MARINE MAMMAL RESEARCH UNIT
University of British Columbia

Synthesis of Scientific Knowledge and Uncertainty about Population Dynamics and Diet Preferences of Harbour Seals, Steller Sea Lions and California Sea Lions, and their Impacts on Salmon in the Salish Sea

Technical Workshop Proceedings

May 29-30, 2019

Editors: Andrew W. Trites
David A.S. Rosen

Hosted by:

Marine Mammal Research Unit
Institute for the Oceans and Fisheries
University of British Columbia
Vancouver, BC, Canada

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Workshop Summary

This workshop assembled scientists and managers with technical expertise on seals, sea lions, and salmonids to identify and evaluate knowledge and uncertainties about the diets and population dynamics of pinnipeds (harbour seals, Steller sea lions, and California sea lions), as well as the impacts that pinnipeds may be having on salmonids in British Columbia and Washington State waters. The primary focal area was the Salish Sea, but included coastal Washington and British Columbia. Pinniped impacts in the Columbia River basin were not addressed.

The workshop focused on what is known about predation by seals and sea lions on salmon—and how assumptions and uncertainties in the data affect the conclusions drawn to date about the effect of pinnipeds on salmon.

Workshop participants listened to presentations on the state of scientific knowledge about 1) pinniped abundance, diets, and feeding behaviours, 2) prey abundance, and 3) rates of predation on salmon by pinnipeds in the Salish Sea and within a long-term Salish Sea study site (Cowichan Bay). They also considered 4) the factors that affect rates of predation by pinnipeds on salmon (e.g., density of other prey species, hatchery practices, other predators of salmon, presence of transient killer whales, and man-made objects and conditions) as well as 5) ecosystem considerations (e.g., additional direct and indirect effects of predation by seals).

Following sets of presentations on particular themes, workshop participants split into four groups with an even distribution of expertise. They were tasked with discussing:

1) How good are the pinniped abundance data?
2) Are better diet estimates needed to make management decisions?
3) What additional data are required to resolve the impact of pinnipeds on salmonids?
4) What else needs to be factored into a full assessment of predatory impacts of pinnipeds?
5) How can estimates of consumption and predation rates be improved?

After hearing all of the presentations, the workshop groups addressed four pre-defined questions related to resolving uncertainties about pinniped impacts:

1) What are the biggest knowledge gaps that need to be filled to draw sounder conclusions about the role of pinnipeds in the ecosystem?
2) How can the impacts of predation by seals on salmon be assessed without doing an experiment?
3) What experiment could be done and what is the time frame to assess the outcome?
4) What are the research priorities going forward?

It was readily apparent over the course of the workshop that considerable research has occurred over the past decade in the Salish Sea to evaluate the role that pinnipeds may be playing in the dynamics of salmonid populations. It has resulted in significant advances in identifying the proportion of salmon in pinniped diets, including the species consumed by males and females by time of year, location, and life stage. Research has also contributed to understanding when and how predation is occurring, and the environmental factors that affect predation rates. Other research has added significant insights into the possible direct and indirect effects of predation by pinnipeds on salmon and the Salish Sea ecosystem.

However, this increase in knowledge has also come with a greater appreciation of the uncertainties, biases and limitations inherent in some of the data sets that constrains applying them to draw definitive region-wide conclusions about how pinnipeds affect the Salish Sea ecosystem. Workshop participants repeatedly noted that additional data are needed on aspects of pinniped foraging. However, they were equally adamant that additional data are also needed on salmon, because ascertaining the impacts of predation is as much a salmon question as it is a pinniped question.

It was further noted that the system is exceedingly complicated, and that this complexity must be more clearly understood to make accurate predictions. Ecosystem models are one means for gaining better insights, but they currently lack the necessary data to accurately model the system and therefore predict the outcome of potential management actions. Many of the data gaps identified by workshop participants relate to uncertainties in pinniped numbers, diets, and salmon demographics.

Reducing uncertainty in estimated numbers of pinnipeds in the Salish Sea requires better census data. This can be improved by having greater transboundary coordination for aerial counts, increasing US survey efforts, and counting seals and sea lions in rivers. Count correction factors used to account for animals not seen on land during surveys also need to be updated to get more precise abundance estimates by regions and pinniped age-classes.

Better pinniped diet data is required to address current uncertainties, including potential biases. Data are needed on species and size-class composition of diets, consumption rates, and other prey populations (such as herring and hake that dominate their diets). It is particularly important to obtain stock-specific salmon diet data to ascertain which salmonid populations are being consumed given divergence in stock-specific survival trends of indicator stocks. Addressing biases in diet description associated with basic methodology, geographic biases, small sample sizes of scats, and the sex and age of animals using the haulouts were also identified as research priorities.

The potential impact of pinnipeds on salmon depends on the proportions of seals and sea lions that are salmon specialists, which likely vary by region and salmon life-histories. Greater attention should also be given to sea lion predation on adult salmon (as compared to the current primary focus on predation by seals on juvenile salmon). Finally, consideration needs to be given to the alternative hypothesis that bottom-up effects of food supply and food-web competition are primarily responsible for poor juvenile survival which inhibits recovery of salmon.

This workshop was a first step in bringing together scientists and managers with pinniped and salmon expertise from Canada and the United States to identify and evaluate the impact that pinnipeds may be having on salmonids. It has identified the major knowledge gaps and need for focused research to address the key uncertainties that prevent drawing definitive conclusions about the role that pinnipeds play in the Salish Sea and their impact on other important ecosystem components such as salmon.

Workshop Structure

Goals. To engage scientists and managers with technical expertise relevant to:

A. Providing knowledge about pinniped population dynamics and diet preference,
B. Understanding existing scientific knowledge about pinniped predation, and
C. Identifying knowledge gaps and next steps.

Scope. Discussions and presentations focused on the Salish Sea, but included coastal information where relevant. Information sought included population dynamics of pinnipeds (harbour seals, California sea lions and Steller sea lions), temporal and spatial trends in diets, characteristics of populations that influence diet preference, combined impacts of multiple predator species on salmon, and ecosystem considerations (e.g., effects of pinniped consumption on dynamics of other species).

Participants. Participants with technical knowledge about pinnipeds, salmon, and fisheries management were invited from Canada and the United States. These included 39 individuals working for state and federal governments, consulting companies, tribes, nonprofit organizations, and universities (Appendix A). Focus was on technical expertise rather than representation from specific groups.

Agenda. The workshop alternated between presentations by scientists on their fields of expertise, and group discussions and review of the information presented (Appendix B).

Knowledge Gaps and Research Priorities. Following the end of the scientific presentations (Appendices C & D), participants were split into four groups with an even distribution of expertise to discuss:

1. How good are the pinniped abundance data?
2. Are better diet estimates needed to make management decision?
3. What additional data are required to resolve the impact of pinnipeds on salmonids?
4. What else needs to be factored into a full assessment of predatory impacts of pinnipeds?
5. How can estimates of consumption and predation rates be improved?

The final session of the workshop was dedicated to having the four groups address specific questions related to knowledge gaps and research priorities.

Participants discussed the following four questions:

1. What are the biggest knowledge gaps that need to be filled to draw sounder conclusions about the role of pinnipeds in the ecosystem?
2. How can the impacts of predation by seals on salmon be assessed without doing an experiment?
3. What experiment could be done and what is the time frame to assess the outcome?
4. What are the research priorities going forward?

These questions were discussed by the four groups to generate independent lines of thought, and then presented to the entire workshop for consideration. The points raised did not necessarily reflect consensus among all participants, but rather reflected the diversity of opinions.

Group Reflections on State of Knowledge

Following the end of the scientific presentations on the state of knowledge (see summaries in Appendices C & D), four groups of workshop participants with an even distribution of expertise discussed five questions related to uncertainties, data needs, and ways in which assessments of consumption and predation impacts can be improved. The following amalgamates the central points made during group discussions.

How good are the pinniped abundance data?

Concern was expressed about the frequency and consistency of pinniped population surveys in Canada and the United States. Seals and sea lions are mobile, and frequently cross the international boundary in the Salish Sea. Consequently, greater coordination between managing entities (timing, methods, and quality control) can improve overall estimates of numbers and their distributions.

Greater survey frequency will increase the ability to recognize real annual trends (vs. error due to sampling and process variation) as well as seasonal fluctuations (important for prey impacts). However, this may not be feasible over the entire range. Using index sites can help to reduce the costs of increased survey frequency, and would be most appropriate for “stable” populations (in numbers and location; e.g., harbour seals in the Strait of Georgia). Unfortunately, it is less useful for California and Steller sea lions whose populations are more dynamic.

New methods (e.g., satellite imagery, genetic analysis) might provide better total estimates and more relevant population details (e.g., age and sex distribution). However, there may be difficulties in relating new estimates to previous results.

Most survey methods use a correction factor to account for animals that are not visible on land when surveys are flown. In some ways, inaccurate correction factors may be more of a concern than inaccuracies in counts. Small errors in correction factors can dramatically increase or decrease estimates of abundance and consumption since correction factors are a direct multiplier used to estimate the proportion of animals not seen during a survey. Therefore, it is important to account for uncertainty associated with the correction factor used to derive total population sizes.

