outer Coast, 1999: ~10,400 *(Jeffries et al. 2003)*	Adult males and females average 250 lbs.	Clupeidae, Merlucciidae, Perciformes, Pleuronectiformes, Salmonidae, Scorpaeniformes, Gadidae *(Steingass 2017, Thomas et al. 2022)*
Steller sea lion	~2,000 *(Wiles 2015)*	Adult males average 1500 lbs., females average 600 lbs.	Clupeidae, Salmonidae, Sebastidae, Rajidae, Pleuronectiformes, Squalidae, Gadidae, and Merlucciidae *(Lewis 2022, Scordino et al. 2022a, b)*
California sea lion	~3,000-5,000 *(Jeffries et al 2000);* migratory	Adult males average 800 lbs., females average 250 lbs.	Clupeidae, Salmonidae, Sebastidae, Rajidae, Pleuronectiformes, Squalidae, and Merlucciidae *(Scordino et al. 2022a, b)*

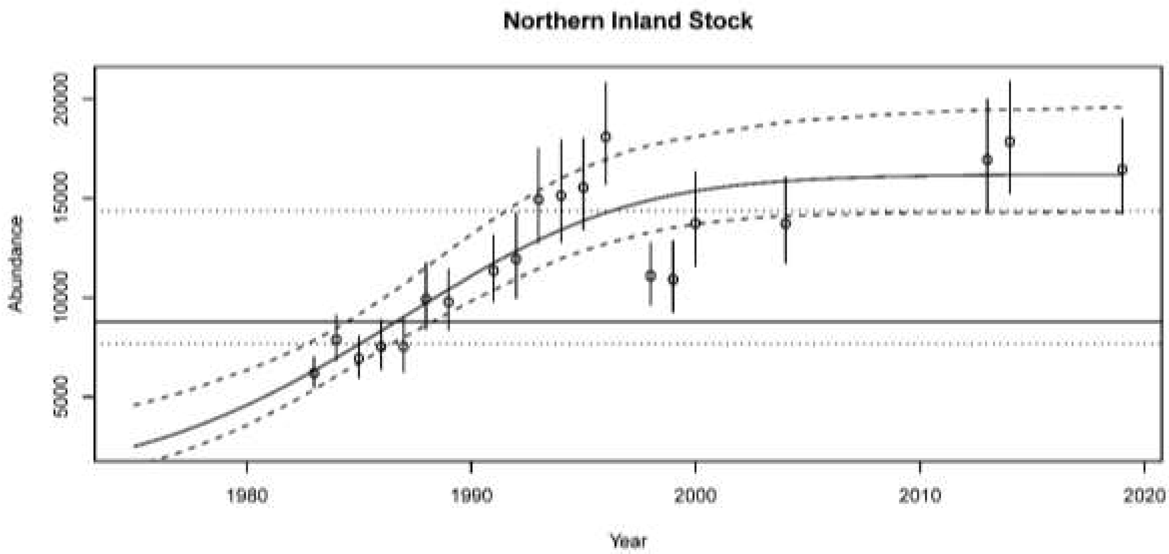
Harbor Seals

Following protection from the MMPA starting in 1972, harbor seal populations in Washington State waters rose steadily until the late 1990s (Jeffries et al. 2003). Harbor seal populations in the Washington's part of the Salish Sea have leveled off since then and appear to have maintained relatively constant numbers for some time (Jeffries et al. 2003, Jefferson et al. 2021, Pearson in review; Figure 1).

The population of harbor seals along the outer coast has also been relatively constant in recent years (Figure 1, Pearson in review). Some scientists believe that this species has reached carrying capacity within Washington State waters.

Harbor seals are widely distributed throughout Washington waters, including the Salish Sea and the outer coast (Jeffries et al 2000). Harbor seals likely had similar geographic ranges in the past as compared to present, but may have had a smaller population due to Indigenous harvest (Erlandson et al. 2019).

Figure 1: Populations of harbor seals in the Salish Sea, 1977-2019, specifically (top) the Northern Inland Stock and (bottom) Southern Puget Sound (Pearson *in review*).



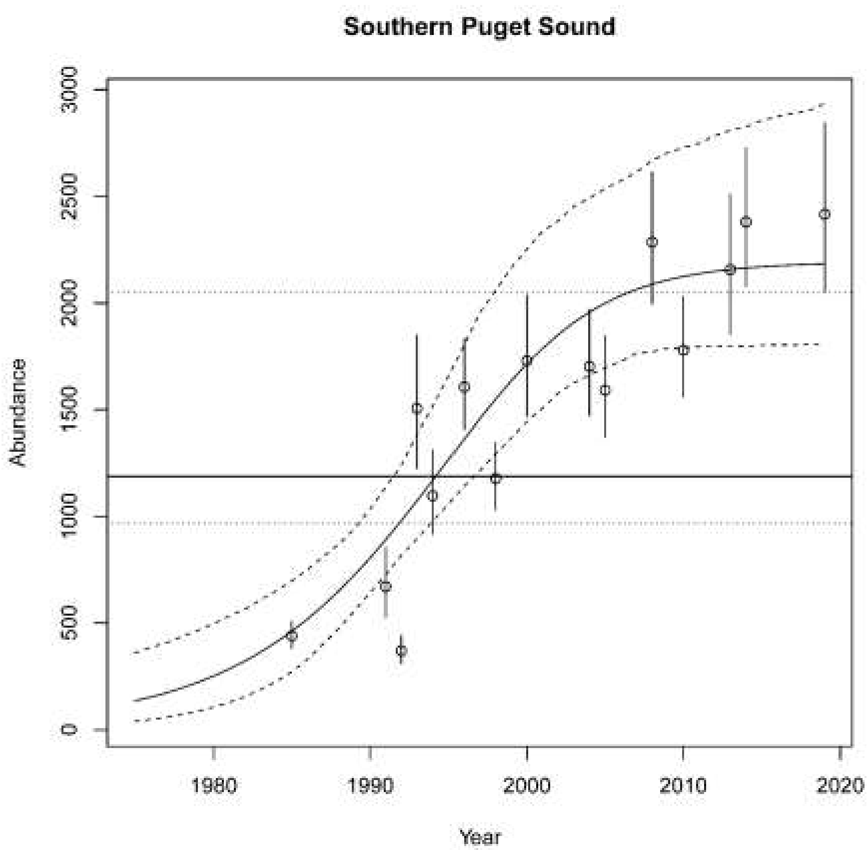


Figure 2: Populations of harbor seals in Washington's outer coast, 1977-2019 (Pearson *in review*).

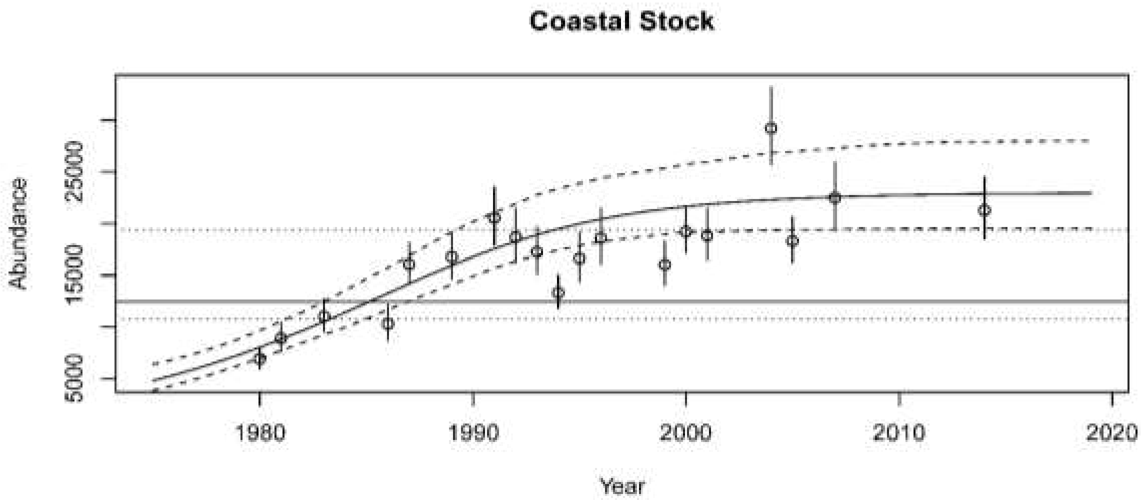
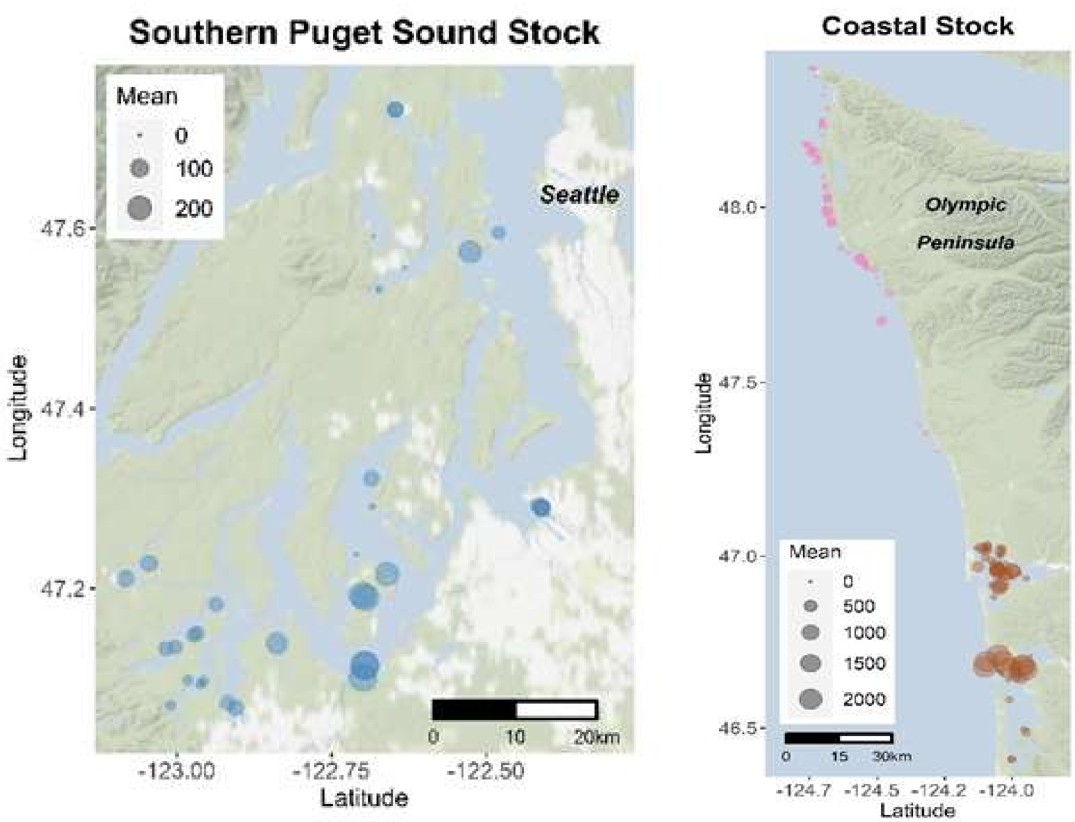


Figure 3: Distribution of harbor seal haulouts in Puget Sound (left) and on the outer coast of Washington State (right) (Pearson 2022)



Steller Sea Lions

Steller sea lion populations continue to rise between California and Southeast Alaska (Carretta et al. 2021, Trites 2021) with increasing counts in Washington State (Wiles 2015, Allyn and Scordino 2020). There have been no studies suggesting that Steller sea lions of the eastern distinct population segment are approaching carrying capacity (Muto et al 2022, Allyn and Scordino 2020). However, a presentation given to the Committee suggested that population growth has slowed in Washington State in recent years (Clark 2022).

Approximately half of the Washington Steller sea lion population of ~2000 animals use haulouts on the northern Washington coast between Sea Lion Rock and Tatoosh Island. There is no previous documentation of Steller sea lion rookery sites in Washington (Wiles 2015): however, in recent years, 2 rookeries were established on the northern Washington coast (Scordino et al. 2022a, b).

Historically, the geographic range of Steller sea lions was likely similar to present-day distribution, though the population may have been smaller due to harvesting practices by Indigenous peoples (Erlandson et al. 2019).

Figure 4: Average annual boat-based counts of sea lions in the Pacific Ocean between Cape Flattery and Sea Lion Rock (Allyn & Scordino 2020)

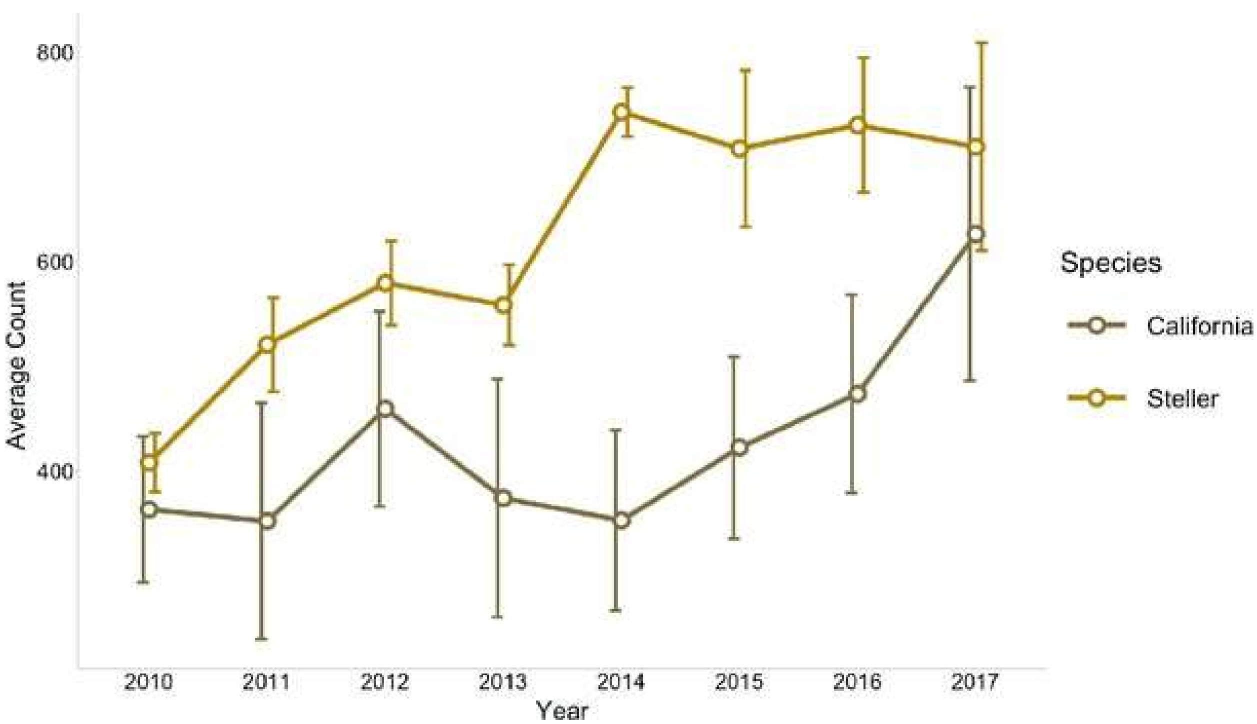


Figure 5: Steller sea lion distribution (Pearson 2022)

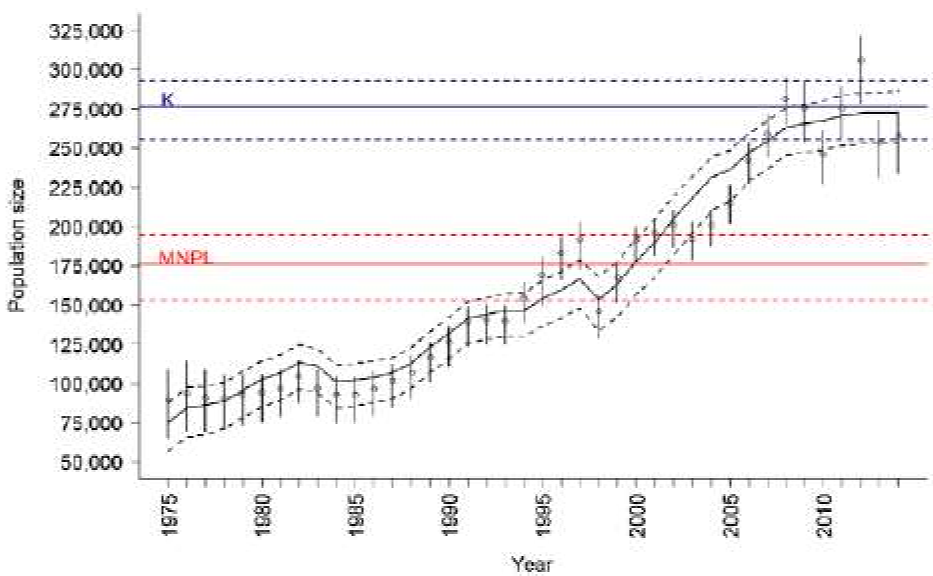
California Sea Lions

California sea lions breed in Mexico and California and migrate into Washington waters. Counts of California sea lions in Washington have increased over time; haulout sites on the northwest coast of Washington show steady increases in population counts of California sea lions (Allyn & Scordino 2020, Figure 5, Figure 6).

In the past, California sea lions migrating into Washington were assumed to be all mature males. In recent decades, a higher number of young and female California sea lions have been observed north of California (Maniscalco et al. 2004) including in Washington waters (Akmajian et al. 2014; Scordino et al. 2014; Scordino et al. 2022a, b). California sea lions are approaching carrying capacity at their breeding sites in US waters (West coast stock: Laake et al. 2019). The California sea lion population may continue expanding if they establish breeding sites beyond the Channel Islands of California (González-Suárez and Gerber 2008; Jefferson et al 2021; Lowry et al. 2017).

Up until 1978, California sea lions were only known to use the outer coast and the Strait of Juan de Fuca (Kenyon & Scheffer 1962, Everitt et al. 1979). In 1979, a large group of California sea lions was observed at Port Gardner, the first known record in Puget Sound (Everitt et al. 1980). There is evidence of male California sea lions expanding their non-breeding season range in recent decades with increased use of Washington waters starting in the 1970s (Edgel & Demarchi 2012) and the current distribution of males and females now extending into Alaska (Maniscalco et al. 2004). Notably, California sea lions use haulouts on coastlines but also commonly use human-made structures like docks, log booms, and jetties that are rarely used by Steller sea lions.

Figure 6: Trends in California Sea Lion population size in the eastern Pacific (Carretta et al., 2021)



The largest rookeries for California sea lions are currently on the Channel Islands (Carretta et al 2021). Historically, the Channel Islands were used by the Chumash Tribe who hunted the sea lions, which likely reduced their population size and restricted their breeding distribution to small islands off the main Channel Islands (Erlandson et al. 2019). As a result, California sea lions would have had a much more restricted range in the past as compared to their present distribution (Erlandson et al. 2019). Some paleobiological evidence suggests that California sea lions had a rookery in Oregon during the period of 100-3,000 years ago (Lyman 1988). It is not definitively known whether California sea lions were present in Washington waters during the same period but if they were, they were probably not common (Etnier & Sepez, 2008).

Figure 7: California sea lion distribution (Pearson 2022)

Historical Context for Contemporary Pinniped Abundance

The Salish Sea and Washington Outer Coast ecosystems have changed over time in both species composition and population levels of pinnipeds. Historical documentation and traditional ecological knowledge inform the understanding of historic pinniped population size, distribution, and the associated impacts to salmon. Prior to European settlement of North America, pinniped population size and distribution were likely strongly influenced by Native American hunting (Erlandson et al. 2019, Hildebrandt and Jones 2002).

Historical knowledge influences the understanding of the natural state of the Puget Sound and outer coast ecosystems. It is possible that historical human harvest of pinnipeds kept pinniped population size at lower numbers than observed today in the absence of human predation. It is generally accepted that the Marine Mammal Protection Act (MMPA), passed in 1972, curtailed state-sponsored, tribal, and private citizen efforts to lethally manage or harvest pinnipeds, leading to population recovery.

Historical changes in the distribution and population sizes of salmon-eating pinnipeds have occurred within the context of broader ecosystem changes over the past few centuries. No direct information on absolute numbers of harbor seals, Steller sea lions, and California sea lions in Washington waters in the historical past exists. However, northern fur seals, which are part of the broader food web for pinniped-salmonid interactions, appear to have had a much greater population size and a broader distribution of breeding rookeries than observed currently (Lyman 1988, Burton et al. 2001, Etnier 2007). Archaeological sites indicate that both Guadalupe fur seal and northern fur seal populations 200 to 400 years ago were larger and more widely distributed than they are currently (Etnier 2002; Etnier 2004).

Pinniped Population Carrying Capacity

Pinniped carrying capacity, the maximum size of a species' population that can be sustainably supported by a given environment, is a key component of pinniped population trends and their related effects on salmon populations. In Washington, potential limiting factors of pinniped carrying capacity include predation, food availability, and haulout and rookery space.

The Committee discussed the potential that transient killer whale predation may be limiting the population size of harbor seals (London 2006, Shields et al. 2018). However, the population size of harbor seals in the Salish Sea appears to have leveled off prior to the increase in transient killer whale use of the area, which appears to be increasing in recent years (Shields et al. 2018) without concurrent declines in harbor seal population size (Clark 2022).

Food scarcity can also limit carrying capacity. Indicators of food scarcity could include increased strandings of emaciated individuals, reduced pup production, and reduced pup survival. Stranding records gathered by the Marine Mammal Stranding Network do show a rapid increase of strandings of both pups and all ages of harbor seals at the time that the population appeared to level out, but this finding is confounded by increased human interactions (Warlick et al. 2018). As density of individuals using a haulout or rookery increases, disease transmission, conspecific aggression, and trampling of pups become more likely (Kim 2016, LeBoeuf et al. 2011).

Human use of coastal areas may create habitat limitations for harbor seals (Becker et al. 2011) but may also increase haulout habitats for harbor seals (Jeffries et al. 2000). While the State of Washington has suggested that the decline in the harbor seal population near Hood Canal since the 1970s is linked to reduced haulout availability, other studies suggest harbor seal populations are not limited by food or haulout space (Jefferson et al 2021).

Knowledge Gaps and Uncertainties

The most significant knowledge gaps around pinniped populations pertain to current distributions, movement of pinnipeds over time, and historical populations and distributions.

While existing haulout maps (e.g. Jeffries et al, 2000) are useful in terms of understanding pinniped distributions, an updated haulout map for the entire state of Washington (including new data from recent aerial surveys of Puget Sound) would be helpful for understanding the current distribution of pinnipeds. The committee recognizes that it would be a highly intensive effort to conduct sufficiently fine-scale studies that account for seasonal changes and geographic variation in pinniped population size, distribution, and behavior to create an accurate map.

More research and analysis, including modeling of existing data on pinniped distributions over time, is needed to better understand the movement of pinnipeds, population trends, and related implications for predation on salmonids. For example, a large number of California and Steller sea lions that use Washington waters were individually branded for studies of their life histories, but the resight patterns of branded individuals are largely unanalyzed (except see Scordino 2006). Two studies report on the movements of satellite tagged Steller sea lions that used Washington waters (Laughlin et al. 2003, Olesiuk 2018) and two on California sea lions (Wright et al. 2010, Gearin et al. 2017), but the studies addressed other objectives and did not focus on how the sea lions used the marine waters of Washington State. More is known about harbor seal movements than other pinniped species in Washington State (e.g., Peterson et al. 2012), but knowledge is still relatively poor and outdated, particularly along the outer coast.

Increased understanding of historical pinniped populations and distributions is also needed. The committee acknowledges that traditional ecological knowledge often contributes valuable historical data and suggests conducting a linguistics study to determine whether the languages of local Indigenous groups contain references to California sea lions. The committee also suggests examining traditional ecological knowledge to determine whether California sea lions have historically been present in Washington waters.

Salmonid Populations

Salmon are an important economic and cultural resource for Washington State. This report, and others like it, have been motivated by declines in salmon populations. Some salmonid species and stocks are in such crisis that they are listed under the Endangered Species Act of 1973 and their population trends do not show evidence of recovery.

A comprehensive summary of the status of salmonids in Washington State waters is neither possible with the currently available data on stock abundances, nor is it within the specific scope of this committee. However, some general trends in population size are worth noting as a means of motivating discussion of this report and providing context to the concerns about increasing pinniped predation on salmonids in Washington State waters.

Six species of salmonids pass through the Salish Sea on their way to the Pacific Ocean: Chinook, chum, coho, pink, and sockeye salmon, and steelhead trout. Chinook salmon comprise a large proportion of outmigrating juveniles, with approximately 5 million natural origin fish outmigrating each year and another 20-30 million hatchery origin fish released each year over the last decade (Nelson et al 2021).

The Chinook salmon hatchery release population size at times has exceeded 70 million fish per year, with peaks in the late 1980s (Nelson et al. 2019a). Coho salmon smolt production is currently 10-13 million a year, split between natural and hatchery-origin (Nelson et al. 2021). While the majority migrate to the Pacific Ocean, a non-trivial proportion of most species stay resident within Puget Sound, especially Chinook and coho salmon (Quinn and Losee 2021).

Data for Puget Sound stocks clearly show general trends and demographic characteristics of salmon and steelhead; populations of wild Chinook salmon, coho salmon, sockeye salmon, and steelhead have decreased from the 1970s to the present (Losee et al. 2019, Figure 8). At the same time, populations of hatchery-produced Chinook salmon have increased, as have wild and hatchery populations of chum and pink salmon.

Reliable data on salmon population size outside of Puget Sound are sparse, creating challenges in establishing trends over time. Nonetheless, data from a collection of coho salmon populations in both Puget Sound and the outer coast show a coherent trend towards reduced numbers of wild coho between 1986 and 2020 (Figure 9). The committee was not able to access data covering a comparable timeframe for other species of salmon throughout Washington State waters.

Since the 1970s, the average body size of returning adult Puget Sound Chinook salmon, sockeye salmon, chum salmon, pink salmon and steelhead has declined (Losee et al. 2019). Only coho salmon have shown a different pattern, with interdecadal variation in the average size of mature adults (Figure 8).

In the late 1970s, salmon marine survival appears to have been higher than in recent decades characterized by poor marine survival rates (Pearsall et al. 2021), especially among hatchery-origin fish (e.g., Zimmerman et al. 2015). Marine survival rate, primarily measured as smolt-to-adult return from recaptures of tagged salmon, has been suggested to be lower for steelhead (Kendall et al. 2017), coho (Zimmerman et al. 2015), and Chinook salmon (Ruff et al. 2017) in the Salish Sea than for coastal populations. Although several causes of this decline, including reduced prey availability to disease (Pearsall et al. 2021) are plausible, pinniped predation is considered a primary driver of increasing mortality rates (Berejikian et al. 2016, Nelson 2020, Moore et al. 2021, Sobocinski et al. 2021).

Figure 8: “Body mass (a), abundance (b) and survival or productivity rate (c) of Pacific salmon and steelhead in Puget Sound from 1970 to 2015. Circles represent annual estimates for naturally produced (open circles), hatchery-produced (closed circles) and unknown origin (grey circles) salmon and steelhead. Dashed (for naturally produced fish) and solid (for hatchery-produced fish) lines represent slopes that are statistically different than zero at the p < 0.05 significance level.” (Losee et. al 2019)

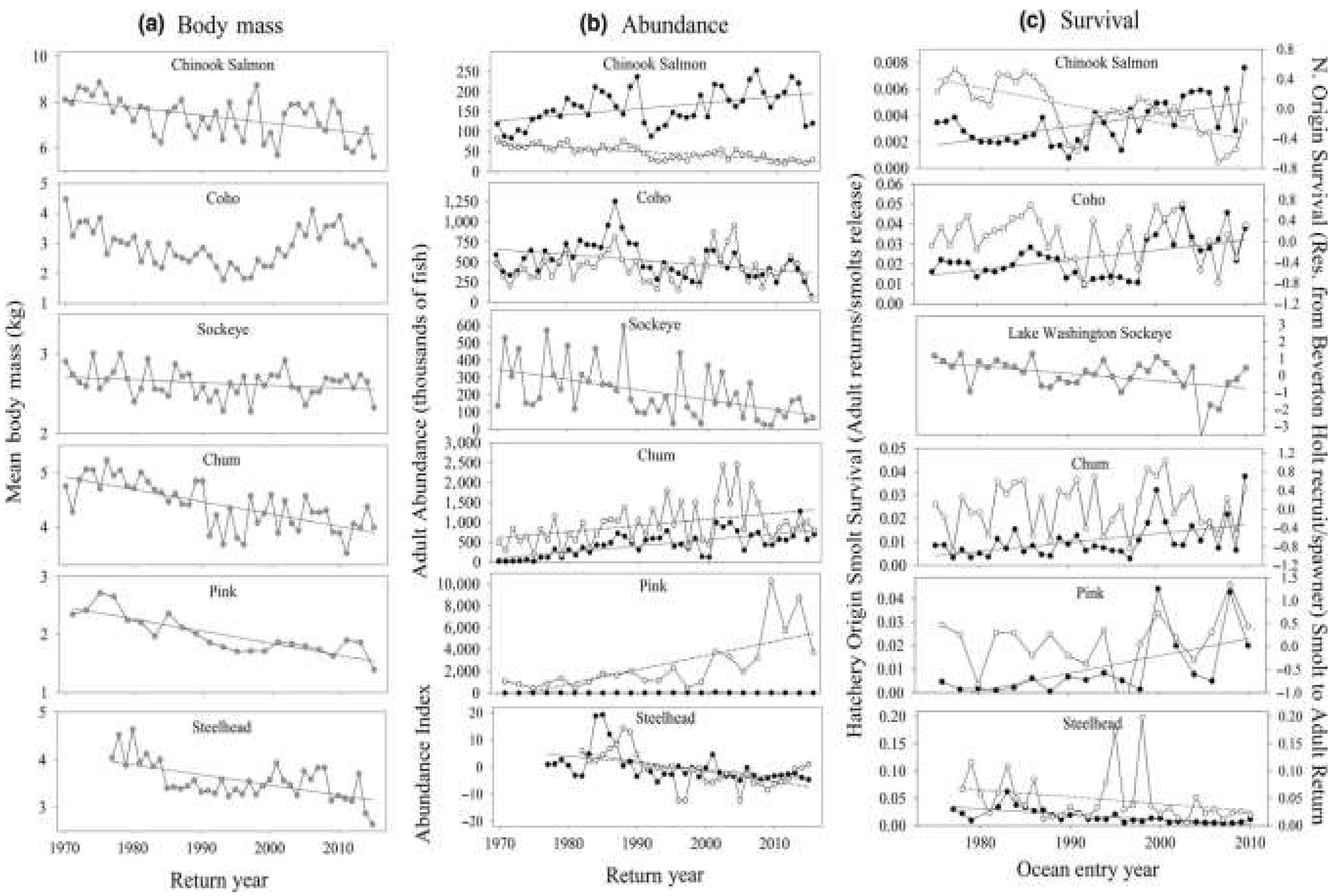
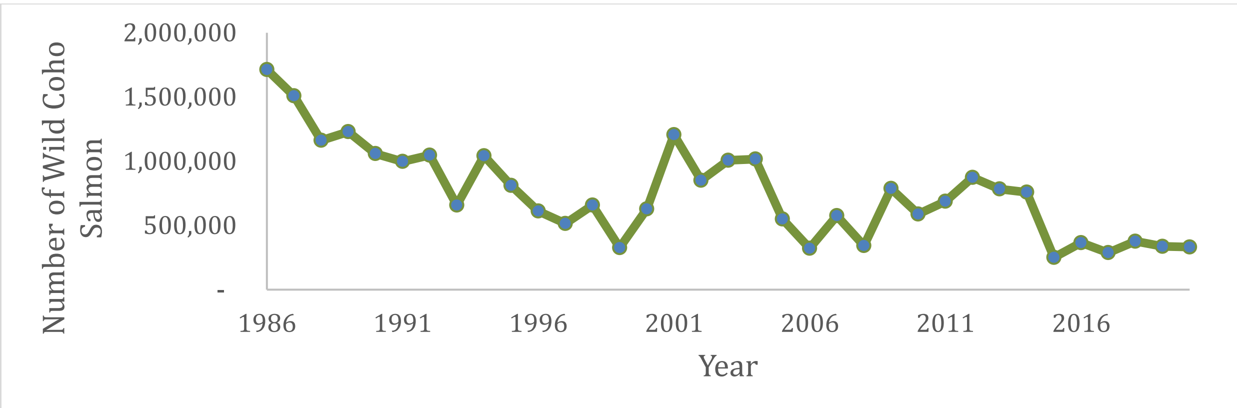