The commonly used Huber et al. correction factors are 30 years old. They need to be updated using current data on haulout patterns. There is reason to believe that correction factors are not necessarily static, and that they likely differ by region. Factors that might influence correction factors include changes in predation pressure on seals (caused by transient killer whales and terrestrial predators such as wolves and cougars), exposure and habituation to humans (level and type of activity), and physical environment (type of haul out and surrounding water). Research is being undertaken and may be expanded to produce suitable species-appropriate correction factors.

For harbour seals, there is concern about potential expansion in numbers outside of the Strait of Georgia. Coast wide surveys were completed in British Columbia in 2018, but will take a couple of years to yield final estimates. Sea lion surveys need to increase in frequency. The range of California sea lions appears to be rapidly changing (perhaps in an unpredictable fashion), which could have large ecological impacts that change annually. Surveys of Steller sea lions may be more important to address because their consumption impact on commercial species may be greater than previously recognized. Riverine surveys also need to be undertaken, given the potential concentration of predation impact on salmon.

It is often assumed that the level of predation pressure depends on the size of the predator population. However, there are questions regarding the applicability of applying overall population sizes of predators to estimate the effects of local predation. For example, there may be almost no relationship between total seal abundance and salmon abundance (although there may be relationships at a localized level).

Changes in population growth rates are constrained by the ability of the ecosystem to support the population (i.e., carrying capacity). However, carrying capacity is not fixed for any marine mammal population. Understanding what factors limit population size is incomplete (i.e., food, predation, haulout space).

The consistent survey data from Canada and the less consistent data (in recent years) from Washington State suggest that harbour seal populations are relatively stable or declining slightly within inside waters (Strait of Georgia and Puget Sound) indicating they are at or near carrying capacity. However, it is uncertain if this is also the case along the outer coast. Timing of the leveling off trend were similar in OR, WA, and BC. However, the carrying capacity could be going down with increased predation pressure and decreased fish abundance. In coastal Washington, there is some suggestion of a declining harbour seal population.

California sea lions appear to be at carrying capacity. The small breeding sites in Mexico are declining, while the much larger colonies in California appear stable (although numbers of pups born each year has decreased). The presence of male California sea lions in the Salish Sea can vary significantly from year to year, and does not necessarily follow the smoother population trends of the total California sea lion population breeding in Mexico and California. The distribution and abundance of males during the non-breeding season is likely to vary depending on where food resources are abundant. Additional increases in numbers could also occur in the Salish Sea if climate change expands the northward distribution of California sea lions.

The Eastern population of Steller sea lions is increasing range-wide, but it is unknown whether the Steller sea lions seen in the Salish Sea reflect the overall increase in abundance or is due to a change in their distribution. New rookeries (breeding sites) are being established in BC and WA. It is unknown whether their growth will ultimately be limited by food or by predation.

Are better diet estimates needed to make management decisions?

Answering this question hinges on how much the reconstructions of pinniped diets are biased due to methodologies, sampling regimes, etc. — and how these biases impact predation estimates. Biases in diet estimates may also have been introduced by the combination of genetic and traditional methodologies now being used.

There was strong consensus that the different methodologies used to describe diets need to be validated using controlled feeding trials with captive animals, particularly Steller sea lions. This should be a high research priority.

There was also concern that a significant bias associated with the sex of the pinnipeds using haulouts where scats are collected has been introduced into some diet estimates. A number (but not all) of the sampling sites have significant biases in male vs female scat samples. It is unknown whether it is a population bias, a real sampling bias, or apparent bias due to methodology.

Resolving the question of sex-bias might be done by looking at other types of data (e.g., live-capture data) relative to fecal samples to see whether there is sex-based sampling bias. The problem might also be minimized by using the gender-based data to construct a sex-specific consumption estimate vs complete population estimate (assuming that the bias is due to sampling and not analysis).

Diets are unlikely to be uniform across individuals or within a species, time, or geographic area. This reflects the inherent variability in pinniped diets. For example, the diets of seals using six different haulout sites within Puget Sound have been found to have very different diet profiles. However, diet variability can also result from sampling bias associated with small sample sizes or due to changes in the sex ratio of predators. Predation rates in the Strait of Georgia are based on "small" spatial and temporal sampling events and limited seasonal scat collections.

Another important distinction needs to be made between ecological and statistical differences and variation in diet estimates. This entails recognizing the source of variation in diets, such as whether most pinnipeds are generalists or specialists. Care must also be taken when applying previously collected diet data to project consumption within a changing environment.

While small sample sizes can result in huge variances, stratification and targeted collection of scats can improve precision and, in theory, provide more specific diet information. The observed high variation in diet suggests it will be very difficult to come up with a generalized (range wide) predation value.

An alternative way to derive a generalized predation value might be to focus on small spatial scales, concentrating on key areas and times (e.g., Johnstone Strait in late summer when Fraser River bound sockeye pass through).

It is also important to differentiate between estuary and non-estuary data (an example of data stratification), recognizing that it is harder to get scats in non-estuary sites. This opinion was not universal; others suggest collecting as broadly as possible and see what patterns emerge, and not to be as concerned by such differences as estuary and non-estuary representation. Regardless of the approach, sampling designs should take into consideration the relatively high site fidelity of harbour seals but very large migratory patterns of California and Steller sea lions.

What additional data are required to resolve the impact of pinnipeds on salmonids?

The nature of the question "What do pinnipeds eat?" tends to automatically focus discussion within an unrealistic two-species paradigm of "seal vs. salmon" rather than placing the discussion within an ecosystem framework. Ecosystem interactions need to be considered. This includes knowing the impact that pinnipeds have on other prey species that may in turn benefit salmon, or have indirect effects on other species complexes. Ecological relationships are rarely linear; pinnipeds prey on species which, in turn, prey on other species.

To ascertain the potential impact of pinnipeds and other predators on populations, better data are needed on diets, consumption rates, and forage fish populations (e.g., anchovy, sand lance). Stock-specific data to ascertain which populations of salmon are being consumed is a high priority. Unfortunately, analysis of scat samples has not identified which runs of salmon are preyed on by pinnipeds. Technologies should be explored to help assess impacts by salmon population unit. Understanding salmon population survival, distribution, and residence time is important to relate to predation. For example, lots of juvenile chinook stay and rear in North Puget Sound. Many of these fish are from the Harrison and Chilliwack systems which have been bucking broader trends in declining numbers.

In addition to studying the top-down effects of predation on salmon, other studies are addressing the equally important consideration of the bottom-up effects of food supply on juvenile survival. Both hypotheses could explain declines of some salmon populations. Food competition affecting body growth and survival could be exaggerated by hatchery increases into the system.

Predation on adult salmonids should also be carefully evaluated, in addition to the recent focus on juvenile salmon. Just because juvenile predation occurs does not mean it is a driver of population trends.

Another consideration is that diet is not constant, but varies between seasons, years, species, etc. — even within a relatively predictable environment. However, seasonal diets are rarely quantified. Year-round estimates of pinniped diets are required for a comprehensive overview of diet, as well as sex and age composition of the predator population (which will greatly impact consumption estimates). This level of dietary information is needed to infer ecosystem interactions, but may require application of novel methodologies.

Even less clear (and perhaps more important) is how the diet of pinnipeds changes with changes in prey base within the local ecosystem (i.e., how much of an opportunist strategy do they use?). While prey preference appears to be a learned behaviour, there is considerable debate over whether seals switch to target salmon or whether they are just opportunistic feeders.

What else needs to be factored into a full assessment of predatory impacts of pinnipeds?

In many respects, assessing the impact of predation on salmon is a fish question and not a pinniped question. Pinniped scientists can determine how much salmon is consumed, but fishery scientists are better placed to determine the impact of this consumption on specific fish stocks. These very different questions need addressing before considering "what to do about it?" Framing this question within an ecosystem perspective may ultimately be the best means to answer this management question.

Other fish. Assessing the impact of pinnipeds on salmon cannot be done without considering the dynamics of other fish species such as herring, hake, and anchovy. These species ultimately affect the rate at which pinnipeds prey on salmon (e.g., via prey buffering) --- and their abundances can change rapidly in response to changes in marine water temperatures, as seen in recent years.

Stock-specific analyses. Additional data are also needed at a stock level for salmon to properly evaluate impacts that seals may be having. While there is considerable summary data for salmon at a regional and species level, emphasis needs to be placed on what is happening locally and how this relates to what is going on with specific fish stocks. Much of the current stock-specific data reflects logistical and funding considerations --- and was never designed to answer ecological and conservation questions.

A localized approach to assessing impacts of pinnipeds on specific stocks of salmon could be done using a 3D hotspot mapping analysis that overlays predicted density surface for pinnipeds with locations where there are shallow dives (salmon) and deep dives (not salmon). This type of analysis could show where salmon are spatially most at risk so that more attention could focus on local effects. It would be a valuable means to evaluate the extent to which different levels of predation affect salmon dynamics.

Scaling up from specific localized instances of predation to an ecosystem-wide effect may be challenging or not possible. Facilitating a meaningful analysis will require more data about which stocks are not doing well, and how that may overlap with the distributions of pinnipeds and other predators (e.g., sharks, birds, etc.).

Other predators. A lack of data on other predators (e.g., numbers and diet information) is concerning, and tends to bias the discussion towards the better studied pinniped predation. This type of information is important given concern over whether mortality rates are additive or not (additive mortality rates may be appropriate if the rates are converted to instantaneous mortality). Accounting for the extent of predation on salmon by all the major predators is critical for assessing potential mitigation assessments.

Role of hatcheries. The role of hatcheries must also be considered in an ecological analysis of the Salish Sea and predation impacts of pinnipeds. There is pressure to increase hatchery production to provide more adult salmon for killer whales, but many key questions regarding the impact of hatchery fish remain unanswered. For example, information is needed on whether there are higher predation rates on hatchery fish vs. wild fish. Does the pulse of fish caused by hatcheries result in densities of fish that are more susceptible to predation? This is separate from the concern that increased hatchery releases cause increased competition (and decreased survival) among juvenile salmonids.

Differences between predation rates on hatchery vs. wild salmonids complicates simple assessments of the impact of pinnipeds on salmon (hatchery fish typically have lower survival rates compared to wild fish). Unfortunately, it is a difficult to separate the extent to which hatchery and wild fish are consumed using current research methods (e.g., PIT tagging), although novel methods (e.g., thermal marks on otoliths for hatchery populations) might eventually provide data.

It is possible that the mass release of smolts and fry from hatcheries buffers wild and hatchery salmonids from predation and benefits overall salmon survival. However, there are equally valid concerns that hatchery releases create predictable, concentrated prey sources for pinnipeds — essentially reinforcing (bad) pinniped behaviour. Further experiments could be undertaken to evaluate the effects of release timing and size at age on predation rates.

Man-made objects. It is recognized that certain man-made objects increase predation potential. For example, artificial haul outs such as log booms, docks, and marine floats can increase local seal concentrations. Impacts from light pollution, specifically on bridges, have been recognized as an enabling function for increased salmon predation. Bridges and other structures can physically concentrate fish. The question is, what (if anything) can be done about these objects?

Reconciling contrary trends. Finally, it is recognized that the ecological relationship between pinnipeds and salmon is complex and not nearly as easy to predict as many suggest. For example, returns of chinook salmon to the Cowichan River have been increasing since 2009 despite being preyed upon as juveniles and adults by pinnipeds. CPUE of juvenile coho has also been increasing since 2011, and increases in adult coho and chinook have been occurring in other natal rivers, not just the Cowichan system. This increase in survival needs to be reconciled with the model conclusions that seals are causing population declines. Has there been a change over time in the impact that seals have on salmon?

One possible explanation for the apparent "disagreement" between increased salmon survival and harbour seal predation at local scales is that the relative abundance of their primary diet items has increased (e.g., herring and hake). Basically, pinnipeds might consume less salmon when their primary prey is more available.

The large herring stock in the Strait of Georgia should be a boon for chinook and pinnipeds alike. The degree of piscivory in juvenile coho and chinook is highly variable and correlated to marine survival. For chinook, the switch from euphausiids to piscivory appears to be critical for enhanced growth and survival. However, substantial levels of piscivory by juvenile salmonids has not been observed within the Strait of Georgia where chinook are primarily consuming euphausiids.

How can estimates of consumption and predation rates be improved?

Improving predation estimates. Inter-annual variability is a pervasive "problem" in ecology. It is a major source of uncertainty that needs to be incorporated into decisions about how data are used, and how uncertainty in model estimates are expressed. This means including variability of salmon stock characteristics (numbers, size) into predictive ecosystem models, as well as incorporating variability in the abundance of other prey species (e.g., herring and other forage fish). The general preferred approach is to look at data across the years to better understand how this system is changing. But it is important to use the right statistical approach.

A number of things could be done to incorporate and reduce uncertainties in model predictions associated with inter-annual variability. These include:

- Coordinate dietary methodologies used by researchers to better determine size selectivity (e.g., use of vertebrae from scats).
- Use data from well-studied sites for a preliminary assessment of variability and selectivity. Results will help to identify the relative importance of inter-annual variability on model predictions, as well as where data collections should be undertaken. It is important to do this to get a concept of the sources of variability in the well-studied areas before moving onto other less-studied areas.
- Predation is one source of mortality on salmonids. Non-predatory sources of mortality could be leading to decreasing populations of salmon, and could also make them more susceptible to predation (e.g., ocean conditions/temps, food availability, disease). Marine survival needs to be linked to all of these other factors (not just pinniped predation).
- A model like Atlantis may be the best type of model to account for direct and indirect effects. However, such models require a lot of input data, which has been a struggle for assessing impacts of predation in the Salish Sea.

Improving consumption estimates. A number of things are required to improve estimates of amounts of salmon consumed by pinnipeds. One of the most critical is to calibrate and validate the methods used to describe pinniped diet across the three primary pinniped species. Current methods (a combination of genetic and hard part analysis) have only been partly validated, and only for harbour seals. It is essential that additional validation studies (controlled feeding experiments) be performed with captive animals to improve diet estimates via scat analysis for Steller (and California) sea lions.

Even if individual diet estimates are assumed to be accurate, there is no consensus on how to weigh habitat and sex-specific diet differences. DFO is partly addressing this by broadening its sampling effort, but it will inevitably be limited by habitat type (especially tidal areas). The influence of various types of sampling sites needs to be weighed (i.e., a correction factor) to get accurate, overall consumption estimates.

Impact assessments will also be improved by knowing more about both predator and prey demographics. Most notably:

- The apparent sex bias in scat analyzed needs to be addressed, as indicated by the Strait of Georgia data. Sex identification can be tested through captive studies.
- Refining prey size is also important; both absolute size and growth rates of fish being consumed will provide important predation information. It might be possible to look at otoliths from scats to see if they are feeding on slower or faster growing fish.

Collectively, this new information will help identify which component of the fish population is being taken and the indirect effect of other environmental factors on susceptibility of salmon to predators.

Would removing pinnipeds increase juvenile salmon survival?

Other mechanisms that affect predation. Many believe the basic premise that increasing smolt numbers (and their survival) will increase adult returns. However, substantial questions remain regarding the relationship between increased number of smolts and smolt-to-adult ratios (SARs). Increasing the number of smolts in the system (i.e., through hatchery releases or decreased pinniped predation) may increase competition, thereby ultimately lowering ocean survival. This hypothesis is partly backed by research on chinook salmon in other study areas. Other studies have noted increased marine survival in the face of increased predation by pinnipeds.

The US-Canada Salish Sea Marine Survival Project (www.marinesurvivalproject.com) has been investigating other sources of mortality that affect marine survival and decrease salmon abundance. This includes studies of both bottom-up and top-down effects. A majority of the predation studies have been focused on harbour seals due to the correlations between increased abundance of seals and concurrent declines in coho, steelhead, and chinook marine survival. However, there are other potential predators of juvenile salmon such as Humboldt squid, resident salmon, great blue Pacific herons, Pacific harbour porpoise, Pacific white-sided dolphins, Pacific hake, river lamprey, salmon sharks, sturgeons, tuna, grey and humpback whales, northern fur seals, piscivorous birds, etc. More information regarding impacts from these multiple predators could contextualize the impact of harbour seals and broaden understanding of where salmon are most affected.

There are a host of environmental factors affecting the rate at which salmon are preyed upon, which may require greater attention. These include the extent of kelp forests, habitat complexity, water temperature, stream water height and flow, man-made obstructions to fish passage (bridge, dam, etc.), proximity to pinniped haul outs, alternative prey availability, fishing efforts, and hatchery fish. However, the indirect effects of these environmental factors makes it difficult to incorporate them into the structure of current predictive models.

These factors reflect the inherent complexity of the ecosystem we are dealing with. Creating a simplified model will be faster and will yield "results", but it is disingenuous and dangerous to assume these predictions will be accurate.

Compensatory mortality – is it a major factor? *Additive mortality* is when all of the predation in the system is independent; i.e., removing a specific predator means that those prey will not be consumed by other predators in the system. *Compensatory mortality* refers to the situation when the potential prey of a predator that is removed from the system will be consumed by other predators or die of other natural causes such as disease. The distinction is critical for predicting how an ecosystem will react to removal of a predator.

There is unlikely to ever be 100% compensatory mortality. In other words, it seems unlikely that all of the juvenile fish eaten by pinnipeds would be eaten by another predator in the absence of seals. Instead, some of the morality caused by seals and other predators is likely additive mortality (i.e., each predator adds to the increasing total natural mortality rate of salmon). But how can the degree of compensatory mortality be assessed? Could a comparative study be undertaken to determine the extent to which pinniped-caused mortality is additive or compensatory?

The level of compensatory mortality may vary depending on how the fish behave and how healthy they are. Do they quickly pass through areas where seals feed or are they more resident in areas where predation risk is high? The range of possibilities may make it difficult to determine susceptibility to predation. Furthermore, the behaviour of the fish may be stage-specific and may vary between years.