Figure 9. Figure 9. Population size of selected wild stocks of coho salmon (escapement plus fishery harvest) throughout Washington State waters from 1986-2020. Stocks included in this plot are: Area 10, Area 10E, Area 11, Area 12/12B, Area 12A, Area 12C/12D, Area 13, Area 13A, Area 13B, Area 7/7A, Baker (Skagit), Chehalis River, Deschutes River (WA), Dungeness River, East JDF, Elwha River, Grays Harbor, Hoh River, Humptulips River, Lake Washington, Nisqually River, Nooksack River, Puyallup River, Queets River Fall, Quillayute River Fall, Quillayute River Summer, Quinault River Fall, Samish River, Skagit River, Skokomish River, Snohomish River, Stillaguamish River, Wash Early, Wash Late, West JDF, Willapa Bay. Data are from Pacific Salmon Commission Coho Technical Committee Post-Season Coho FRAM Database through 2020, updated 2/16/2022, provided by Angelika Hagen-Breaux.



Knowledge Gaps and Uncertainties

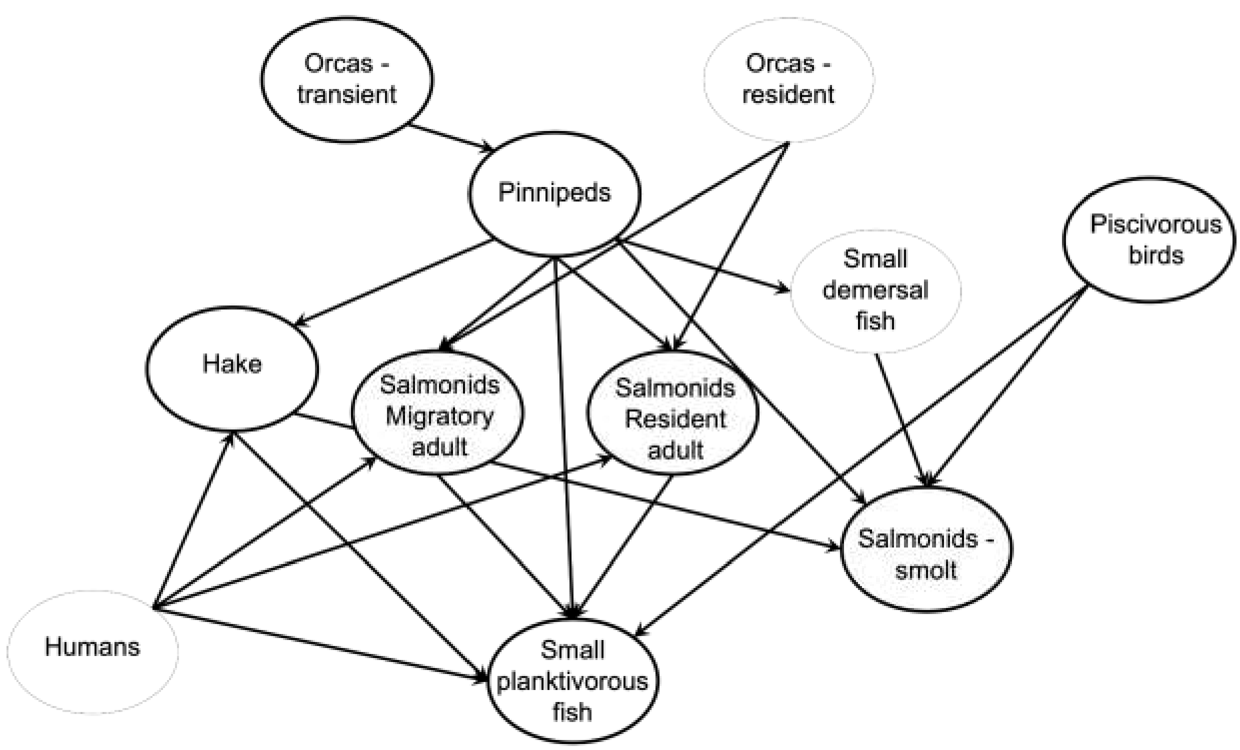
The committee has identified the primary data gaps around salmonid populations as a lack of standardized comparison of population trends across Washington waters and information on juvenile salmon abundance and distribution in Puget Sound. The current data do not allow for a transparent and easily interpreted summary of historical and current population sizes of salmonid stocks throughout the state. A concerted effort focused on standardizing and organizing all available data on stock-specific escapement and harvest for all salmon species in Washington State waters will be critical for understanding trends in population sizes and interpreting the response to any future management actions. In addition, there are few data on juvenile salmon distribution and population size within Puget Sound, once away from river-mouth deltas. There is also a need for further research on this issue to better understand the current status.

Trophic Relationships

Trophic interactions involving pinnipeds and salmonids in the Salish Sea and Outer Coast are numerous and complex. Pinnipeds and salmonids exist within a greater ecological context and food web; many of these trophic interactions have the potential to either mediate the impact of pinniped predation on salmonids or affect the outcome of management actions aimed at reducing pinniped predation on salmon (Figure 10). Outcomes for salmon and the rest of the food web under scenarios in which the number of top predators changes are essentially impossible to predict with certainty.

The increase in pinniped populations in Washington State since the enactment of the MMPA in 1972 has likely influenced the structure of the entire ecosystem. Because they have broad geographic range and consume large amounts of prey, pinnipeds affect competitors, predators of, and prey species of Pacific salmon, as well as species occupying lower trophic levels. Ecological interactions, including those between pinnipeds and other predators, among pinnipeds, and with alternative prey, impact pinniped predation on salmonids. Seasonal variation in predation is another important factor when considering ecological interactions between pinnipeds and salmonids.

Figure 10: Food web diagram of known and potential trophic interactions thought to be most influential for pinniped predation on salmonids. The groups discussed in the text are highlighted. Original figure created by WSAS Committee on Pinniped Predation on Salmonids.



Other Salmonid Predators. One relevant trophic relationship is predation on salmon by non-pinniped species (such as hake, rockfishes, sculpins and other small demersal fishes, and piscivorous birds). Salmon at all life stages are consumed by a wide range of animals in Washington's marine waters, including mammals, birds, and other fishes.

Pinnipeds consume a wide range of prey, some of which are known predators of salmon throughout the Salish Sea and Washington Coast food webs (Harvey et al. 2012). One of the most common species in the diets of Puget Sound harbor seals and sea lions is Pacific hake, which are salmon predators (London et al. 2002). The proportion of hake in the diets of pinnipeds varies annually with hake population size and distribution (Scordino 2022a, Wiles 2015). Pacific hake prey on juvenile salmonids, although salmon may constitute a minor portion of the hake diet, which is dominated by euphausiids (small crustaceans) and herring (Ressler et al. 2007). Work in other systems has determined that culling of pinnipeds increases the population size of large piscivorous fish species when the proportion of that large piscivorous fish species in the pinniped diet is high (Punt and Butterworth 1995). This suggests that reductions in pinniped populations may release Pacific hake and other salmonid predator species from predation, potentially indirectly increasing salmon mortality rates.

However, the population of Pacific hake in Puget Sound has decreased by ~85% since the 1980s, as has their average body size, which may limit their predation on fish overall (Gustafson et al. 2000). Further, while reductions in pinniped populations may allow the populations of pinniped prey that are salmon predators to increase, the overall effects of such increases on salmon populations depends on multiple factors, including the response of fisheries harvest, making predator release effects difficult to predict.

Forage Fish. Pinnipeds are opportunistic predators and the degree to which they eat hake and other salmon predators likely depends on the presence of alternative prey, like herring and anchovies. One of the most common species in the diets of Puget Sound harbor seals and sea lions is Pacific herring (London et al. 2002). Pacific herring and Northern anchovy are considered forage fish, and are part of the pinniped diet but also are consumed by salmonids and hake (Harvey et al. 2012, Duffy et al. 2010). Data suggest pinniped predation on adult herring is a key factor in demographic characteristics of herring populations (Siple et al 2018); thus, reductions in pinnipeds could increase the availability of prey for adult salmon. It is possible that increased abundance of forage fish may either (a) support other salmon predators, including several species of birds and fishes (e.g., spiny dogfish), thus potentially increasing predator populations and predation pressure on salmon, or (b) swamp predator demand and increase the survival of juvenile salmon, buffering salmon from predation pressure (Harvey et al. 2012).

Pinniped Predators. Another factor influencing trophic relationships is the presence of transient killer whales that prey on seals and sea lions (Shields et al. 2018). Reductions in pinniped abundance could affect the health and population growth of transient killer whales. Changes in the abundance and distribution of pinnipeds may in turn alter the behavior of transient killer whales, with unknown feedbacks to pinniped populations and salmon recovery.

Knowledge Gaps and Uncertainties

It is difficult to predict with certainty the extent and duration of effects of a decrease in pinniped abundance on salmon populations, due to the large number of trophic links between pinnipeds and salmonids and the potential for important direct and indirect ecological interactions. For example, the role of small demersal fish in the diets of pinnipeds and as predators of juvenile salmon is not well-understood. In addition, information on how seals redistribute in response to killer whale predation and the subsequent impacts to salmonids is limited. An important unanswered question about this system is whether alternative prey bolsters pinniped populations or diverts attention away from salmon.

Models to explore the consequences of pinniped reductions for food webs of Washington marine waters are also lacking. More understanding is needed about the impacts of pinniped predation relative to other sources of predation (herons, other birds, and other fish like cutthroat trout) in rearing habitats and migratory paths. Overall, uncertainties regarding specific predator-prey interactions prevent adequate prediction of specific outcomes of system perturbations.

II. PINNIPED PREDATION ON SALMONIDS

To inform the discussion of pinniped predation on salmonids, this section begins with a summary of the diets of pinnipeds residing in Washington waters and how salmonids fit in the pinnipeds diet. It then reviews the rates of pinniped predation on salmonids, including factors that influence these rates.

Pinniped Diet Composition

Pinnipeds have wide-ranging diets that often include adult and juvenile salmon (Adams et al., 2016; London et al., 2002; Scordino 2010; Scordino et al., 2022b; Steingass, 2017; Thomas et al., 2022). However, existing research suggests significant variation in consumption of salmon between pinniped species and among individuals within a pinniped species. Much of the existing data on pinniped predation is context-specific by region, habitat (e.g., estuaries, rivers, outer coast, open ocean, constructed environments), and pinniped species. Rather than provide a comprehensive assessment of pinniped diet data, the following considerations relevant to understanding the impacts of pinniped predation on salmonids and can inform future management are highlighted.

Pinniped abundance and behavior. To obtain a full picture of pinniped predation on salmonids, pinniped diet data must be considered alongside population data. A single harbor seal may consume fewer salmon than a single Steller sea lion. However, harbor seals are so numerous in Puget Sound that they still consume many salmon (Chasco et al. 2017a, Howard et. 2013, Moore et al *in prep 2022a*). In addition, pinnipeds can be selective about prey regardless of relative abundance. For example, harbor seals in the Strait of Georgia consume higher percentages of juvenile coho, Chinook salmon, and sockeye compared to more abundant pink and chum (Thomas et al. 2017).

Seasonality. Pinnipeds consume salmon during all seasons of the year, not only during outbound migration of juveniles and inbound migration of adults. However, there is temporal variation in salmon consumption and this variation differs among species. Harbor seals tend to consume more salmon during salmon migrations, while the salmon predation rates of California sea lions on the outer coast are consistent in the spring, summer, and fall, though the consumption rates of the species consumed may vary (Scordino et al. 2022b). Salmon comprise a similar portion of the diet of Steller sea lions on the outer coast in the fall, winter, and spring but a much lower proportion during the summer (Scordino et al. 2022a).

Salmon life stage. Although pinnipeds consume both juvenile and adult salmonids, predation on juvenile salmonids varies in time and space and may be context-specific, for example, occurring most commonly among some pinnipeds that forage at river mouths and later in the season when juvenile salmon have grown larger (Allegue et al. 2020, Nelson et al. 2021). Because pinnipeds seem to consume juvenile fish with larger body sizes, models that track consumption without accounting for body size may overestimate the number of juvenile salmon consumed by pinnipeds (Nelson et al., 2021). However, whether pinnipeds consume juvenile salmon that would have likely died by other mortality sources remains a key uncertainty.

Historical shifts in pinniped diets. There is little historic pinniped diet data to evaluate shifts in pinniped diet over time. Emerging technologies examining trophic relationships from bones may in the future provide historical estimates of salmon consumption by pinnipeds (Newsome et al. 2009).

Interpreting Pinniped Diet Studies

Diet studies based on analysis of scat samples, which are some of the most prevalent diet studies, have significant limitations. These studies assume that scat represents the totality of what the animal has eaten. However, a number of variables can bias interpretations: First, scat represents a pinniped's most recent meals, but animals foraging in the open ocean and defecating prior to returning to their haulouts will not be accurately represented in studies using scats retrieved from haulouts to infer the full diet of the study animal. Second, passage rates through the pinniped digestive system of bones and other hard parts and spewing of bones also affect the recovery of prey remains in scat and may disproportionately affect the recovery of identifiable bones of some species or sizes of fish. Third, methods of reconstructing diet from prey remains in scat can introduce bias (Laake et al. 2002). For instance, split samples have demonstrated over reporting of the importance of small-bodied prey species and under reporting of large-bodied prey species (Olesiuk et al. 1990, Tollit et al. 2007). Studies of pinnipeds using stable isotope and fatty acid analyses may provide complementary long-term diet data (Bromaghin et al 2013, Bjorkland et al 2015).