Anecdotal data does not show seals causing a lot of mortality of larger juvenile salmon, which raises the question of “who is eating them – and when and where is it occurring?” It is a knowledge gap that is important for accurately predicting the potential effect of changes in pinniped numbers.

Large adult hake or other large predatory fish (possibly salmon shark or some other unconsidered predator) could be a large component of subadult mortality. Other pinnipeds and marine mammals (harbour porpoise, white sided dolphin, etc.) could also contribute to potential compensatory mortality. The lack of data might partly be due to not having samples at the right time and place to detect salmon in diets, highlighting a gap in appropriate study designs.

Next Steps—Resolving Uncertainty

1. What are the biggest knowledge gaps that need to be filled to draw sounder conclusions about the role of pinnipeds in the ecosystem?

Broader ecosystem considerations

A significant knowledge gap identified was a lack of empirical data needed to understand the vast array of ecological linkages in the system (Salish Sea). Ecosystem modelling is an important tool for gaining insights into dynamic systems—and there are a number of good predictive ecosystem modelling approaches that can be used. However, real-world data is required to evaluate which models are most appropriate and accurate. This is needed to improve understanding of the biological and physical drivers that affect salmon populations so that educated decisions can be made regarding the results of altering aspects of the system.

It is important to recognize that there are likely factors not yet considered that are more important than pinniped populations in driving salmon declines. Environmental factors, for example, can be major drivers of salmon populations—but may not affect all stocks of salmon alike.

Drivers of salmon populations are not limited to predation, but are likely a combination of interacting factors that differ between regions and salmon stocks. However, the spatial scale that is the most appropriate for understanding these interactions is unclear. Determining the appropriate scale would help determine the appropriate level of management interventions.

A broad examination of all salmon mortality factors is necessary to properly assess the impact that seals may be having on salmon (e.g., dynamics of other fish stocks, other predators, environmental change). The proportion of salmon mortality that is directly caused by predation also needs careful examination. The focus also needs to be widened beyond just harbour seals. Questions to address include:

- What impacts are others consumers of salmon (e.g., herons, cormorants, mergansers, and fish) having in estuaries?
- How much salmon are other predators consuming (e.g., other fish, Steller sea lions and other marine mammals) once salmon leave the estuary?
- What predation patterns (e.g., areas where predation occurs, and age classes of salmon consumed) have the greatest impact on returns?

The spatial-temporal overlap of pinnipeds and salmonids needs to be determined. This also needs to be done for other predators of salmon, as well as for the prey that salmon feed upon.

Pinniped numbers and diet

Having accurate population estimates of pinnipeds is essential for determining predation impacts on salmon. Canadian harbour seal estimates are reasonable, but surveys need to increase on the US side of the border. In addition, the spatial expansion of harbour seals outside of the Strait of Georgia should be re-evaluated to derive a more accurate population estimate.

The Strait of Georgia harbour seal population is believed to be stable, which raises the question of what is limiting harbour seal abundance in this area. The seals do not appear to be limited by food given there are no signs of malnutrition or poor body condition. Predation by transient killer whales is a reasonable explanation given the frequency with which they occur in the Salish Sea.

Surveys of sea lions also need to be done more frequently—perhaps even monthly given that their numbers can change quickly in time and space (vs. seals). This is particularly true for California sea lions whose movement patterns are not understood. Pinniped census counts have tended to focus on harbour seals and Steller sea lions at marine sites. Census counts should be extended to riverine systems for all species.

It is a tremendous effort to survey all pinniped haulout sites. Counting at index sites may be a way to offset this. They can be appropriate for "stable" populations, such as harbour seals in the Strait of Georgia. However, existing uncertainty with population estimates and recent information around spatial re-structuring may negate the value of index sites. Most notably, a shift in animals from index sites to non-index sites would appear as a population decline when one has not occurred. Consideration needs to be given to the pros and cons of using index sites to census pinnipeds in the Salish Sea.

A year-round collection of pinniped scats is necessary to obtain a comprehensive description of diet. Although increasing numbers of scats are being collected, there are always practical and financial limits.

Basin-wide impacts of pinnipeds on salmon are being estimated from small samples of diet samples. These small samples ultimately lead to uncertainty and low confidence in predicted impacts due to the possibility that they are biased by age, sex, or sampling location—and are therefore not representative of the average seal diets. For example, genetic information suggests a disproportionate (~3:1) number of male scats being collected in some areas.

Scat sampling can give a snapshot of prey intake, but does not reveal anything about the dynamics between predator and prey. For example, it cannot be used to infer the degree of size selectivity by pinnipeds—in the absence of information about the sizes of potential prey available to them.

The remains of salmon contained in seal scats also cannot yet by broken down to salmon conservation units. New technologies may ultimately help refine the estimate of impacts by salmon population units.

Fish dynamics

Hatchery salmon typically experience higher marine mortality rates than wild salmon, which means that it is possible that hatchery fish are inflating estimated rates of predation for wild fish. Resident chinook and coho may also be disproportionately present in seal scats, and lead to incorrect conclusions about rates of predation on hatchery and wild fish. Thus, wild and hatchery fish, and resident and non-resident salmonids may experience different levels of predation based on having different behaviours and life histories.

Resolving why mortality rates differ between salmon stocks is needed to predict what would happen if pinniped predation is altered through culls or removals. Similarly, understanding whether predation by pinnipeds is additive mortality is needed to determine the level of seal removal that would make a significant difference.

Continued focus is also needed on stock-specific trends (and underlying causes) of marine survival. In particular, a better understanding is needed of the mechanisms that affect the relationships between smolt numbers and adult returns.

It is currently only possible to determine the spatial and temporal aspects of salmon biology (by species) at certain points in their life-histories. Filling in more of the missing pieces will require greater surveying effort and consideration of how to spatially stratify the way in which samples are collected (e.g., rivers, basins, Management Areas, habitat types, and oceanographic features). Identifying the data needed to evaluate management options will help define the sampling regime.

For consistency, spatial sampling units should be agreed upon between Canada and the USA—and sampling designs should not just be for salmon. Recent increases in abundances of forage fish (e.g., anchovy) have been observed. Obtaining information on forage fish populations should be a priority.

Not enough is known yet about the interaction between predators and salmon populations. Some of the major outstanding questions include:

- Which fish life-history stage targeted by pinnipeds has the greatest impact on overall population salmon numbers and harvest levels?
- What is more important for salmonid population survival—predation on smolts or adults?
- What proportion of pinniped populations are salmon specialists—and are they smolt or adult specialists or both?
- Is predation by pinnipeds on salmon additive or compensatory—and how would the ecosystem change if it is compensatory mortality and pinnipeds were removed?

Important clues to help answer these questions might be found by looking at all trajectories of different fish populations and determining whether they are explained by pinniped predation. For example, there is some evidence that the dynamics of herring are bottom-up driven, such that top-down effects play less of a role in controlling their numbers. However, some have expressed the view that top-down effects of predation may explain declines in sizes and ages of herring.

There is also a broader question of “When do you have enough information to do an experiment?” General trends in ecosystem interactions will start to emerge as ecosystem models continue to be developed, but care must be taken not to extrapolate on too general a level.

2. How can the impact of predation by seals on salmon be assessed without doing an experiment?

There was a general consensus that data are insufficient at this time to make defensible model predictions and undertake a broad culling experiment. Making reliable predictions requires a better understanding of indirect effects of culling, food web relationships, and the factors that influence the major components of the ecosystem.

Ecosystem models need to be developed and refined to include:

- freshwater survival
- fishing removals
- reduced pinniped levels
- stage-specific mortalities of salmon
- life-history variance of salmon (resident and non-resident fish)
- changes in diet pattern based on habitat conditions, forage fish availability, etc.

One means to better understand ecosystem processes is to construct historical (back-casting) models. It may also be possible to take advantage of "natural experiments" that are created by either temporal changes in conditions or defined differences between locations such as:

- changes in transient killer whale distribution
- warm water events
- known changes in forage fish (prey) species
- survival of fish populations exposed to seals vs. those not exposed to seals
- west coast of Vancouver Island vs. other areas
- inland waters vs. coastal
- changes in hatchery releases to test if buffering of other fish have a negative impact on salmonids
- historic seal removals, e.g., Puntledge River and historic bounty program.

In theory, hind-casting models can identify what other sources of mortality exist and put predation into context. It is important to recognize, however, that extrapolating relationships based on historic patterns and time series may be compromised by changing environmental conditions (e.g., climate change). There may also be limited historic data to analyze.

However, even if such improved models were developed, the following must be considered before any test cull could be implemented:

- What threshold of uncertainty is acceptable by management? In all likelihood, the threshold for this type of management action will be higher than for other (non-lethal) types; and
- How can the inherent model uncertainties be reduced to meet the threshold of confidence required by management?

Mathematical models are the only way to assess the impact of predation by seals on salmon without doing an experiment. However, the general consensus is that there is too much uncertainty at this time in the current data to yield reliable predictions.

3. What experiment could be done and what is the time frame to assess the outcome?

There are four types of experiments that could be done involving a) varying hatchery production, b) enhancing fish survival, c) non-lethal removal of pinnipeds, and d) lethal removal of pinnipeds. All require power analyses of effect size of a given experimental change (and time), and the sampling requirements to detect efficacy. All also require careful thought about how the ecosystem will be effectively monitored to track changing dynamics—as well as the time and cost of doing so.

Vary hatchery production

Hatcheries provide a relatively easy means to experimentally manipulate the system, particularly as plans are already in place for increasing production. For example, there are plans for potential massive increase in hatchery smolt production in Puget Sound. These actions can be used as an opportunity to further understand the system, with the appreciation that they may not actually be an effective solution.

Instead of culling pinnipeds, more fish can be added to the system to see if marine survival stays constant or if it continues to decline. Hatchery experiments can involve not just altering overall output but also shifting timing and location of releases (including level of pulse). It is important to recognize that such experiments may have unintended consequences. For example, increased releases may increase competition, and actually ultimately decrease marine survival. Therefore, an alternative experiment might be to reduce hatchery production to see if it reduces competition with wild fish and enhances the body growth and survival of wild salmon.

While such hatchery experiments can provide insight into how the fish interact in the ecosystem, it is important to also consider how the effect of such manipulations in relation to the ecosystem can be monitored.

Enhance fish survival

Fish numbers can be increased via increased survival, and not just by increasing the number of fish entering the system. Experimental changes to the physical environment can be undertaken to measure their effect on survival and returns. For example, kelp cover or other natural suitable habitat could be increased, or artificial reefs could be built to increase hiding places and forage fish spawning habitat. Artificial barriers or pinch points (e.g., Hood Canal Bridge) that decrease survival and increase predation risk might also be modified or removed.

Deploying PIT tags in young salmon is one means to get a clearer picture of when mortality occurs during the ocean phase. This would facilitate properly partitioning mortality, particularly if combined with better detection (i.e., antennae) adjacent to pinniped haulouts.

Non-lethal removal of pinnipeds

As an alternate to culling pinnipeds, non-lethal methods that involve capturing or harassing pinnipeds could be used to mediate their predation impact. Experimental designs could aim to disrupt the effect of pinniped predation at certain critical times, such as during a pulse of wild and/or hatchery fish. Actions could also be site-specific. For example, pinnipeds might be excluded from certain west-coast Vancouver inlets, but allowed in others.

Any such action would need to be viewed as an experiment, and therefore would need to have a control to determine potential success and better understand salmon stocks. A downside to experiments that harass or move pinnipeds around is that they likely cause ‘downstream effects’ (i.e., predation is shifted to other locations).

Potential non-lethal actions include acoustic deterrence, particularly at bottlenecks. However, acoustic deterrents have not been too effective so far. In theory, something could be designed that is specific to pinnipeds, and would have to be implemented on a schedule that minimizes habituation. Removing or disrupting haulouts in select places, including log boom removal, might be an effective strategy, particularly near estuaries.

Contraceptives might be used as an alternate way of controlling overall population numbers. However, if used on juveniles, there might be semi-permanent effects (lessons from eastern Canada studies should be heeded).

Lethal removal of pinnipeds

A cull would remove a percentage of all Salish sea pinnipeds (i.e., decrease the population by fixed amount that does not threaten the long-term existence of the species). Modelling suggests an initial 50% reduction, plus killing 3,000 animals per year for harbour seals is required to increase numbers of returning adult salmonids. A short-term removal would be followed by monitoring smolt-to-adult return ratios in multiple locations (e.g., in Quatsino, Nisqually).

Experiments require replicates and controls for comparison to evaluate the effectiveness of the experiment. Lethal removals similarly require some sort of control to determine whether the removals produced the intended effect. The timeline to evaluate the effectiveness of killing pinnipeds should be 8-10 years, or longer if compensatory mortality occurs (i.e., other predators consume the fish that pinnipeds would have taken). This requires good planning and resources.

The potential impact of the action would have to be evaluated by comparing similar systems (e.g., Nanaimo vs Cowichan). It will also require an in-depth monitoring program with associated increase in effort. For example, the current seal assessment surveys done every 5 years would be inadequate for population level monitoring of any such experiment.

In addition to removing pinnipeds, it may also be necessary to concurrently remove other predators from the system (i.e., herons, mergansers, otters, raccoons, and trout). Considerations might also be given to using different approaches for in-river, in-estuary, and in-ocean predation. River systems where stocks are nearing extinction and where seal predation is occurring (such as predation of steelhead on the Gould River) could provide a more "closed" system for study.

An experimental lethal removal will entail killing large numbers of pinnipeds in urbanized areas in the Salish Sea. Such actions would also have to satisfy UNEP protocols for justification.

4. What are the research priorities going forward?

Research priorities to address the most pressing scientific knowledge gaps were identified through group discussions. They were not prioritized, and do not necessarily represent a consensus. They include:

Pinniped abundance

- Undertake California sea lion counts (important for regional impact)
- Determine abundance and distribution of pinnipeds cross-boundary (surveys)
- Maintain long-term pinniped abundance time-series

Pinniped diet

- Obtain Steller sea lion diet information, with attention to stocks, areas
- Refine diet assessment methods (including identifying biases)
- Develop corrections for DNA diet techniques using captive sea lion studies
- Analyze prey clustering – provides insight into ecology and predation effects
- Conduct a meta-analysis of all existing diet information (including cross boundary analysis)
- Evaluate size selectivity
- Assess sex ratio bias of scat collections—validate using captive studies; also use alternate data to understand ratio of actual population

Impact of predation on salmon

- Initiate studies to better track predation on salmon stock - genetics, microchemistry, others?
- Deploy pop up tags to follow the fate of salmon (not just pinniped predation, but other sources too)

- Assess stock-specific vulnerability to predation
- Build spatial models of predator and prey distributions
- Survey for presence and impacts of pinnipeds in fresh water
- Map broader ecological linkages
- Determine roles of different pinnipeds and other predators—and obtain information on demographics and diet info (prime example: Steller sea lions)
- Use a management strategy evaluation (MSE framework) to design and test candidate management approaches that might be taken to increase marine survival of salmonids
- Undertake small scale removals of pinnipeds in conjunction with paired studies of appropriate control population systems.
- Identify predation hotspots using predictive models

A possible next step to refine these lists is to conduct a comprehensive survey of scientists and managers to prioritize and more clearly define the research questions and issues raised during this workshop—as well as to rank the research priorities.

Conclusions

What Actions to Take

The four discussion groups had evenly balanced expertise on pinnipeds, chinook salmon, and fisheries management — and came to similar conclusions regarding key uncertainties that prevent drawing definitive conclusions about the impact of pinnipeds on salmon.

Some of the recommendations to reduce uncertainty included greater transboundary coordination for aerial counts, counting in rivers, and updating correction factors to get more precise estimates by region and age-classes. Better data are also needed on diets, consumption rates, and forage fish populations. It is particularly important to obtain stock-specific data to ascertain which populations of salmon are being consumed. Biases in diet description associated with small sample sizes and the sex and age of animals where scats are collected were further identified as research priorities. And finally, consideration needs to be given to the alternative hypothesis that it is the bottom-up effects of food supply on juvenile survival that are limiting recovery on salmon.

Careful thought needs to be given to determine the top research priorities in light of limited financial resources, the broad scope of identified research gaps, and the timeline sought to make management decisions. Addressing knowledge gaps needed to inform ecosystem management decisions is particularly important.

Future Refinement and Planning

This workshop was a first step in bringing together scientists and managers with pinniped and salmon expertise from Canada and the United States to identify and evaluate the impact that pinnipeds may be having on salmonids.

Going forward will require focused research to address the key uncertainties that prevent drawing definitive conclusions about the role that pinnipeds are playing in shaping the dynamics of salmonids and other species in the Salish Sea.

Acknowledgements

The original concept for this workshop was to synthesize the considerable body of research funded by the Salish Sea Marine Survival Project on predation by pinnipeds on salmonids. Interests from managers and scientists from Fisheries and Oceans Canada and the Washington Department of Fish and Wildlife broadened the agenda and led all three to come together to review and assess a much larger body of knowledge. The workshop was supported by Fisheries and Oceans Canada through a contract to the UBC Institute for the Oceans and Fisheries. We are grateful for the logistical support provided by Pamela Rosenbaum (UBC Marine Mammal Research Unit). We are also grateful to UBC Earth and Oceans Sciences, and to the Institute for the Oceans and Fisheries for providing meeting spaces.