In recent years, more pinniped diet studies have used DNA metabarcoding to analyze pinniped food habits and relative read rates to reconstruct pinniped diet (Thomas et al. 2016). However, both DNA metabarcoding and hard part analyses are subject to digestion bias, resulting in a different proportion of prey items found in studies than the actual proportions of prey ingested (Lance et al. 2001, Bowen and Iverson 2012, Thomas et al. 2016). These digestion biases have been estimated for hard parts analyses (Bowen and Iverson 2012) and must be calibrated for both predator species and expected prey species in DNA metabarcoding (Thomas et al. 2016).

Another challenge with scat analysis is the difficulty of determining what proportion of salmonid bones or DNA found in pinniped scat may have originated from a secondary source through the pinniped's consumption of a prey item that consumes salmon (Pierce & Boyle, 1991). To remove potential environmental contamination or secondary prey items from sample analysis in DNA metabarcoding, it is common practice to remove species accounting for <1% of read abundance within a sample (Littleford-Colquhoun et al. 2022).

Pinniped Foraging Behavior

Pinnipeds are typically considered central-place or multiple central-place foragers, meaning they seek prey radiating away from their 'central place' with greater foraging effort near that 'central place' than at sites further away (Orians & Pearson 1977, Womble et al. 2009). Pinnipeds generally make foraging trips away from terrestrial haulout sites and return to the central place to rest and provision young; most foraging activities occur near where they haul out, although sometimes they have extended activity at great distances from their haulouts (Loughlin et al. 2003, Wright et al. 2010, Gearin et al. 2017). The seasonal use of haulouts is correlated to the presence of prey (Womble et al 2009).

Pinnipeds can also move and forage well outside of their haulout locations. The tendency of harbor seals to travel far from the haulout location can vary by haulout location and sex, with males moving farther than females and crossing stock boundaries within the Salish Sea (Peterson et al 2012).

A study from Southeast Alaska suggests that Steller sea lions may frequent multiple central foraging areas to maximize foraging success by using haulouts in proximity to seasonal aggregations of fish (Womble et al. 2009). Observations of Steller sea lions show age- and sex-specific movement patterns. During the breeding season, younger Steller sea lions and males in Alaska and Oregon and California were generally more broadly distributed than older animals and females (Scordino 2006, Jemison et al., 2018). The distribution and range of movement of adult male Steller sea lions during the non-breeding season suggest that Steller sea lion males can travel substantial distances to forage for seasonally abundant prey whereas females generally stay within a few 100 kilometers of their rookery (Scordino 2006, Jemison et al., 2013).

Knowledge Gaps and Uncertainties

The most significant areas where knowledge is needed around pinniped diet composition include pinniped diet by habitat type, location-specific data by species, and year-round diet data. In addition, there are gaps in knowledge due to the limitations of diet study methodologies.

A helpful first step to assessing the knowledge gaps in diet information would be a meta-analysis of pinniped studies in Washington waters that compares pinniped diet by habitat type. For example, a study that overlays the distribution of salmon runs by life stage with an updated map of pinniped haulouts and estimates of seasonal salmon consumption for those haulouts compared to non-salmon consumption would provide a clearer overall picture of impacts of pinniped predation on salmonids.

To fill gaps in pinniped diet data in the region, the committee recommends conducting diet studies in areas where studies have been intermittent, with small sample size, or not conducted at all. For each species, there are knowledge gaps in particular locations. For example, while the diet of harbor seals in Puget Sound is well studied, the committee identified a need for more research on the diet of harbor seals residing in large coastal estuaries, and along the outer coast, as the data from Puget Sound cannot be generalized to the entire population. Conversely, diets of California and Steller sea lions are better studied on the outer coast than in Puget Sound. Our knowledge of California sea lion diet would benefit from studies throughout the state. Many of the studies conducted in the 1990s and 2000s focused on evaluating pinniped diet in river and estuary environments, where the taxa were thought to be impacting a salmon population (see Scordino 2010)), and at constructed sites (e.g., California sea lions at Ballard Locks; harbor seals at Hood Canal Bridge). The spatial gaps in diet data become particularly pronounced in individual studies; for example, a recent study recovered thousands of harbor seal scats at 52 haulouts over seven years (Thomas et al. 2022), but even these data are missing many critical regions (e.g., the outer coast, the coastal estuaries, and the Strait of Juan de Fuca).

In addition to spatial knowledge gaps, there are also temporal knowledge gaps about year-round salmon consumption. Most diet analyses occur during the summer and fall, and year-round analysis would likely provide further insights on whether and how predation rates fluctuate throughout the year. One study found that Steller sea lions consumed salmonids at a higher rate during the winter than during the summer (Scordino et al 2022a) — a counterintuitive finding since adult salmonids are abundant in the study area during the summer as they travel through the area to their spawning grounds. Other recent work found that salmonids composed a similar portion of Steller sea lion diet on the outer coast between summer and winter (Lewis 2022); these findings warrant further exploration. Long-term monitoring of pinniped diet from relevant and representative areas can address the spatial and temporal knowledge gaps.

Estimates of salmon consumption by pinnipeds based on diet-reconstructions are influenced by assumptions on the size of the salmon eaten (Chasco et al. 2017a,b, Nelson et al. 2021). Future studies of pinniped diet in Washington should commit to measuring all salmon bones that are of suitable quality for measuring for reconstructing the size classes of salmon consumed. Furthermore, many diet studies only report what portion of the diet is salmonidae without reporting the proportion of the diet comprised by each salmon species (Adams et al. 2016).

It is also desirable to evaluate how pinniped predation affects distinct evolutionarily significant units or distinct segments of salmon populations. As such, it would be beneficial to conduct genetic analyses of salmon bones to determine species and stock of origin. To classify the size-classes of salmon consumed, individual stocks of salmon, and estimate the overall proportion of salmon in pinniped diet by species it is recommended that future studies utilize both hard part analysis and DNA metabarcoding and conduct genetic analyses on recovered salmon bones to determine stock of origin.

With respect to pinniped foraging behavior, the committee encourages future research to determine if behavioral variation exists between pinnipeds that eat salmon and those that do not. Understanding the type of behavior that leads to the consumption of salmon may inform future management efforts. Similarly, understanding whether individual pinnipeds near rivers behave differently than those along the coast would provide important insight.

Complementing scat studies with other forms of diet analysis (e.g., fatty acid and stable isotope analysis) will be important in addressing the biases of scat studies. Stable isotope analysis may hold promise as a method of assessing the proportion of salmon in historic pinniped diets (e.g. Feddern et al. 2021). Complementary studies that tag salmon and analyze temperature and dive profiles of salmon consumed by predators to determine the predator species (see LaCroix 2014, Seitz et al. 2019) will improve assessments of the role of pinnipeds as salmon predators as compared to other salmon predators in the ecosystem.

Rate of Pinniped Predation on Salmonids

Models suggest that the increased abundance of pinnipeds residing in Washington waters since the 1972 passage of the MMPA has led to a corresponding increase in the consumption of salmon by pinnipeds (Chasco et al 2017a, b). The available scientific evidence, including data on pinniped diets, points to an increase in salmon consumption by pinnipeds in the last few decades, coinciding with an increase in the overall pinniped population. The committee notes that, given the low abundance of threatened salmonids and large numbers of pinnipeds, even minimal predation can strongly impact salmonid stocks.

Geographic Location. Rates of pinniped predation on salmonids vary by geographic location and through time in response to seasonal availability of salmon and intra-annual changes in feeding rates of the predators. Pinnipeds that use river mouths, estuaries, and upriver habitats are more likely to be specialists in predating on salmon than those that forage in open-ocean habitats. Wright et al. (2007) found that harbor seals hauling out more inland in a coastal estuary in Oregon were more likely to be observed foraging upriver, where salmon was the most likely prey, than seals that hauled out closer to the mouth of the estuary to the ocean. Nevertheless, studies of pinnipeds at haulout sites well away from major salmon rivers (e.g., studies on the northwest coast of the Olympic Peninsula and at the San Juan Islands) have documented a high occurrence of salmon in the diet of pinnipeds (Lance et al. 2012, Howard et al. 2013, Scordino et al. 2022b), suggesting pinnipeds are effective and significant predators of salmon in all habitats of the state.

Seasonality. Pinniped predation varies seasonally based on availability of migratory prey species such as Pacific hake, Pacific sardine, salmon, and flatfish (e.g. Lance et al 2012). Pinniped predation of salmon may also be affected by years of higher or lower abundance of alternative prey. Scordino et al. (2022a) reported much higher rates of salmon predation when Pacific hake abundance was low in the study area as compared to a previous study when Pacific hake abundance was high in the same study area (Wiles 2015). Pinniped abundance, distribution, and behaviors may also influence predation (e.g. Wilson et al 2014).

Behavioral Variation by Sex. Some studies have highlighted differences in predation rates based on the sex of the pinniped; harbor seal males tend to consume more salmon than females and harbor seal females tend to consume more salmon predators (for example, small demersal fish) than males (Schwarz et al 2018; Voelker et al 2020). Female harbor seals tend to have a more specialized diet while male harbor seals tend to have a more generalized diet (Voelker et al. 2020). There appear to be no discernable differences in the diets of male and female Steller sea lions (Lewis 2022), although the study could not differentiate sex-specific diet according to age class, which is relevant because juvenile males and adult females are similarly sized.

Natural and Constructed Environmental Features

Certain aspects of the natural and built environment can affect pinniped predation on salmon by causing salmon to congregate in certain areas, influencing salmon migration and anti-predation behaviors, or increasing pinniped predation behavior.

Salmon aggregate in the marine environment at habitat features that increase biological productivity. For instance, Swiftsure Bank off northwest Washington has higher biological productivity than surrounding areas (Marchetti et al. 2004, MacFayden et al. 2008) that concentrate salmon and marine mammals at the site (Rounsefell and Kelez 1938). Pinnipeds also appear to congregate around areas where natural geomorphology creates migration bottlenecks for salmon, reducing their ability to avoid predator encounter (i.e., estuaries; Brown and Mate 1983, Wright et al 2007, Moore et al. 2017).

Artificial structures can also interfere with salmon migration behavior and cause increased vulnerability to predation. Pinnipeds can develop specialized foraging strategies based on the built environment once they learn that fish congregate or pause at an unnatural structure. This behavioral change coupled with increased prey density can create a new focal foraging area, substantially increasing the impact on salmonids in those locations (locks, tidal gates: Moore and Berejikian 2022).

Artificial structures can also compromise or reduce the effectiveness of salmonid anti-predator behaviors. Traveling in groups, changing migration patterns and timing, and increasing swim speed, for example, are strategies that have evolved over time to reduce the likelihood of predation (Sabal et al 2021). For instance, steelhead migrate quickly through Puget Sound, which is likely a strategy to bypass predation in that predator-rich environment. The Hood Canal bridge bisects their migration and causes delay, increasing the time during which each migrant is vulnerable to predation (Moore & Berejikian 2022). Increased densities of steelhead and other species encountering the barrier are a byproduct of these delays and attract predators, compounding the problem. The construction of artificial structures like log booms (Farrer & Acevedo-Gutiérrez, 2010), artificial reefs (Russell et al. 2014), and marinas (Patterson & Acevedo-Gutiérrez, 2008) creates newly accessible haulout sites for pinnipeds, essentially expanding their foraging range (Jeffries et al 2000).

As pinnipeds are central place foragers, current evidence suggests that the chance of salmon predation is elevated near haulouts. Research has identified a link between salmon survival and the proximity of harbor seal haulouts to the salmon's river of origin (Nelson et al. 2019). Furthermore, specialists may forage in portions of rivers that are further from the river mouths, and these specialists are likely to use haulouts near or in salmon-bearing rivers. In Oregon, for example, harbor seals who hauled out further upriver showed higher likelihood of specialized predation tendencies (Wright et al. 2007). The location of pinniped haulouts – either natural or artificial – influences pinniped predation behavior.

Individual Pinniped Behaviors

As predator populations increase, there is an increase in intrapopulation competition and a corresponding tendency for the development of dietary specialists. Some individual pinnipeds are considered salmon specialists (Wright et al. 2007).

Several lines of evidence suggest that the population-level generalist diet of harbor seals in the Salish Sea is comprised of a mixture of individual specialists (Bjorkland et al. 2015, Bromaghin et al. 2013, Lance et al. 2012, Schwarz et al. 2018, Voelker et al. 2020); there is evidence of similar patterns for Steller sea lions along the outer coast of northwest Washington (Lewis 2022). In addition, one study in the US Salish Sea provided evidence that some harbor seal individuals at a creek are more successful at capturing returning salmon than others (Freeman et al. 2022). Similarly, a study in Oregon found that the majority of predation on returning salmon is done by a relatively small proportion of the local seal population (Wright et al. 2007) and a study in the Canadian Salish Sea indicated that most predation on outgoing juvenile salmon is performed by <25% of individual seals tagged (Allegue et al. 2020). Finally, stable isotope and fatty acid-based diet data suggest diet differences among individual harbor seals (Bjorkland et al. 2015, Bromaghin et al. 2013).

Sea lions have demonstrated an ability to learn from each other's successful foraging habits and change their foraging behavior (Shakner et al. 2016). Among pinnipeds, learned predation behavior is possible through horizontal (between animals of the same age) and vertical (from elder to younger animals) transmission of knowledge regarding foraging opportunities.

Salmon Characteristics

Research suggests that the size, behavior, and origin of salmon may play a role in which salmon are consumed by pinnipeds.

All three species of pinnipeds covered in this report eat all life stages of salmon in the marine environment. Of the three species, California sea lions are more likely to eat adult-sized salmon, whereas consumption of juvenile-sized salmon is more common for harbor seals and Steller sea lions (Thomas et al. 2017, Scordino et al. 2022b).

Salmon species that migrate into the ocean at a larger size, such as steelhead and coho, may be targeted earlier in their life cycle when in rivers and estuaries, while pinnipeds may wait to prey upon Chinook salmon until they are larger and further offshore (Nelson et al. 2021). One study found that juvenile Chinook salmon (as well as coho and sockeye to a lesser extent) were largely targeted by harbor seals in the Strait of Georgia despite abundant smaller-bodied juvenile chum, but harbor seals targeted adult chum and pink salmon in the fall (Thomas et al 2017). Scordino et al. (2022b) hypothesized that the higher occurrence of coho in California and Steller sea lion diet, by comparison with other salmon species, was due to the longer time that coho spent in the upper portion of the water column.

A number of studies raise the possibility of differences in salmon predation based on rearing history, but the data on differences in pinniped predation on hatchery versus wild fish remain insufficient. The high density of migrating hatchery fish typically released in mid-May may attract predators more than migrating wild fish because their migration is protracted, with fry migrants in late winter and continuing into summer (Nelson et al. 2019a). Compared with hatchery fish, wild origin salmon remain in estuaries longer because they tend to outmigrate at smaller size (Rice et al. 2011). This finding suggests that wild salmon may be exposed to predators in the estuary for a longer period of time; conversely, pinnipeds may preferentially target larger hatchery fish. In one study, the period when most hatchery fish were released coincided with lower steelhead survival across Puget Sound populations (Moore et al 2015). New evidence suggests that the timing of coho hatchery smolt releases coincides with periods of decreased wild steelhead smolt survival, indicating a possible attractant effect of hatchery fish (Malick et al. *in press*). Existing data also indicate that hatchery fish are more vulnerable to tern predation because they swim closer to the water's surface —a behavior that could translate to heightened vulnerability to other predators (Collis et al. 2001).

Effects of Ecological Interactions on Pinniped Predation of Salmonids

Prey buffering, the hypothesis that pinniped consumption of salmonids should be reduced in the presence of alternative prey species, may affect pinniped predation on salmonids. Prey buffering can shift the focus of predation from salmon to a different species of fish, such as herring. On the other hand, feeding on abundant alternative prey can build up pinniped populations, thus increasing the impacts of pinniped predation on salmonids.

Observations from Southern Puget Sound have shown that during years of high anchovy abundance, outmigrating steelhead smolts survived at a higher rate, suggesting lower pinniped predation pressure (Moore et al. 2021). In another example, Scordino et al. (2022a) found that salmon comprised a larger portion of Steller sea lion diet in 2010-2013 than suggested in studies of the same study area conducted in the late 1990s and early 2000s (Wiles 2015), likely due to much higher abundance of Pacific hake in the earlier study. Understanding prey buffering relationships is difficult owing to the complex predator-prey interactions among pinnipeds, salmonids, and other species in the ecosystem.

Knowledge Gaps and Uncertainties

The most significant knowledge gaps around pinniped predation rates on salmon pertain to pinniped redistribution based on changes to haulouts, the influence of ecological interactions with other salmon predators, salmon species most vulnerable to predation, and what role, if any, salmon origin plays in salmon survival.

The committee suggests a review of past aerial surveys, in concert with a review of changes in artificial haulout areas to determine if changes in haulouts resulted in redistributions of pinnipeds. This could be followed by an experiment in which log booms are removed to determine if this removal results in pinniped redistribution. As part of this experiment, individuals should be tagged to provide data on their movement. The study should also aim to ascertain whether any resulting redistribution influences predation on salmon.

An important area of knowledge gaps is the effect of ecological interactions on pinniped predation on salmonids. To fully understand the impact of pinniped predation on salmonids, data on salmon mortality caused by other predators are needed. For instance, piscivorous birds are salmon predators, warranting further study. In addition, piscivorous fish eat salmon, but little is known about the proportion of salmon in the diets of Pacific hake and other piscivorous fish in Washington waters. This knowledge gap makes it impossible to predict the effect of an increased abundance of these salmon predators if pinniped abundances are reduced. Although little is known about the potential for predator release – that is, an increase in piscivorous fish populations due to a reduction in pinniped population – this uncertainty should not be an obstacle to management.

Spatially and temporally explicit information also are essential in understanding the species, stocks, and age classes of salmonids most vulnerable to predation and how pinniped and salmonid distribution affects salmonid populations. Given that some salmon remain resident in Washington (Puget Sound and Washington coast) for their entire lives, current data collection methods do not account for all salmon life stages. A better understanding of life-stage-specific predation rates is essential. It would also be beneficial to have stock-specific information on pinniped predation throughout the state to allow evaluation of pinniped impact on runs of concern. The committee, however, recognizes the challenge of obtaining more granular diet data, i.e., determining the species of salmon eaten or whether consumed salmon were resident in Washington or only present in Washington's marine waters at the beginning and end of its marine life phase.

Finally, the committee suggests further consideration of whether the presence of hatchery salmon influences the survival of wild salmon. Hatcheries put out a high volume of salmon, which may result in one of two scenarios: hatchery releases may attract predators, leading to increased predation on wild salmon; or hatchery releases may "swamp" predators, leading to increased survival of both hatchery and wild salmon. Current data do not address this question in Washington State waters.

III. IMPACTS OF PINNIPED PREDATION ON SALMON RECOVERY

It has been postulated that pinniped predation on salmonids in Washington waters has impeded salmonid recovery. Scientific evidence from other ecosystems demonstrates that pinnipeds can impede fish recovery (cod: Cook et al 2015, Neuenhoff et al. 2018; skate: Swain et al. 2019). The committee observes that large pinniped populations are present in Washington waters and that these populations consume large numbers of salmonids, likely negatively impacting salmonid populations. However, the magnitude of these impacts is not directly generalizable from one situation to another; rather, impact is context-specific. In addition, impact must be expressed relative to other sources of mortality, many of which are unquantifiable or poorly understood.

The primary question around the impacts of pinniped predation on salmon recovery is how changes in pinniped abundance translate to changes in salmon abundance, marine mortality rates, and population productivity. To fully understand this relationship, it is important to consider whether pinnipeds are responsible for additive or compensatory salmon mortality, how pinnipeds impact salmon relative to other sources of mortality, and how specialized individuals contribute to predation impacts.

Additive Mortality from Pinniped Predation

When considering the impact of mortality from various sources on recovering animal populations, mortality from predation is often assumed to be additive and to directly correspond to an equal reduction in survival rate. In this additive model, all mortality sources (i.e., disease, predation, starvation, fishery removals, etc.) sum to the total mortality acting on a population. Alternatively, subsequent mortality factors (i.e., density dependence, environmental factors, dynamics of other predators) may counteract or reduce the impact of predation in a compensatory way. Complete compensatory mortality then, does not directly affect the total (lifetime) mortality of a population but is associated with a reduction in mortality from other sources or processes. Theoretically, pinniped predators may consume a high percentage of the smolts from a salmon population, but if these predators target diseased individuals that would have died in the ocean, or if decreased smolt densities resulting from predation reduces the risk of later starvation, for example, pinniped predation mortality may not impact the survival of adult salmon to spawning grounds. Thus, when considering whether measures to reduce predation rates ultimately will affect survival and productivity of recovering salmon populations, it is important to understand if predation mortality is additive or compensatory.

Assessing the degree to which predation mortality is additive or compensatory is complex, particularly given environmental and seasonal variation, density-dependence, and disease interactions that are difficult to quantify. Disagreement between two recent studies attempting to determine if avian predation in the Columbia River tends to be additive or compensatory demonstrate this complexity (Payton et al. 2020, Haesaker et al. 2020). One model indicated compensatory effects of predation on steelhead smolts (Haeseker et al. 2020), while analysis of a similar data set suggested additive effects of predation (Payton et al. 2020) in the same predator-prey system. Other studies documenting selective removal of diseased individuals by a predator species provide a potential mechanism by which predation mortality may be compensatory (Hostetter et al. 2012, Tucker et al. 2016, Furey et al. 2021), but none of these studies document the ultimate effect of selective removal on total survival of the prey population. Whether predation mortality correlates with total survival may vary by life stage, species, habitat, or year (Allen et al. 1998, Haesaker et al. 2020), with combinations of these factors creating an array of interactions that are extremely difficult and expensive to measure with accuracy, if at all, over the lifespan of individuals within a population. Therefore, experimental manipulation of predation rates and subsequent measurement of survival rates, while controlling for confounding variables, may be the only way to determine whether changes in predation rate translate into commensurate changes in prey survival.

When considering the relationship between additive and compensatory mortality, it is important to note that there is a threshold at which predation rates cannot be compensated by decreases in other sources of mortality (Walters & Christensen 2019). Pinniped predation rates on salmon may be close to or above this threshold, particularly at high impact situations in Washington. However, accurately quantifying the role of pinniped predation on salmon populations in an appropriate ecological context will be nearly impossible to accomplish without large-scale management experimentation.

Pinniped Predation Relative to Other Sources of Mortality

The contribution of pinniped predation to salmonid mortality rates by life stage must be measured relative to other sources of mortality, such as predation by birds or other fishes (see Trophic Relationships above).

Substantial uncertainty surrounds the effects of pinniped predation on salmon populations relative to other sources of mortality. A thorough understanding of all causes of salmonid mortality and their impacts is difficult to obtain, since diet analysis alone cannot provide the answer to this question. Typically, mortality due to pinniped predation is readily identifiable because it can be observed directly or determined through scat analysis. Other sources of mortality, however, are more difficult to quantify and become less important when the percentage of mortality attributable to pinniped predators is high. A recent study found that harbor seal predation accounted for 90% of the mortality of steelhead smolts migrating through the Nisqually estuary, where 20% mortality occurs within a 5 km stretch (Moore et al. in prep 2022b).

Just as pinniped predation on salmonids has changed over time, it is likely that competing causes of mortality have also shifted. Simulation modeling studies highlight the complexities of understanding the interrelationships between direct and indirect effects in salmon-pinniped food webs, leading to a variety of plausible responses to changes in pinniped abundance.

A model of the central Puget Sound basin indicated that the strongest top-down effects of predation by pinnipeds on salmon were found between harbor seals and California sea lions on subadult pink salmon (Harvey et al. 2012). The only other support in the model for top-down food-web effects on other salmonids was on juvenile pink salmon by migratory diving birds, which include grebes, loons, and murres. However, Chinook salmon, coho salmon, and chum salmon were lumped together in the model, which would mask important predation impacts on a single species.

A similar model for the Strait of Georgia (Lessard et al. 2005) showed that coho and Chinook salmon marine survival rates increased, though only temporarily, following the reduction of pinniped populations. Reducing pinnipeds allowed other salmon predators (such as hake) to eventually increase in abundance, resulting in compensatory predation on coho and Chinook salmon. Changes in the diet composition of various predators altered the magnitude of this response, further exemplifying the difficulties of understanding how changes in a single predator propagate through entire food webs. Modeling is a helpful tool for understanding pinniped predation on salmonids, but inherent uncertainties in scaling up from individual processes or observations to a response at the system level are significant.

Impacts of Individual Pinnipeds

Research shows that salmon consumption may vary among individual pinnipeds (Bromaghin et al. 2013; Bjorkland et al. 2015; Schwarz et al. 2018). Data on fine-scale movements and behavior from photo identification work and acoustic tags show that some individual pinnipeds exhibit specialist feeding behaviors on salmon and thus have greater impact than others (Wright et al. 2007; Ballard Locks, Willamette Falls, and Bonneville monitoring; Freeman et al 2022). However, limited diet data are available regarding the extent to which salmon consumption varies among individual pinnipeds because scat samples show a snapshot of the foraging activities of sampled pinnipeds and cannot be analyzed for individual variation in diet over time to fully quantify diet specialization. Complementary data on the cumulative diets of individual pinnipeds through time comes from studies of stable isotopes and fatty acids (e.g. Bromaghin et al. 2013, Bjorkland et al. 2015, Feddern et al. 2021).

The impact of specialists must be understood within the context of the entire system. The most important consideration is how the per capita predation rates scale up to the population. For example, if specialists eat 50 times more salmon compared to other individual pinnipeds but there are 1,000 times more non-specialists, the overall specialist impacts may not significantly affect the system. On the other hand, given that the impact of individual pinnipeds is a scale-wide issue for Puget Sound and the outer coast, a small number of specialists could have significant impacts on a weak stock. Another possibility is that a generalist pinniped that eats a variety of prey species could end up consuming many salmon as part of its diet – for example, Steller sea lions and harbor seals eat salmon as part of a generalist diet, as determined from scat samples (Voelker et al. 2020, Lewis 2022).

Knowledge Gaps and Uncertainties

To understand the impact of pinniped predation, the committee highlights the following as areas that require additional research: i) whether pinniped predation primarily creates additive or compensatory mortality, ii) if pinniped predation causes population-level impacts for salmon, and how other sources of mortality fit in, and iii) the role of geographic and temporal context.

To parse additive and compensatory effects of pinniped predation on mortality and evaluate population-level effects on the salmon population, research should focus on testing whether reductions in pinniped predation at specific locations increases the number of salmon returning to contribute to the next generation. To yield new insight, these studies must consider salmonid total mortality over the course of multiple years. Further study of whether pinnipeds preferentially consume diseased or otherwise-compromised salmon would also be helpful. The committee emphasizes that unknowns and uncertainties about pinniped contributions to additive versus compensatory mortality should not be considered an obstacle to management. A carefully designed adaptive management approach that includes measurement of survival to reproduction with paired controls will allow managers to act on the preponderance of evidence while informing future management (see *Adaptive Management Approaches* for additional detail).

Suggested directions for future research include improving methods for identifying non-pinniped sources of mortality, such as seabirds and other predators. Research could also support gaining a better understanding of what proportion of the salmon bones found in pinniped scat can be attributed to secondary sources (e.g., the pinniped has eaten another animal with salmon bones in its stomach). Quantifying other sources of mortality for salmon in Washington waters, particularly returning adult salmon, will help to determine the role of pinniped predation in salmon mortality.

Another knowledge gap is whether predation on salmon near the Hood Canal Bridge, which has caused documented high mortality, is mainly due to a small number of individual harbor seals. This would require photographing and characterizing individuals that frequent these locations to determine whether this behavior is restricted to a small set of specialists or if all seals in the area use the site without any clear sign of disproportionate use of the area by specific individuals.

Further data on pinniped foraging behavior and individual specialization can be obtained by collecting and sequencing scat from the same individuals repeatedly, but this type of research is costly and labor intensive given the large number of collection trips necessary to gather scat from the same individuals (Rothstein et al. 2017).

A lack of spatially/temporally explicit data regarding seals and outmigrating fish is another knowledge gap; models indicate a range of impacts but could be informed by additional data to improve estimates (see Nelson et al. 2021 for an example of model sensitivity to imperfect inputs).

IV. ADAPTIVE MANAGEMENT AND SCIENCE

The committee encourages an adaptive management approach arranged as a set of experiments organized around competing models such that management can yield more information about effective strategies. As outlined in the preceding sections, small-scale mechanistic studies of pinniped-salmon interactions have inevitable uncertainties that distinctly limit their ability to inform ecosystem-wide questions about the roles of pinnipeds in preventing recovery of salmon stocks in Washington State waters. We believe further small-scale studies will do little to reduce these uncertainties and promote the scalability of results to an ecosystem context.

The design of adaptive management experiments involves weighing risks versus potential benefits of alternative actions. Given that Washington pinniped populations are all at high abundance, any lethal removal except on a massive scale would seem to pose little to no risk to the viability of the pinnipeds. Given that the salmon are already listed as threatened or endangered, the risk of not conducting experiments whose results can inform management actions is high. The major risks of lethal removals appear largely social and political, rather than risks to pinniped populations as a whole.

The committee notes that, while more research is needed to fully understand the complexities of pinniped predation on salmonids, research takes time and salmon populations in Washington are threatened right now. Further, there is little potential to understand the compensatory nature of pinniped predation on juveniles without direct manipulation of the pinniped abundance. There is an urgency to implement management strategies in the short term to take action while testing interventions.

Effectiveness of Existing Management Strategies

Previously applied pinniped management strategies provide some insight into approaches that may be effective for improving salmon survival and how they may be optimized in the future. Examples of non-lethal and lethal management strategies are discussed in the following sections. While the committee has reviewed and provided observations regarding several potential management actions below, we are not recommending any particular approach within this report.

Non-Lethal Interventions

Several non-lethal management strategies have been deployed in Washington waters with varying levels of success. One commonly discussed non-lethal management approach involves the use of acoustic deterrent devices, but the effectiveness of this approach is highly variable and effects tend to be short-term. A study conducted at Ballard Locks concluded that acoustic deterrent devices did not affect salmon abundance but did influence California sea lion distribution (Scordino 2010); however, this study was conducted over only nine days. Individual seals and sea lions learned that the food reward was worth the irritation of the acoustic deterrents and continued foraging behaviors within the ensonified area.

In a study that used tagged steelhead smolts to track consumption by pinnipeds in the Nisqually River estuary (a natural environment), targeted acoustic startle devices (TAST) did not influence steelhead survival or seal behavior (Moore et al *in prep 2022b*). The study found that 90% of predation in the estuary was attributable to harbor seals, with their impact outweighing all others at the site. However, it is important to note that the relatively small number of acoustic deterrent devices in this study may have been insufficient to elicit a response. Another study suggested that TAST devices decreased seal presence and consumption of salmon; however, the study also found individual variation and no lingering effects in the following year (McKeegan 2022). Additional studies of TAST are warranted, but should be designed to account for confounding variables, last long enough to measure the effect of habituation, and measure clear metrics of salmon population response to gauge the impact of the technology.