Appendix A: Participants

Name	Affiliation
Anderson, Joe	Washington Dept. of Fish and Wildlife
Beamish, Dick	Fisheries and Oceans Canada (Ret)
Becker, Penny	Washington Dept. of Fish and Wildlife
Berejikian, Barry	Nat'l Oceanic and Atmospheric Admin
Christensen, Villy	University of British Columbia
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Dickison, Jeff	Squaxin Natural Resources
Duguid, Will	University of Victoria
Freshwater, Cameron	Fisheries and Oceans Canada
Fu, Caihong	Fisheries and Oceans Canada
Gaydos, Joe	SeaDoc Society
Hammill, Michael	Fisheries and Oceans Canada
Jackson, Corey	Fisheries and Oceans Canada
Jeffries, Steve	Washington Dept. of Fish and Wildlife
Jones, Lisa	Fisheries and Oceans Canada
Kemp, Iris	Long Live the Kings
Kennedy, Eddy	Fisheries and Oceans Canada
Luedke, Wilf	Fisheries and Oceans Canada
MacConnachie, Sean	Fisheries and Oceans Canada
Majewski, Sheena	Fisheries and Oceans Canada
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Nelson, Ben	Nat'l Oceanic and Atmospheric Admin
Neville, Chrys	Fisheries and Oceans Canada
Nordstrom, Chad	Fisheries and Oceans Canada
Oldford, Greig	University of British Columbia
Olesiuk, Peter	Fisheries and Oceans Canada (Ret)
Pearsall, Isobel	Pacific Salmon Foundation

Pearson, Scott	Washington Dept. of Fish and Wildlife
Pellett, Kevin	Fisheries and Oceans Canada
Rosen, David	Ocean Wise
Schmidt, Michael	Long Live the Kings
Scordino, Jonathan	Makah Tribe
Sherker, Zach	University of British Columbia
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Szaniszlo, Wendy	Fisheries and Oceans Canada
Thomas, Austen	SmithRoot
Trites, Andrew	University of British Columbia
Tucker, Strahan	Fisheries and Oceans Canada
Walters, Carl	University of British Columbia
Ward, Eric	Nat'l Oceanic and Atmospheric Admin

Appendix B: Agenda

AGENDA

Synthesizing scientific knowledge about population dynamics and diet preferences of harbour seals, Steller sea lions and California sea lions, and their impacts on salmon in the Salish Sea

Workshop 1

University of British Columbia
Earth & Ocean Sciences (EOS 5104/5106)
2207 Main Mall, Vancouver B.C. Canada V6T 1Z4

May 29-30 2019, 8:00 am – 5:30 pm

GOALS, SCOPE & DELIVERABLES

Goal—to synthesize existing knowledge and identify knowledge gaps about the population dynamics and diet preferences of pinnipeds in British Columbia and Washington State, and the predation pressure they place on salmonids on the Pacific Coast.

Scope—focus is on the Salish Sea, but will include coastal information where relevant. Information sought includes population dynamics of pinnipeds, temporal and spatial trends in diets, characteristics of populations that influence diet preference, combined impacts of multiple predator species on salmon, and ecosystem considerations (e.g., effects of pinniped consumption on dynamics of other species).

Deliverable—a white paper on the state of knowledge of the populations dynamics and diet preferences of pinnipeds and their potential impact on salmon populations in British Columbia and Washington State, with an emphasis on the Salish Sea.

DAY 1

8:00 **Welcome and Introductions** - 20 min

8:20 **Workshop series overview and objectives** - 10 min

8:30 **Pinniped[1] abundance, distribution, sex and age composition, and seasonal movements**

- Puget Sound and Coastal Washington overview (Jeffries and Pearson) – 25 min
- Steller sea lion patterns in abundance and movements (Olesiuk) – 10 min
- Strait of Georgia and Coastal British Columbia overview (Majewski and Tucker) – 25 min
- Discuss/identify data limitations and strengths/weaknesses in methodologies, etc. (4 breakout groups[2]) – 20 min

[1] Pinniped = harbour seals, California sea lions and Steller sea lions for this workshop
[2] Participants will sit with their assigned groups to facilitate discussions

- Discussion & synthesis of major points (Trites) – 10 min

10:00 Break

10:15 Pinniped diets and diet trends: seasonal and inter-annual year variability; sex-based variability; specialization

- Puget Sound and Coastal Washington overview (Jeffries and Pearson) – 20 min
- Outer Coastal Washington diets (Scordino) – 10 min
- Strait of Georgia and Coastal British Columbia presentations (Thomas, Tucker) – 30 min
- Large-scale molecular diet analysis in a generalist marine mammal reveals male preference for prey of conservation concern (Schwartz) – 10 min
- Early results from harbour seal bone analysis: diet/trophic position snapshots over 100 year period (Ward) – 10 min
- Are sampled harbour seal haulouts representative of average Salish Sea diets? (Olesiuk) – 10 min
- Impacts of sampled habitat type on the occurrence of juvenile salmon in seal diet (Thomas) – 5 min
- Discuss/identify effects of sample size, spatial/temporal limitations, methodology strengths/weaknesses (4 breakout groups) – 20 min
- Discussion & synthesis of major points (Trites) – 10 min

12:15 Lunch

1:00 Pinniped prey abundance, trends and availability to pinnipeds in Salish Sea

- Trends in abundance and distribution of gadids/hake and clupeids/herring in Puget Sound and outer coast (Ward: Schmidt to help compile). – 15 min
- Trends in abundance and distribution of gadids/hake and clupeids/herring in Strait of Georgia and coast (MacConnachie) – 15 min
- Trends in marine survival of Strait of Georgia salmon stocks (Freshwater – 15 min)
- Trends in marine survival of Salish Sea Chinook, coho and steelhead, and correlations with harbour seal abundance in Puget Sound (Schmidt) – 15 min
- Enumerating availability of juvenile Chinook and coho to pinnipeds (Neville, Nelson/Anderson) – 30 min
- Discuss/identify relationships between prey and pinniped abundance and distribution trends, data limitations and methodologies for enumerating availability of Chinook and coho effects of sample size, spatial/temporal limitations, methodology (4 breakout groups) – 20 min
- Discussion & synthesis of major points (Trites) – 10 min

3:15 Break

3:30 Pinniped foraging behavioural diversity, size selectivity, and spatial and temporal differences in predation pressure on salmonids

- Puget Sound harbour seal and sea lion behaviour (Jeffries) – 15 min
- Puget Sound & Big Qualicum presentations (Thomas) – 20 min
- Strait of Georgia presentations (Trites, Tucker) – 20 min
- Discuss/identify diversity in foraging behaviour. How broadly can what is learned in one place be applied elsewhere? When and where are salmon most vulnerable to pinniped predation? What evidence supports prey size selectivity, targeted vs incidental predation, size preferences, etc.? (4 breakout groups) – 25 min
- Discussion & synthesis of major points (Trites) – 10 min

5:00 Perspectives on pinniped impacts on commercially and culturally important prey species

- Eastern Canada – Central questions, data needs, and analytic approaches (Stenson/Hammill) – 30 min

5:30 Adjourn

6:00 Mahony & Sons (Irish Pub, 5990 University Blvd). If you are unsure where to go for dinner and would like to continue the conversations — please join us at Mahony's (about a 10 min walk).

DAY 2

8:00 Rates of predation on salmon and steelhead and amounts consumed by pinnipeds in Salish Sea and Coast

- Harbour seal predation rates in Puget Sound and Strait of Georgia (Nelson) – 20 min
- Harbour seal predation on Puget Sound Chinook and coho (Pearson, Jeffries, Anderson) – 20 min
- Evidence of high predation impact on Chinook and coho (Walters) – 20 min
- Harbour seal predation on Puget Sound steelhead (Berejikian) – 15 min
- Review of published estimates of seal predation on chinook (Olesiuk) – 15 min
- Consumption of salmonids by Steller sea lions (Olesiuk) – 15 min

9:45 Break

10:00 Rates of predation on salmon and steelhead and amounts consumed by pinnipeds in Salish Sea and Coast (*cont.*)

- Discuss/identify methodology strengths/weaknesses, accounting for variance in estimates, how previous uncertainties mentioned affect predation estimates, etc. (four breakout groups) – 20 min
- Discussion & synthesis of major points (Trites) – 10 min

10:30 Rates of predation and amounts consumed – Cowichan focal area

- Pinnipeds (Thomas/Majewski/Nelson) – 25 min
- Blue herons (Sherker) – 10 min
- Acoustic tagging findings (Duguid) – 10 min
- Chinook releases, returns and survival rates (Pellett) – 30 min
- Discuss/identify major predators, when and where mortality is occurring, interannual differences in mortality rates, methodology strengths/weaknesses, etc. (four breakout groups) – 20 min
- Discussion & synthesis of major points (Trites) – 10 min

12:15 Lunch

1:00 Brief review and discussion of factors that affect pinniped predation of salmonids

- Relationships between early marine mortality of steelhead, anchovy abundance and PDO (Berejikian) – 10 min
- Impacts of the Hood Canal Bridge on outmigrating juvenile steelhead (Berejikian) – 10 min
- Discuss/identify — What factors may affect predation of salmonids (e.g., transient killer whales, artificial haulouts, hatchery managements, migration barriers, availability of other prey species, etc.)? What is known about each? (4 breakout groups) – 20 min
- Discussion & synthesis of major points (Trites) – 10 min

1:50 Ecosystem considerations: indirect effects of pinniped predation on salmon mortality, effects of disease on predation rates, and questions surrounding additive and compensatory mortality

- Overview of progress on Atlantis model that will include assessing relative impact to Chinook and coho salmon of pinniped predation of other predators of salmon (Harvey by Skype) – 15 min
- Ecosystem modelling – prey consumption by pinnipeds in the Strait of Georgia and Pacific North Coast Integrated Management Area (Fu) – 10 min
- Pinnipeds removing other consumers or competitors such has hake and herring (Olesiuk) – 15 min
- Predators disproportionately consuming the weak or sick salmon (Tucker) – 15 min

2:45 Break

3:00 Ecosystem considerations: indirect effects of pinniped predation on salmon mortality, effects of disease on predation rates, and questions surrounding additive and compensatory mortality (*cont.*)

- Discuss/identify — What are the indirect effects of pinniped predation? How does pinniped predation affect ecosystem health? etc. (4 breakout groups) – 20 min

- Discussion (Trites) – 10 min

3:30 Breakout group discussions on outstanding questions:

- How can the impact of predation by seals on salmon be assessed without doing an experiment?
- What experiment could be done and what is the time frame to assess the outcome?
- What are the biggest uncertainties pertaining to assessing the impact of pinnipeds on salmon?
- What are the research priorities going forward?
- Other questions....