Additional non-lethal management approaches were discussed in a workshop on this topic; this discussion is summarized in Appendix A.

Lethal Removal of Pinnipeds

Under the MMPA, states can request approval to enact specific lethal management strategies. One approved management method is removal of individually identifiable pinnipeds that have consumed salmon listed in the Endangered Species Act. While such an approach is possible, its potential for success would be scale- and system-dependent, and it is subject to management constraints that require significant time and financial resources. The committee notes that such removal would be complex because the MMPA also requires proof that non-lethal harassment does not work, which is challenging to prove in most marine systems. Further, the committee cautions that identifying and removing specialized individuals can prove challenging.

To date, the most relevant experiment in Puget Sound involved the removal of California sea lion salmon specialists from the Ballard Locks area, accompanied by an acoustic deterrent system to push away naïve individuals. The sea lions stopped using the site possibly due in part to this experiment and the simultaneous large reduction of the steelhead population (Scordino 2010). The removal of individual California sea lions with specific knowledge of sites at Willamette Falls also reported successful reduction in use of the sites by sea lions and in the recruitment of new individuals (ODFW 2018). These outcomes suggest it may be feasible to disrupt socially transmitted predation behaviors among pinnipeds by removing individual specialists (Scordino 2010). In general, removal of specialists near migration obstructions or in estuaries and other pinch points appears effective at reducing pinniped predation on salmonids in that specific area, including in other ecosystems (Blomquist et al. 2022). However, research does not indicate how long such effects last and when new individuals replace the removed ‘problem’ individuals. In addition, population responses of salmon to these interventions remain unknown.

The committee cautions that removals may be ineffective where pinniped populations are dense and there is the potential for other individuals to replace removed animals. In addition, while data show that behavioral avoidance of an area may follow lethal removal, this change in behavior can take significant time. Further, as pinniped learning is well-documented, the expectation should be for ongoing management and interventions rather than single actions. However, tracking of individual behaviors within populations near such removal sites could provide information about whether and when problem individuals are functionally replaced.

Any management interventions designed to understand the effects of pinniped predation on salmon should explicitly consider local and regional effects of any management intervention. For example, limited pinniped removals in specific sites with disproportionately high impacts on salmon populations (e.g., the Nisqually Delta, Hood Canal Bridge, and around Ballard Locks) would likely be beneficial to the highly impacted salmon populations at that site.

Another management approach used in the past was large-scale lethal removals of pinnipeds to reduce pinniped population size, often referred to as culls. Culls were used prior to the MMPA to manage pinnipeds in Washington and in the Pacific Northwest more broadly. Unfortunately, the effectiveness of previous culls in increasing the productivity of salmon were not formally monitored, making it difficult to evaluate their effectiveness (Bowen and Lidgard 2012).

Directions for Future Research

The preponderance of evidence supports the hypothesis that current populations of pinnipeds are likely impeding the recovery of salmon populations in Washington waters. As such, strategic lethal removal of pinnipeds is an approach that may be required for understanding the magnitude of impacts of pinnipeds on salmonids, either at local scales or at the ecosystem scale. Large-scale experimental management of predators may help determine whether pinnipeds are contributing to the salmon decline. Deterring or removing predators might be the most effective approach for experimentation and likely would contribute to salmon recovery while building a greater understanding of the role of pinnipeds in the ecosystem. However, a management experiment of this scale and complexity would involve both substantial investment in scientific capacity and political will over long time periods.

Efforts to measure the impact of excluding pinniped predators should focus on known hotspots, and development of the experimental design should take spatial and temporal considerations into account. Ideally, experiments should take place over several years and use appropriate control sites and salmon populations. The geographic scale of the experiment should not be limited to rivers, as marine systems are dynamic, and pinnipeds are highly mobile. The committee emphasizes that making predictions about pinniped-salmon population dynamics without considering the trophic interactions would lead to ineffective forecasting of changes in salmon abundance as a result of pinniped removal.

Combining multiple studies that feed into ecosystem models would increase the pace of learning about how the entire system responds to perturbations. For example, a process-based study within a larger experiment may involve comparing salmon mortality rates at reference sites before and after selective pinniped removal. Recent pinniped removals to aid salmon recovery at the Ballard Locks, Willamette Falls, Puntledge River, and at Bonneville Dam could be evaluated. However, these are not appropriate sites for the abovementioned experiment because they would likely fail to capture compensatory mortality, as few other predators of adult salmon live in freshwater and estuary systems.

The MMPA and the constraints it creates effectively block most pinniped removal and, as such, the type of experiment being described. Thus, careful experimental design will be key to ensuring that lethal removals would result in an increased understanding of the system with minimal uncertainties.

Knowledge Gaps and Uncertainties

The primary uncertainty regarding adaptive managed pertains to how pinniped removals may affect ecological interactions within Washington ecosystems. The complex relationships among pinnipeds, salmonids, and other predators and prey will affect predation rates by pinnipeds upon salmonids and associated impacts. Therefore, ecological interactions among the many species inhabiting Washington waters can also influence the effectiveness of potential management actions. A key uncertainty in lethal removal of pinnipeds is what would happen if pinnipeds were removed from the Puget Sound and outer coast ecosystems beyond the very limited removals currently permitted. There are a number of ecological interactions and there is no direct analogue in previous studies that would indicate all of the ecosystem responses. However, potential unintended effects should not be a barrier to strategic removals.

One consideration is whether reducing pinniped abundance in state marine waters may reduce prey availability sufficiently as to negatively affect transient killer whales (an ecotype of killer whales that eats marine mammals). Washington State marine waters are primarily used by West Coast transients. Within the West Coast transients, there are two subgroups, a “coastal” assemblage and an “outer coast” assemblage (McInnes et al. 2021). The coastal West Coast transient killer whales utilize the Salish Sea and are specialists that prey on marine mammals including pinnipeds; less is known about the behaviors of the outer coast assemblage (McInnes et al. 2021). While there is minimal data on whether killer whales are limited by prey availability, data points to an increase in transient killer whale populations coinciding with a rising abundance of pinnipeds (Shields et al. 2018). The committee cautions that the rise in the transient killer whale population has also coincided with the passage of the MMPA, and the number of days that transient killer whales are spotted in the Salish Sea has increased in recent years without a corresponding decrease in pinniped abundance. Larger groups of transient killer whales have been observed in the Puget Sound for longer periods of time than in the past (Shields et al. 2018). An evaluation is warranted to determine how many pinnipeds could be removed without affecting west coast transient killer whale abundance. Such an evaluation would need to consider variation in predation behaviors between the coastal and outer coast assemblages.

Consideration of trophic interactions is a crucial factor in predicting changes to salmon populations. While it is feasible to generate testable predictions, there is a need to design experiments with modeling components that extend beyond population dynamics models to full ecosystem-based models (Walters 2022).

Standards for Adaptive Management Approaches

Management actions can serve to not only manage the current situation but also learn from the actions to inform future management. There is a need for more experimental research approaches to inform best practices beyond anecdotal evidence. Management approaches have frequently been deployed on an ad hoc basis without first being experimentally investigated. The committee argues that it is important to treat management approaches as experiments and test them across appropriate time scales to assess their efficacy and anticipated impacts on salmon. In general, accurate prediction of ecosystem effects is difficult or impossible, though it is possible to develop hypotheses that are testable and can be adapted.

To maximize learning from the management of pinnipeds and improve understanding of the impacts of pinniped predation on salmonids, the committee suggests using an active adaptive management approach (Walters 1986).

The committee suggests that any future research on pinniped predation on salmonids use the following standards. These research elements should be determined before the experiment begins:

- Measurement of a strong response variable, such as salmon survival (observations of pinnipeds are not considered to be a strong response variable).
- Pairing of the experiment with models to help determine which variables to measure, the length of time needed for detection, the magnitude of perturbation needed for detection, the spatial scope, and how and where to monitor for reference conditions outside of the experiment
- Sufficient time for the experiment to develop, which varies based on the research questions and variability of the response variable being measured
- A designated control or reference population(s) that would represent what happens if the management action was not implemented.
- Pre-and post-manipulation monitoring at appropriate intensity to detect experimental effects.
- Use of existing ecosystem-based models to compile what is already known, help identify what information is missing, and determine how to design the experiment.

Generally, the most powerful designs are before after controlled intervention (BACI) designs but this is often an unattainable goal given the realities of scale and population connectivity.

CONCLUSION

The MMPA was spectacularly successful at rebuilding the abundances of pinnipeds (harbor seals, California and Steller sea lions) throughout Washington State marine waters over the last five decades. Coincident with this increase in marine mammal predators, many stocks of salmon have declined. Declines have been most pronounced for wild sockeye salmon, coho salmon, Chinook salmon, and steelhead trout, while populations of pink and chum salmon have increased over this time frame. While pinnipeds are predators of all life stages of salmon in Puget Sound and on the outer coast of Washington State, the importance of salmon to each pinniped species varies substantially both over time and among geographic locations. Pinnipeds are particularly focused on salmon as prey at both natural and human-made pinch points in salmon migration (i.e., dams), thereby rendering some salmon stocks more vulnerable to pinniped predation than others. Taken together, the preponderance of evidence supports the hypothesis that current populations of pinnipeds are a contributing factor in the decline and depression of salmon populations in Washington State waters. Ecological complexity within the broader food webs in which salmon and pinnipeds reside generates substantial uncertainty about the degree to which pinnipeds have and currently are depressing salmon stocks, including those that remain listed under the Endangered Species Act and across the entirety of marine ecosystem of Washington State.

Scientific research to improve our understanding of pinniped—salmon ecological interactions (e.g., further characterizing behavior and diets) will resolve some of the uncertainties in our understanding of the role of pinnipeds as predators in salmon food webs. Development and refinement of models to synthesize field observations will also be needed to interpret emerging information from new and ongoing field studies. However, it is unlikely that these mechanistic approaches will lead to robust conclusions about the importance of pinniped predation in the depression of Washington State salmon populations. Strategic and appropriately scaled adaptive management of pinniped populations are key to resolving these uncertainties but likely will require lethal removals. Other approaches to studying this ecosystem are not likely to lead to fundamentally new insights. Importantly, current uncertainties about the salmon-pinniped system should not be perceived as an obstacle to adaptive management, but rather should motivate well-crafted experimental approaches funded with adequate resources.

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APPENDIX A: NON-LETHAL DETERRENTS AND INTERVENTIONS

Non-lethal deterrents and interventions to manage pinniped predation on salmonids:

Summary of 10/13/2022 meeting hosted by the Washington State Academy of Sciences for the Pinniped Predation on Salmonids project

Present: Mike Brown, Bob DeLong, Keith Dublanica, John Edwards, Ava Fuller, Mike Mahovlich, Sharon Melin, Megan Moore, Joe Scordino, Jonathan Scordino, Kyle Tidwell, Lauren Urgenson, Rob Williams
Contributing by email: Bryan Wright

In commenting on the following non-lethal management actions, the group considered: science underpinning the intervention, application of the intervention and its level of success, potential benefits, risks, and uncertainties, effects on other management actions, and the potential for the action to further our understanding of pinniped predation on salmonids.

A few ideas that came up repeatedly were:

- Location and context matters. Impoundments (artificial water bodies) are entirely different contexts from larger estuaries and open waters. Impoundments tend to have highly habituated animals. Features of some locations limit deterrent options (for example, waterfalls near the entrance of a fish ladder at Willamette Falls). What works at one location may not work at another, because of differences in prey accessibility and vulnerability.
- Naive pinnipeds are easier to influence than those which have an existing strong food reward association. Proactive approaches to prevent new animals from entering an area and learning its benefits (and removing those animals that know) can be one approach to address this.
- Pinnipeds have different sizes, natural behaviors, tolerances, and adaptability, and thus an intervention which works for one may not work for another.
- Combining multiple non-lethal deterrence methods that are compatible (for example, TAST with a physical barrier) as part of a “swiss cheese” model with multiple dimensions of intervention that each have their downsides and animals that will “slip through.”
- Non-lethal deterrence has its limits of effectiveness; in some situations, lethal removal may be more effective.

Management Action / Intervention	
Seal bombs and other non-lethal measures	• Generally effective at discouraging animals from holding in specific locations but effects are temporary; harassment needs to be continuous in order to work. • Species differences are important. At Bonneville Dam, Steller sea lions responded more rapidly than California sea lions.

such as projectiles	● Pinnipeds quickly learn the range at which the seal bombs and other non-lethal pyrotechnics can be deployed and will continue their activities outside the range of influence of the deterrence. Some individuals will ignore the deterrence if they are motivated and knowledgeable of potential food reward. ● The environment and other factors are important. ○ At Gold Beach in Oregon, seal bombs were more successful when deployed by boat and combined with removal of fish carcasses. This program has remained successful through 2022 by combining seal bombs, cracker shells, and a chase boat. ○ Bonneville Dam has a certain group of habituated animals at a fish passage pinch point; findings from here may not apply elsewhere.*(Tidwell et al. 2021)* ● Seal bombs can scare away fish or even cause fish mortality if fish are close by. ● *Also: Findlay et al. 2022, Long et al. 2015, Pamplin et al. 2020, Scordino 2010*
Harassment and flushing by boats and other means	● Harbor seals change their behavior as a result of disturbance by vessel activity ● Pinnipeds are able to evade harassment by boats, minimizing the effectiveness of the approach. ● *Also: Cates et al. 2017, Paterson et al. 2019*
Targeted Acoustical Startle Technology (TAST)	● In general, results have been promising for naive harbor seals consuming adult salmon in habitat bottlenecks. Effectiveness with sea lions and for reducing predation on juvenile salmonids is less clear. ● This method seems to be more effective on naive seals than those who already have food reward/reinforcement. ● Local tests have been short in duration, and the effects on pinnipeds have generally also been short. Will need longer-term testing at a single location. ● This method would seem to be more effective in deterring animals in impoundment areas and human-built bottlenecks than larger estuaries and open waters (would require massive scaling). ● Case studies: ○ Ballard Locks - in 2020 displaced seals and reduced predation rate (*Williams et al. 2020)* but in 2021 and 2022 was found ineffective and the test canceled *(Williams et al. 2021)* It is unclear whether the pinnipeds habituated, the food reward was too strong, pinnipeds had hearing loss from previous hazing, or some other reason. ○ Muckleshoot Tribe's observations at the Ballard Locks - the presence of an operating TAST's "startle effect" did not deter harbor seals from moving through the ensonified area and entering the fish ladder to eat salmon. ○ Whatcom Creek – Large individual variations: some seals were displaced, showed reduced individual foraging success, and reduced mean predation rate. Changes in fish passage were not assessed. *(McKeegan MSc thesis 2022, Williams et al. 2020)* ○ Nisqually - Displaced seals; predation rate on juvenile steelhead not significantly reduced *(Moore et al. 2022)*

	○ Deschutes River, Olympia 5th Ave Bridge - In progress; So far seems to have displaced seals and substantially reduced local predation rates
Acoustic deterrents (e.g., pingers; sonic barriers; transient killer whale vocalizations)	• High decibel-level acoustic deterrents at Bonneville Dam fish ladders had no effect on California sea lions *(Tackley et al 2008, Scordino 2010)* • Acoustic deterrents at Ballard Locks caused altered behavior in California sea lions and deterred new, naive sea lions *(NMFS 1996, Scordino 2010)* • Acoustic harassment reduced vulnerability of outmigrating salmonid smolts from harbor seal predation in British Columbia *(Yurk & Trites 2000)* • *Also: Deecke et al. 2002, Olesiuk et al. 2002; Scordino 2010, Yurk & Trites 2000*
Mechanical barriers	• Can be effective in preventing pinniped use of very confined fish passage areas. Tend to shift predation to a different location (e.g. the face of the barrier/net). • Case studies: ○ A net was installed at Ballard locks downstream of the fish ladder where predation was highest. There was no discernable benefit and there were issues with maintenance. Sea lions moved their predation to the face of the net from the fish ladder entrance. ○ Sea lion exclusion devices placed at the entrances of fish ladders at Bonneville dam (spaced vertical bars that were wide enough for large Chinook salmon to pass, but not sea lions) were effective in preventing most sea lions (larger males) from entering the fish ladder. These devices caused sea lion predation to move to less-confined areas which may have given the fish a better chance to evade predation. It is uncertain whether these same devices would be effective on smaller harbor seals. ○ Cork line had little effect on harbor seal predation on outmigrating smolts *(Yurk & Trites 2000)* • Mechanical barriers can also cause salmon to pause when they approach a barrier.
Relocation of pinnipeds to another natural habitat	• Generally considered ineffective, as well as labor-intensive and expensive • California sea lions relocated 230 miles away from Willamette Falls returned in 3-29 days *(ODFW 2018)* • California sea lions relocated from Ballard Locks to as far away as Southern California returned to the same area within a month *(Scordino 2010)* • *Also: Hume et al. 2002*
Increase or decrease in hatchery production and programs	• One hypothesis is that hatchery releases of smolts ‘swamp’ pinnipeds; Another hypothesis is that hatchery releases create a reward that attracts pinnipeds. The effect of hatcheries likely depends on species, location, and season. • Modeling shows hatchery releases as uncorrelated with wild Chinook populations *(Nelson et al. 2019)*

	• In Puget Sound, hatchery coho releases were found to coincide with periods of low steelhead smolt survival (*Malick et al., in press*)
Removal of artificial haulouts	• Following removals of log booms in downtown Bellingham, WA, numbers of seals hauled-out decreased from consistent peaks of 40-60 to 15-40 seals (*Alejandro Acevedo-Gutiérrez personal comm.)* • The area of artificial haulouts in South Puget Sound has declined in recent years but there has not been an assessment of how that affected seal movements or distribution. *(Jon Scordino personal comm.)*
Improved fish passage at artificial structures that serve as "hot spots" for predation	• A project is underway in 2023 to test modifications to the Hood Canal Bridge to allow juvenile salmon and steelhead to aid passage past the pinniped predation "hot spot". This collaboration between NOAA, the Port Gamble S'Klallam Tribe, and Long Live the Kings, using acoustic telemetry and sonar imaging to visualize and quantify the pinniped and steelhead smolt response to modifications The project is also assessing the impact of the bridge on adult chum and Chinook salmon returning to spawn in Hood Canal streams.
Increased forage fish abundance through restoration of nearshore habitat	• Years of high anchovy abundance in Puget Sound are strongly and positively correlated with steelhead survival and coincide with lower evidence of harbor seal predation (Moore et al. 2021), providing evidence that healthy forage fish populations reduce pinniped predation on juvenile salmonids. • *Leach et al. 2022*
Pinniped fertility management	• A study in wild grey seals (an Atlantic Phocid) tested a contraceptive vaccine treatment that led to a 90% reduction in pup production; it is unclear whether this would work in other pinnipeds and the duration of the treatment efficacy remains unknown *(Brown et al 1997)* • Pacific harbor seals would be a logical candidate species for this intervention. • It would likely be a high-effort and logistically challenging endeavor to treat enough individuals in a population to make this method effective

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APPENDIX B: SCOPING QUESTIONS

Guidance for WSAS Scope of Work

Pinniped Predation on Salmonids in the Washington Portions of the Salish Sea and Outer Coast

August 30, 2021

Introduction

The Washington State legislature has directed the Washington Department of Fish and Wildlife (Department) to contract with the Washington State Academy of Sciences (Academy) in the 2021-23 biennium to:

> *"..report on current evidence on pinniped predation of salmon, with an emphasis on Washington's portion of the Salish sea and Washington's outer coast. The academy must provide an independent study that reviews the existing science regarding pinniped predation of salmonids, including what is known about pinniped predation of salmonids, and with what level of certainty; where the knowledge gaps are; where additional research is needed; how the science may inform decisionmakers; and assessment of the scientific and technical aspects of potential management actions."*

WDFW in coordination with the NWIFC and western Washington treaty tribes, provide the following questions within the broad categories of scientific review identified by the legislature to help guide the work of the Academy.

Pinniped Predation on Salmonids

Predation

To the extent possible, please address the following questions with respect to region (Washington's portion of the Salish sea or Washington's outer coast), pinniped species (harbor seals, by designated stock; Steller sea lions; or California sea lions), *Oncorhynchus* species, and *Oncorhynchus* life stage (i.e., migration of juveniles through transitional areas such as estuaries and Puget Sound, marine rearing, or migration of adults through estuaries and rivers).

1) What information is available on the consumption of salmonids by pinnipeds in Puget Sound and Washington's outer coast? In particular relative to predation on all phases of salmon life history.

2) What information is available on how predations levels have changed over time, relative to other predation or impacts on salmonids and relative to salmonid abundances?

    a. Does the increase of pinniped population sizes over the past 50 years affect predation rates and their impact on salmon recovery relative to decreasing salmon population sizes?

3) Do available estimates of predation reveal generalizable patterns? Even where consumption estimates are not available, could the magnitude of predation impacts be inferred or categorized based on similar information collected elsewhere? For example, "low," "medium," and "high" relative to other sources of mortality.

4) What is the best approach to determine if pinniped predation rates are either contributing to salmon population declines or preventing rebuilding populations to healthy harvestable levels? Is there any evidence that they are contributing to declines in marine survival rates?

Factors Affecting Predation

5) What characteristics of pinnipeds (e.g., number, age, location), salmonid populations, the natural environment, artificial structures, or anthropogenic activities promote an increased pinniped predation rate on salmonids?

6) Is there a relationship between the number and size of haulout areas and consumption of salmon in a geographic region? Do *Oncorhynchus* species migrating through rivers/estuaries closer to large pinniped haulouts experience greater pinniped predation rates?

7) What empirical evidence is there that certain individual pinnipeds (aka, "specialists") have a greater impact than others on salmonid predation in estuaries and rivers? What about in offshore areas of the Salish Sea and the Pacific Ocean?

8) Is there any evidence for "hot spots" of pinniped predation, or locations where predation impacts on salmonids are particularly acute? Is there learned behavior by pinnipeds to focus on rivers, chokepoints (e.g., hatcheries, Ballard), nets, etc. to exploit more salmon?

9) What are the key gaps in our understanding of pinniped predation rates on salmonids and factors affecting predation rates?

10) What are the relative pinniped predation impacts on hatchery-origin salmon compared with pinniped predation on wild or natural-origin salmon?

11) What evidence is there that may show whether resident harbor seal stocks forage within their stock boundary or do they move into other stock areas to forage?

Potential Management Actions

Ecological Interactions

The effectiveness of potential management actions may be affected by ecological interactions among the many species that inhabit the Salish Sea and the coastal waters of Washington

12) What it the potential for generalist predators, which can expand their range extensively (e.g., as has been the case for male California sea lions), to reach carrying capacity? Are there examples of management success or failure for other generalist predators (e.g., coyotes) to draw from?

13) How are California sea lion migration patterns changing over time (e.g., do younger male California sea lions reside in the Salish Sea year-round?)?

14) What factors may limit the population size of pinnipeds?

a. Does the availability of haulouts limit the carrying capacity for pinnipeds?

15) What are the key points to understand regarding:

a) trophic relationships (direct and indirect) between pinnipeds and other predators of salmonids in the Salish Sea and Washington's outer coast; and

b) biomass and seasonal consumption of salmonids relative to other prey species consumed by pinnipeds? (e.g., starry flounder)

16) What empirical evidence supports a hypothesis that a reduction in the number of pinnipeds would result in an increase in the abundance of other salmon predators and a concomitant increase in predation rate of those species on salmonids (i.e., "predator release" hypothesis)? What insights do theoretical or model analyses provide regarding this topic?

a. Were the previous pinniped culls effective in reducing salmon predation rates?

b. What other historical/traditional ecological knowledge about pinniped abundance and distribution that can be reviewed to assess historical impacts of predation compared to salmon predation levels observed today?

17) What empirical evidence supports a prey buffering hypothesis in which pinniped consumption of salmonids would be reduced if other potential pinniped prey species (e.g., herring, anchovy) were available to pinnipeds in greater abundance?

18) What evidence is available to support the notion of behavioral avoidance of areas where lethal removals occur, especially at specific locations?

19) What are the plausible impacts of hatchery production on the consumption of wild salmonids by pinnipeds? Could hatchery production increase impacts on wild salmonids by attracting predators to migration routes or increasing overall predator abundance? Conversely, could hatchery production reduce predation on wild salmon through predator swamping effects? Is there any evidence to support these hypotheses?

20) Could reducing pinniped abundance in the Salish Sea (constrained by PBR removal limits set by the MMPA) result in a detectable reduction in the prey for transient killer whales? What insights do empirical evidence or model analyses provide regarding this topic?

21) Could reducing pinniped abundance in the Salish Sea (constrained by PBR removal limits set by the MMPA) result in a detectable increase in the prey for Southern or Northern resident killer whales?

Benefits, Risks, and Uncertainty.

22) For each of the following potential management actions, please summarize empirical information or model analyses relative to the potential benefits (i.e., low, moderate, high reduction in predation rates), ecological risks (low, moderate, or high), and uncertainty (low, moderate, or high). Further, please describe whether the use of one technique may preclude the later use (or effectiveness) of another method (e.g., using seal bombs that may impact pinniped hearing, making them less susceptible to acoustic deterrents).

Immediate:

a) Seal bombs and other non-lethal measures such as projectiles

b) Harassment and flushing by boats and other means

c) Targeted Acoustical Startle Technology (TAST)

d) Acoustic deterrents (e.g., pingers; sonic barriers; transient killer whale vocalizations)

e) Mechanical barriers

Short-term:

f) Transportation (or attempted relocation) of pinnipeds to offsite location

g) Reduction in pinniped abundance or individual points of concentrated predation

h) Increase hatchery production and programs consistent with sustainable fisheries and stock management, available habitat, recovery plans and the ESA

i) Reduction in hatchery production (to reduce potential predator attraction or population boost effects)

Immediate Initiation, Mid-Term Implementation:

j) Removal of artificial haulouts

Immediate Initiation, Long-Term Implementation:

k) Improved fish passage at artificial structures that serve as “hot spots” for predation

l) Reduction via lethal removal in pinniped abundance in Puget Sound (up to the MMPA PBR)

m) Reduction via lethal removal in pinniped abundance off Washington’s outer coast (up to the MMPA PBR)

n) Reduction via lethal removal in pinniped abundance within estuary and mainstem migration corridors during juvenile out migration and adult return migration periods.

o) Increased forage fish abundance through protection, acquisition, and/or restoration of nearshore habitat

Long-term Initiation, Long-Term Implementation

p) Fertility management through chemical treatments (e.g., artificial control of birth rates)

23) Can we reliably predict changes in salmon abundance as a result of pinniped removal (up to the MMPA PBR)?

Implementation

24) There are three administrative methods for a state agency to receive authorization to lethally remove pinnipeds from the NMFS. One of which, MMPA Section 120, requires that pinnipeds that are permitted to be removed are individually identifiable and documented to have consumed ESA-listed salmon. What recommendations does the Academy have for achieving that standard in a cost-effective manner in Puget Sound or the Outer Coast in areas where there are not dams (e.g., Bonneville) or concrete infrastructure (e.g., Ballard Locks) to view individually marked pinnipeds preying on salmonids? Is photo ID a viable tool to recognize individually identifiable pinnipeds, across years, for the purposes of MMPA 120 with and without capture and marking?

25) Is there evidence that it is feasible to break/interrupt socially-transmitted predation behaviors by removing re-occurring pinniped predators?

26) What are the key gaps in our understanding of pinniped predation to implement effective management actions?

APPENDIX C: WORKSHOP PARTICIPANTS

Science Workshop, February 9, 2022

Role	First Name	Last Name	Affiliation
Committee	Alejandro	Acevedo-Gutiérrez	Western Washington University
Committee	Mike	Etnier	Western Washington University
Committee	Tessa	Francis	University of Washington
Committee	Ray	Hilborn	University of Washington
Committee	Megan	Moore	NOAA Fisheries
Committee	Daniel	Schindler	University of Washington
Committee	Jonathan	Scordino	Makah Fisheries Management, Makah Tribe
Committee	Kathryn	Sobocinski	Western Washington University
Committee	Andrew	Trites	University of British Columbia
Observer	Mickey	Agha	Washington Department of Fish and Wildlife
Observer	Mark	Baltzell	Washington Department of Fish and Wildlife
Observer	Sarah	Colosimo	Washington Department of Fish and Wildlife
Observer	Derek	Dapp	Washington Department of Fish and Wildlife
Observer	Joe	Ebersole	Environmental Protection Agency
Observer	Tara	Galuska	Governor's Office
Observer	Lucas	Hall	Long Live the Kings
Observer	Robert	Harris	St. Andrews University, Scotland
Observer	Dennis	Heinemann	Marine Mammal Commission
Observer	Kirt	Hughes	Washington Department of Fish and Wildlife
Observer	Iris	Kemp	King County
Observer	John	Kocik	NOAA NEFSC
Observer	Robert	Kopperl	Willamette CRA
Observer	Kessina	Lee	Washington Department of Fish and Wildlife
Observer	Ryan	Lothrop	Washington Department of Fish and Wildlife
Observer	Charles	Morrill	Washington Department of Fish and Wildlife
Observer	Nate	Pamplin	Washington Department of Fish and Wildlife
Observer	Coral	Pasi	Washington Department of Fish and Wildlife
Observer	Jeremiah	Shrovnal	Washington Department of Fish and Wildlife
Observer	Tim	Sippel	Washington Department of Fish and Wildlife
Observer	Jessica	Stocking	Washington Department of Fish and Wildlife
Observer	Eric	Winther	Washington Department of Fish and Wildlife
Participant	Adrianne	Akmajian	Makah Tribe
Participant	Liz	Allyn	Makah Tribe
Participant	Robert	Anderson	NOAA/NMFS
Participant	Barry	Berejikian	NOAA/NMFS/NWFSC/efs
Participant	Michael	Brown	Oregon Department of Fish and Wildlife
Participant	Virginia	Butler	Portland State University
Participant	Robert	DeLong	NMFS, AFSC, MML (Retired)