4:30 Wrap up

- Presentation of working group conclusions (group leaders)
- Strategy for completing white paper (Trites)
- Workshop 2

5:00 Adjourn

Appendix C: Summary of State of Knowledge and Uncertainties

The following summarizes the state of knowledge and uncertainties regarding the population dynamics and diet preferences of harbour seals, Steller sea lions and California sea lion, and their impacts on salmon in the Salish Sea. Bulleted points provided by workshop participants are contained in Appendix D, and are cross-referenced by lettered superscripts.

Pinniped abundance & trends

Harbour seals, Steller sea lions, and California sea lions all prey on salmon in the Salish Sea. California and Steller sea lions occur seasonally in the Salish Sea from August through May, and are most abundant in central and northern Puget Sound, and the Strait of Georgia. They may be found year-round on the outer coast of BC and WA. In contrast, harbour seals are present year round in the Salish Sea and along the outer coasts.

In the United States, the California sea lion population only breeds in California—and is considered to be within its optimal sustainable population range and at or near carrying capacity in recent years[A,P]. They began to occur regularly in WA and BC in the mid-1960s, and increased from a few hundred to over 3,000 between 1972 and 2018[A,P]. Numbers of California sea lions (almost entirely males) and the areas they use in the Salish Sea vary between years—due to their tendency to aggregate where large concentrations of prey occur[A]. There are often dramatic fluctuations in numbers of California sea lions at local scales.

Steller sea lions that occur in the Salish Sea are part of the eastern population of Steller sea lions that range from California to Southeast Alaska. Their breeding populations have been increasing since the 1960s[P]. Like California sea lions, Steller sea lions rarely occurred in the Salish Sea prior to the mid-1960s—but have been occurring in greater number during winter since the 1970s [A,B]. They are listed as *Special Concern* in Canada, and were recently *delisted* from *Threatened* in the United States[P]. They have not yet reached carrying capacity.

The BC harbour seal population has been stable for the past 20 years[C] —but their distribution has changed over time. In Washington waters, harbour seals have been generally stable, but densities may have fallen in recent years due to predation[A]. The most recent counts of seals were done in 2013 in Puget Sound, and in 2014 in the Strait of Georgia. Coordinated surveys of harbour seals will occur this summer (2019) in Canada and the United States.

Estimates of numbers of seals in the Salish Sea are derived from aerial counts of animals on haulouts. These counts are multiplied by correction factors that account for non-visible animals based upon time of day relative to low tide[C]. The correction factor currently used for correcting Washington surveys was determined 30 years ago for a representative sample of adult and immature harbour seals—and needs to be re-evaluated to ensure that it has not changed significantly over time and has not been affected by killer whale predation. In British Columbia, harbour seal counts are corrected by DFO using another method that calculates proportion ashore relative to time of low tide during the survey (which was also calculated using instruments deployed in the 1990s). With either correction method, changes in either human disturbance or transient killer whale foraging activities could have changed seal haulout behaviour, and ultimately the correction factor.

In addition to counting pinnipeds in marine areas, attention needs to be given to numbers of seals using rivers and lakes that are not currently surveyed[C]. The correction factors only account for animals in the water that haul out on tidal haulouts (e.g., Fraser River estuary). Significant numbers of seals (from a salmon predation perspective) may be distributed farther upriver and therefore not accounted for by correction factors. There are also likely seals in lakes which are not captured by the tidal-site correction factors.

Pinniped diets & trends

Diets of pinnipeds have been primarily determined from prey hard parts (bones, teeth, scales, cephalopod beaks, etc.) and prey DNA recovered from pinniped fecal samples (scats) collected at haulout sites. Some studies have also attempted to assess diets using stable isotopes and fatty acids. Prey species and their proportions identified in any given scat often differ between DNA and hard part analyses, but they tend to show consistent results when sample sizes are increased and scat collections are pooled[D,F].

In the Salish Sea, over 50 species of prey have been identified in pinniped scats in a given region[D,E]. However, pinniped diets are dominated by three families of fish: gadids (primarily hake), forage fish (primarily herring and sand lance), and salmon (during summer and fall). Salmon smolts are consumed by all three species of pinnipeds during spring and early summer, but represent a tiny portion of total biomass of prey consumed each day by pinnipeds when averaged over a year or within a given month or season[D].

In terms of salmon consumption, harbour seals primarily eat adult chum and adult pinks in the fall, and predominantly eat juvenile chinook, coho and sockeye in the spring and early summer (10-16 cm) [F]. Steller and California sea lions also consume adult chum salmon in the fall [G].

Steller sea lion diets tend to be dominated by forage fish and gadids with proportions of adult salmon increasing in the fall. California sea lions also consume high proportions of forage fish with high amounts of salmon in the fall—and gadids in the spring [G].

The small percentage of the overall pinniped diet made up by salmon smolts (e.g., 1-2% chinook smolts in a given region and month)[G] extrapolates to a large number of individual fish when size of fish, numbers of pinnipeds, and energetic demands are accounted for. However, there is considerable variance surrounding the estimated proportions of smolts consumed. Some of this uncertainty is due to the broadness and high variability of diets between sampling sites. Some of the uncertainty can also be attributed to not having collected sufficient scat samples to give reliable estimates for species that are consumed in tiny proportions.

The targeted number of scats collected typically reflect costs, ability to obtain samples, and the desired precision of estimating the importance of a prey species within each sample. It is generally difficult to collect large numbers of harbour seal scats because most haulout sites are tidally washed each day. Accessibility of seal haulouts differs by time of year, and is particularly challenging during spring when smolts are entering estuaries.

Numbers of scats collected in the field typically target ~60 samples to accurately determine the proportion of species making up >5% of the diet. However, larger sample sizes (>300 scats) are required when trying to accurately estimate portions of relatively rare species in the diet. In Washington, samples sizes for harbour seal dietary analyses have been >70 scats, and in most cases >90.

Diet methods are generally less accurate for prey species eaten in small proportions—and more accurate for those eaten in greater proportions. Accuracy can be improved with larger sample sizes.

Prey size is also an important consideration that can significantly affect estimates of numbers of fish consumed. This is particularly pronounced in salmonids such as chinook. Juvenile chinook enter the marine environment at a range of sizes and can reside in the Salish Sea as juveniles, subadults, and adults.

Sizes of fish consumed are best determined by measuring the lengths of vertebrae and otoliths recovered in fecal samples—and then applying regression equations to derive the corresponding size and weight of fish that were originally eaten. Referencing specific size classes and habitats where the fish are consumed (e.g. in-river, estuary, nearshore, offshore) would avoid the ambiguity of broadly categorizing fish as smolts, juveniles, or subadults.

Smolts and subadult salmon are sometimes collectively referred to as juveniles. However, juvenile salmon have, by definition, undergone smoltification while smolts have not. Subadult fish already in the Salish Sea are joined by smolts of the year coming out of rivers in a number of different size ranges—all of which are potential prey for pinnipeds. Misclassifying subadults as smolts in diet estimates will inflate the estimated numbers of smolts actually consumed by seals.

Attention needs to be given to correctly determine the sizes and proportion of each life-stage of salmon consumed by seals. This is important because some "juvenile" fish consumed by pinnipeds may actually be 1-year old fish that stayed in the Salish Sea rather than migrating to the open ocean. Estimates of consumption will drop significantly if seals and sea lions preferentially eat the larger fish. Size is needed to derive reliable estimates of consumption.

Harbour seals are thought to prefer fish between 10 and 16 cm. A possible length cutoff between the two size categories of juvenile salmonids is 12 cm. However, the high variability in size-at-age of different stocks may mean that there is no simple cutoff between smolts and subadult fish (or fish returning from the ocean).

Another concern about the current estimated proportions of smolts contained within scats is that may not be representative of seals throughout the Salish Sea (i.e., site selection may be biasing population diet profiles). Diets are known to vary significantly by year, season, and location—particularly between estuary and non-estuary sites—and smolts may be more concentrated near some seal haulouts than others. Inappropriately applying the diets from one or a few study sites and times to other areas and years within the Salish Sea will yield biased estimates of predation rates.

A recently recognized factor that may also over-inflate the estimated proportion of salmon smolts consumed is the sex and size of the predator. Diets differ between male and female pinnipeds[P], and between large and small individual animals. Female harbour seals appear to feed closer to shore compared to males, with larger individuals of both sexes feeding further from shore than smaller individuals. It also appears that males eat more salmon than females[G,P], and that scats are collected more frequently from male seals than from females. Of concern is an apparent significant sex bias in scat samples analyzed—which can be corrected in part using DNA to determine the sex of the individual that deposited the scat.