Participant	John	Edwards	Washington Department of Fish and Wildlife
Participant	Joseph	Gaydos	SeaDoc Society, UC Davis Wildlife Health Center
Participant	Deborah	Giles	University of Washington
Participant	Cecilia	Gobin	Northwest Indian Fisheries Commission
Participant	Frances	Gulland	Marine Mammal Commission
Participant	Lee	Harber	Fisheries and Oceans Canada
Participant	Doug	Hatch	Columbia River Inter-Tribal Fish Commission
Participant	Mark	Henderson	US Geological Survey
Participant	Rob	Jones	Northwest Indian Fisheries Commission
Participant	Dyanna	Lambourn	Washington Department of Fish and Wildlife
Participant	Kaitlyn	Manishin	University of Alaska Fairbanks
Participant	Iain	McKechnie	University of Victoria
Participant	Sharon	Melin	National Oceanic and Atmospheric Administration
Participant	Eric	Palkovacs	UC Santa Cruz
Participant	Susan	Riemer	Oregon Dept Fish and Wildlife
Participant	Michelle	Rub	NOAA Fisheries
Participant	Mark	Scheuerell	U.S. Geological Survey
Participant	Dietmar	Schwarz	Western Washington University
Participant	Andy	Seitz	University of Alaska Fairbanks
Participant	Maritza	Sepulveda	Universidad de Valparaiso
Participant	Joseph	Taylor	Simon Fraser University
Participant	Amy	Trainer	Swinomish Indian Tribal Community
Participant	Eric	Ward	National Oceanic and Atmospheric Administration
Participant	Julie	Watson	Washington Department of Fish and Wildlife
Participant	David	Welch	Kintama Research Services Ltd
Participant	Rob	Williams	Oceans Initiative
Participant	Bryan	Wright	Oregon Department of Fish and Wildlife
Speaker	Joe	Anderson	Washington Department of Fish and Wildlife
Speaker	Casey	Clark	Washington Department of Fish and Wildlife
Speaker	Scott	Pearson	Washington Department of Fish and Wildlife
Speaker	Brandon	Chasco	National Marine Fisheries Service
Speaker	Peter	Olesiuk	Pacific Eco-Tech Environmental Research
Speaker	Austen	Thomas	Smith-Root
Speaker	Carl	Walters	University of British Columbia
Speaker	Megan	Sabal	Oregon State University
Speaker	Zac	Schakner	NOAA Fisheries
Speaker	Jamie	Womble	National Park Service
Speaker	Hem Nalini	Morzaria-Luna	Long Live the Kings
Speaker	Steven	Jeffries	Cascadia Research
Speaker	Joe	Scordino	Retired NOAA Fisheries

WSAS Staff	Yasmeen	Hussain	Washington State Academy of Sciences
WSAS Staff	Elizabeth	Jarowey	Washington State Academy of Sciences
WSAS Staff	Amanda	Koltz	Washington State Academy of Sciences
WSAS Staff	Sara	Marriott	Washington State Academy of Sciences
WSAS Staff	Katie	Terra	Washington State Academy of Sciences

Stakeholder Workshop, March 14, 2022

Role	First Name	Last Name	Affiliation
Committee	Alejandro	Acevedo-Gutiérrez	Western Washington University
Committee	Mike	Etnier	Western Washington University
Committee	Tessa	Francis	University of Washington Tacoma
Committee	Daniel	Schindler	University of Washington
Committee	Jonathan	Scordino	Makah Tribe
Committee	Megan	Moore	NOAA Fisheries
Committee	Kathryn	Sobocinski	Western Washington University
Participant	Jeannie	Abbott	GSRO
Participant	Kwasi	Addae	Washington Dept of Fish & Wildlife
Participant	Mickey	Agha	Washington Department of Fish and Wildlife
Participant	Adrianne	Akmajian	Makah Tribe
Participant	Liz	Allyn	Makah Tribe
Participant	Molly	Alves	The Tulalip Tribes
Participant	Joe	Anderson	Washington Department of Fish and Wildlife
Participant	Robert	Anderson	National Marine Fisheries Service
Participant	Anthony	Battista	Skokomish Tribe
Participant	Barry	Berejikian	NOAA/NMFS/NWFSC/
Participant	Daryl	Boness	Marine Mammal Commission
Participant	Aaron	Brooks	Jamestown S'Klallam Tribe
Participant	Sarah	Brown	WDFW
Participant	Laurence	Bucklin	Puget Sound Anglers State Board
Participant	Mike	Burger	Muckleshoot Indian Tribe
Participant	Kathleen	Callaghy	Defenders of Wildlife
Participant	Renee	Chamberland	SR3
Participant	Dylan	Collins	The Tulalip Tribes
Participant	Kellen	Copeland	Oregon State Unviersity
Participant	John	Edwards	Washington Department of Fish and Wildlife

Participant	Tara	Galuska	GSRO
Participant	Ron	Garner	Puget Sound Anglers
Participant	Joseph	Gaydos	SeaDoc Society / UC Davis Wildlife Health Center
Participant	Deborah	Giles	Wild Orca
Participant	Erin	Gless	Pacific Whale Watch Association
Participant	Cecilia	Gobin	Northwest Indian Fisheries Commission
Participant	Michael	Gosliner	Marine Mammal Commission
Participant	Cynthia	Gray	Skokomish Tribe
Participant	Frances	Gulland	Marine Mammal Commission
Participant	Lucas	Hall	Long Live the Kings
Participant	Robert	Harris	University of St Andrews
Participant	Dennis	Heinemann	Marine Mammal Commission
Participant	Diego	Holmgren	The Tulalip Tribes
Participant	Rob	Jones	Northwest Indian Fisheries Commission
Participant	Katie	Krueger	Quileute Tribe (Natural Resources Dept.)
Participant	Kessina	Lee	Washington Department of Fish and Wildlife
Participant	Zoe	Lewis	Western Washington University
Participant	David	Low	WDFW
Participant	Derek	Marks	Tulalip Tribes
Participant	Robert	McClure	Upper Skagit Indian Tribe
Participant	Mike	McHenry	Lower Elwha Klallam Tribe
Participant	Iain	Mckechnie	uvic
Participant	Casey	Mclean	SR3 Sealife Response, Rehabilitation and Research
Participant	Jed	Moore	Nisqually Indian Tribe - Salmon Recovery Program
Participant	Gary	Morishima	QMC
Participant	Mary	Neil	Muckleshoot
Participant	Kurt	Nelson	Tulalip Tribes
Participant	Mark	Nelson	Lummi
Participant	Whitney	Neugebauer	Whale Scout
Participant	Kari	Neumeyer	NWIFC
Participant	Nora	Nickum	Seattle Aquarium
Participant	Peter	Olesiuk	Pacific Eco-Tech Environmental Research
Participant	Tony	Orr	Marine Mammal Laboratory/NOAA
Participant	Rich	Osborne	UW Olympic Natural Resource Center
Participant	Nate	Pamplin	Washington Department of Fish and Wildlife
Participant	Christine	Parker-Graham	US Fish and Wildlife Service
Participant	Scott	Pearson	WDFW
Participant	Joseph	Peters	Squaxin Island Tribe
Participant	James	Powell	SR3

Participant	Michelle	Rivard	The Marine Mammal Center
Participant	Gordon	Rose	Northwest Indian Fisheries Commission
Participant	Naomi	Rose	Animal Welfare Institute
Participant	Michelle	Rub	NOAA NWFSC
Participant	Casey	Ruff	Swinomish Tribe
Participant	Casey	Schmidt	Suquamish Tribe
Participant	Joe	Scordino	retired NOAA Fisheries
Participant	Alyssa	Scott	The Whale Museum
Participant	Monika	Shields	Orca Behavior Institute
Participant	Craig	Smith	Nisqually Indian Tribe
Participant	Stephen	St. Pierre	Marine Mammal Alliance Nantucket Stranding Team
Participant	Kevin	Swager	Skokomish Tribe
Participant	Joseph	Taylor	Simon Fraser University
Participant	Stephanie	Thurner	NWIFC
Participant	Amy	Trainer	Swinomish Indian Tribal Community
Participant	David	Troutt	Nisqually Indian Tribe
Participant	Frank	Urabeck	Steelhead Trout Club of Washington
Participant	Lauren	Urgenson	King County
Participant	Carl	Walters	UBC
Participant	Kenneth	Warheit	WDFW
Participant	Colleen	Weiler	Whale and Dolphin Conservation
Participant	Laurie	Weitkamp	NOAA Fisheries/NWFSC
Participant	Jacques	White	Long Live the Kings
Participant	Eric	Winther	WDFW
Participant	Jamie	Womble	National Park Service
Participant	Bryan	Wright	Oregon Department of Fish and Wildlife
Participant	Mara	Zimmerman	Coast Salmon Partnership
WDFW	Jessica	Stocking	WDFW
WDFW	Julie	Watson	WDFW
WSAS staff	Donna	Gerardi Riordan	Washington State Academy of Sciences
WSAS staff	Liza	Jarowey	Washington State Academy of Sciences
WSAS staff	Amanda	Koltz	Washington State Academy of Sciences
WSAS staff	Katie	Terra	Washington State Academy of Sciences

APPENDIX D: COMMITTEE BIOGRAPHIES

Daniel Schindler (*Chair*)

Dr. Daniel Schindler is an ecologist who studies the causes and consequences of dynamics in aquatic ecosystems, and how those dynamics affect the goods and services that aquatic systems provide. He is one of the core faculty with the UW Alaska Salmon Program. In western Alaska, he studies the interactions between the physical features of watersheds and the ecological processes that support wildlife and fisheries. One aspect of this work has been in quantifying how genetic diversity and environmental complexity combine to maintain healthy salmon populations in Bristol Bay. Additionally, Dr. Schindler looks at the effects that urban development has on lakes, both in Seattle and across the Pacific Northwest more widely. Throughout his research program, fieldwork is closely coupled with statistical modeling.

Alejandro Acevedo-Gutiérrez

Dr. Alejandro Acevedo-Gutiérrez is a Professor and lead of the Marine Mammal Ecology Lab at Western Washington University. In his early work, Dr. Acevedo-Gutiérrez studied the social behavior of bottlenose dolphins and the foraging behavior of large whales. He was an advisor and scientist-on-camera in four different educational films, including Telly Award and Silver CINDY Award winner *Marine Science: Exploring the Deep* and Academy-Award nominee and Silver WorldMedal winner *Dolphins*. These experiences led him to a career in science education and a position at the California Academy of Sciences in San Francisco. At WWU, Dr. Acevedo-Gutiérrez is both a science educator that prepares future science teachers and a biologist that along with his students studies the foraging behavior of harbor seals and sea lions and their interactions with humans.

Mike Etnier

Dr. Mike Etnier is an Affiliate Curator of Mammals at the Burke Museum, Owner of Applied Osteology, and an Affiliate Research Professor at Western Washington University. He is a trained zooarchaeologist, primarily interested in studying biogeography and historical ecology of North Pacific marine ecosystems, and how changes in each of these has or has not influenced, or been influenced by, prehistoric human hunting practices. To study these complex systems, he spends nearly equal amounts of time working with modern and ancient bone and tooth samples. Dr. Etnier's current research is examining a long-term faunal record from Dutch Harbor (Unalaska Is.), Alaska. His research on marine mammals combines aspects of modern population studies with applied zooarchaeological studies of the same species.

Tessa Francis

Dr. Tessa Francis is the Lead Ecosystem Ecologist at the Puget Sound Institute, and the Managing Director of the Ocean Modeling Forum. She is an aquatic ecologist whose research is related to aquatic food webs and the impacts of environmental variables and human activities on aquatic species and food-web dynamics. Dr. Francis is interested in the associations between terrestrial and aquatic habitats, and how watershed and shoreline dynamics impact aquatic food webs and populations. At the Puget Sound Institute, she is engaged in projects related to ecosystem-based management of forage fish in Puget Sound, including Pacific herring; food-web dynamics, including trade-offs among trophically-linked targets for recovery (salmon and herring); and linking best available science to ecosystem-based management of Puget Sound. At the Ocean Modeling Forum, Dr. Francis helps bring together multidisciplinary working groups to improve model-based advice for ocean management, using multi-model approaches.

Ray Hilborn

Dr. Ray Hilborn is a Professor in the School of Aquatic and Fishery Sciences at the University of Washington specializing in natural resource management and conservation. He has co-authored several books including "Ocean Recovery: a sustainable future for global fisheries?", "Overfishing: what everyone needs to know", "Quantitative fisheries stock assessment", and "The Ecological Detective: confronting models with data," and has published over 200 peer reviewed articles. Dr. Hilborn has served on the Editorial Boards of seven journals including the Board of Reviewing Editors of Science Magazine. He has received the Volvo Environmental Prize, the American Fisheries Societies Award of Excellence, The Ecological Society of America's Sustainability Science Award and the American Institute of Fisheries Research Biologists Outstanding Achievement Award. He is an elected member of the Washington State Academy of Sciences and a Fellow of the Royal Society of Canada and the American Academy of Arts and Sciences.

Megan Moore

Megan Moore is a Research Fisheries Biologist with the NOAA Northwest Fisheries Science Center in the Environmental and Fisheries Research division. Ms. Moore uses acoustic telemetry techniques to quantify behavior and survival of salmon and steelhead in Puget Sound. Her work addresses the impacts of pinniped predation on the recovery of ESA-listed steelhead populations, and how ecosystem and anthropogenic factors affect predator-prey dynamics in the Salish Sea. Ms. Moore served on the Salish Sea Marine Survival Project Steelhead Technical Team and the Hood Canal Bridge Ecosystem Assessment Team to identify sources of mortality on migrating steelhead smolts. Her career began at the USGS Columbia River Research Lab, before she moved on to study marine fish behavior both in the lab and in Yaquina Bay in Newport OR, home to the Hatfield Marine Science Center and Oregon State University.

Jonathan Scordino

Jonathan Scordino has worked for the Makah Tribe as a marine mammal biologist since 2007 and has run the Marine Mammal Program of Makah Fisheries Management. The objective of Makah Fisheries Management is to use an ecosystem-based approach to manage the Tribe's cultural and biological resources sustainably. To help the Tribe achieve this goal, Mr. Scordino conducts studies on marine mammals and other species of the local ecosystem. An important focus of his research in regards to pinnipeds and salmon were studies conducted on Steller sea lion, California sea lion, harbor seal, and river otter diets and models he developed to estimate seasonal and annual prey consumption for Steller and California sea lions in northwest Washington. Mr. Scordino has previously studied pinnipeds as a contractor for NOAA's Marine Mammal Laboratory, as graduate student at Oregon State University, and as an employee of both Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife.

Kathryn Sobocinski

Dr. Kathryn Sobocinski is an Assistant Professor in the Department of Environmental Sciences and the Marine and Coastal Science program at Western Washington University. She is an applied marine ecologist focusing on fishes, fish habitats, and impacts of human disturbance and climate change in coastal ecosystems and uses statistical and ecological models in conjunction with field data to describe patterns and processes in these ecosystems. She has developed ecosystem indicators related to salmon marine survival and was the lead author for the *State of the Salish Sea* report. Prior to her current position, Dr. Sobocinski held post-doctoral research positions at NOAA-NWFSC in cooperation with Long Live the Kings and the Oregon State University College of Earth, Ocean, and Atmospheric Sciences, and was a research scientist at NOAA-AFSC and the Pacific Northwest National Laboratory in the Coastal Assessment and Restoration group.

Andrew Trites

Dr. Andrew Trites is a Professor at the University of British Columbia where he is Director of the UBC Marine Mammal Research Unit and a research program that involves captive and field studies of seals, sea lions, whales, and dolphins. His research is primarily focused on pinnipeds (Steller sea lions, northern fur seals, and harbor seals) and involves captive studies, field studies and simulation models that range from single species to whole ecosystems. Dr. Trites' research spans the fields of ecology, nutrition, physiology, and animal behavior, including collaborations with researchers in these and other disciplines, and is designed to further the conservation and understanding of marine mammals and resolve conflicts between people and marine mammals.