Optimally, scat samples need to be collected more broadly across the Salish Sea, and throughout the year. Dietary analyses may also need to incorporate weighted stratification schemes to account for seasonal and geographic differences in diet and shifts in the distribution of animals. A better understanding of pinniped population demographics and the size of prey consumed are also important.

Prey abundance & trends

Pacific hake and Pacific herring constitute the greatest portion of Salish Sea pinniped diets. Broadly speaking, there has been variation, but no significant declines in the overall abundance of groundfish over the past 60 years in Puget Sound[J]. Overall abundance of herring has also been stable in recent years[J]. Regionally, however, some stocks of herring have declined while others increased. Declines have also occurred for other forage fish species, as well as true cods and some rockfish species.

In the Strait of Georgia, herring biomass is at all-time high levels, but spawn distribution has changed over time[K]. Anchovy, another important forage fish in pinniped diets, has increased in recent years[K].

Five Pacific salmon, as well as steelhead trout, spend at least some portion of their marine life-history in the Salish Sea. Species, and populations within species, exhibit consistent differences in their duration of residence within the Salish Sea, their trends in abundance, and the available information needed to evaluate management actions or conservation status. Recent work on chinook, coho, and steelhead has shown declines in marine survival or lower marine survival since the 1980s for many Salish Sea populations compared to coastal populations.

In terms of juvenile salmonids that are consumed by pinnipeds, a proportion of coho salmon are now remaining resident in the Strait of Georgia—a behaviour that has been missing for 20 years[L]. In contrast, chinook salmon have much more life-history variation. Those that spend at least one year in freshwater move quickly through the Salish Sea and travel offshore (stream-type or yearling)—while those that spend weeks to months in freshwater generally tend to rear in estuaries or nearshore coastal waters (ocean-type or subyearling)[L]. Most of the Salish Sea populations of chinook are the ocean-type. These smolt variants generally coincide with adult run timing (with stream-type returning during spring and ocean-type returning during fall).

In the Strait of Georgia, yearling chinook have had generally stable survival rates (smolt – age 2), while the Salish Sea sub-yearling chinook had high survival in the 1970s followed by low but stable survival[L].

In recent years, numbers of adult chinook returning to some east-coast Vancouver Island rivers have been increasing (ocean-type that rear in coastal marine waters)[L], while the early arriving Fraser River spring chinook have declined (stream-type that rear in freshwater and exhibit an extensive offshore ocean migration).

Range wide (throughout the Northeast Pacific), the abundance and size-at-age of the oldest age classes of chinook have declined[L]. Possible explanations for the decline in size include size selective predation (killer whales and sea lions), fisheries (sport and commercial), a changing ocean environment and hatchery practices.

In the Strait of Georgia, chinook numbers declined in the late 1970s, coho in the late 1980s, sockeye in the late 1990s. There does not appear to be any connection between the timing of these declines. In general, stocks of salmon that have shorter periods of freshwater residence, longer periods of coastal residence, and smaller size at marine entry (e.g., chum and pink salmon) currently have better status. [L]

In Puget Sound, hatchery-produced coho salmon are twice as abundant as naturally-produced fish, and hatchery-reared chinook salmon are 10-times more numerically dominant than their wild counterparts[N]. Resident chinook and coho salmon that rear year-round in Puget Sound likely have greater exposure to pinniped predation than do those that leave the Sound for extensive offshore migrations. However, marine survival of the coastal coho populations appears to have improved.

Naturally-produced chinook smolts migrate from January through July. They are initially small in January (~ 4.5 cm), but show consistent growth beginning in April, and eventually reach sizes of ~6–10 cm by July[N]. Hatchery-produced chinook are predominantly released in mid-May; while naturally-produced and hatchery-produced coho salmon smolts both migrate mid-April to mid-May[N].

Trawl surveys for juvenile fish in the Strait of Georgia over the past 20 years show that coho smolts from all stocks mix through the Strait of Georgia, and that their numbers are more concentrated northward in the fall[O]. However, the majority of these juvenile coho will migrate though Juan de Fuca Strait later that fall[O]. About 30% of coho are of hatchery origin.

Rearing of chinook smolts in the Strait of Georgia is life-history dependent. The majority of ocean-type fish will remain and rear through their first summer in stock-specific areas (e.g., Cowichan River smolts rear around the Gulf Islands, Big Qualicum and Puntledge Rivers around East Vancouver Island, Chilliwack and Harrison Rivers around the San Juan Islands and Puget Sound, South Thompson River along the mainland side from Fraser up through Malaspina Strait).

In June, coho smolts average ~17 cm, chinook are ~13 cm, chum are ~12 cm, and pink and sockeye are ~11 cm[O].

Survey catches of juvenile chinook are 2–10 times greater in Puget Sound than in the Strait of Georgia[O]. Differences in habitat need to be considered when comparing predation risks posed by pinnipeds to different salmon stocks in different regions of the Salish Sea[O].

In Puget Sound, a statistical analysis undertaken to identify ecosystem indicators that correlate with marine survival of chinook, coho and steelhead marine survival[M] found that freshwater delivery was a poor explanatory variable, while those related to predation, competition, and water quality explained more variance in marine survival (although only 30-40% for the best models). Seal abundance was an important negative explanatory variable for all three species. However, seal abundance explained much more variance in the steelhead trout and coho salmon data (22% and 30%, respectively) than it did for Chinook salmon (<8.6%)[M]. It is important to note that the methods for estimating SAR (survival) varied among the three species, which may account for some of the differences in observed relationships[M].

Pinniped foraging behaviour

There are differences in the haulout behaviours of male and female seals, and between pups, subadults, and adults. In Puget Sound, the probability of finding adult male and female seals on shore increases from June to August during the annual pupping season and fall moult. There is no trend in haulout behaviour of subadults, suggesting the change in adult sex ratios is due to moulting and reproductive behaviour (breeding and pupping)[P].

Steller sea lions (mostly males) move into the Salish Sea in late summer/early fall and are present in higher numbers during the winter and spring, and are largely absent during summer when they return to their rookeries. Male California sea lions similarly move into the Salish Sea in late summer/early fall and are seen most frequently during winter and spring. Most leave by the end of May to return to rookeries in California with a few individuals remaining in the Salish Sea during summer[P].

In British Columbia, electronic tags were glued to the fur of 20 harbour seals at the Big Qualicum River and estuary to document predation of PIT tagged coho smolts released from a hatchery[Q,S]. It revealed that most predation occurs in the evening and night. Four of 20 seals tagged near the hatchery and in the surrounding estuary ate PIT tagged fish. Over a 9-day period, each seal ate between 10 and 50 smolts per day. Predation was concentrated in the 9 days following release. Adjusting these estimates for the total number of seals present (tagged and untagged) suggests that a relatively small number of seals ate ~6% of the hatchery-released coho smolts.

The tagging study also revealed 4 types of seals (based on different foraging strategies)[Q]. One consisted of seals that that specialized on coho smolts while they were present, and ignored chinook in the river mouth—while a second group of seals appeared to target larger fish that preyed on chinook smolts near the river mouth. The two other seal groups identified did not feed at the river mouth in association with the concentrated numbers of smolts, but either remained resident and fed near their main haul-out sites, or were transient and left the study area all together.

For estuary-associated harbour seals, there appears to be individual foraging and diet specialization—with a small number of seals specializing in consuming coho smolts (primarily at dusk)[S]. Interestingly, these smolt specialists did not appear to respond to the large pulse of smaller-bodied chinook smolts as they entered the ocean, suggesting some size selectivity.

This tagging study effectively characterized seal predation on smolts in an estuary, but was unable to effectively characterize smolt predation outside of estuaries. Scat data are the only means currently available to assess the overall impact of harbour seals on juvenile salmon. However, diet and foraging behaviour outside of estuaries may also be site specific—and not representative of overall Salish Sea feeding behaviour.

Perspectives on pinniped impacts on prey species

In eastern Canada, concerns about the impact of grey seals and harp seals on commercial fish species increased following the collapse of cod in the early 1990s. Many of these cod stocks have not recovered. Considerable research has been undertaken to determine the impact of seal predation on cod[T].

The first step to assess the impact of pinnipeds on fish stocks in eastern Canada was to estimate the amounts consumed, which is a function of abundance of seals, their energy requirements and their diets. In general, numbers of harp and grey seals are relatively well known and precise—and tend to be relatively constant from one year to the next. Energy requirements are also well understood. Most of the uncertainty in estimates of consumption are due to uncertainty in the proportions of species consumed and how it varies by age, sex and feeding locations of the seals.

The second step in assessing the impact of seals on fish stocks was to estimate how much of natural mortality (M) of fish can be attributed to seal predation and how much is due to other factors. Ultimately, the impact that seals have on prey populations depends upon the population dynamics of the prey species, as well as the seasonal distribution of predators and prey (often a major data gap). Resolving the impact of seals on fish requires the expertise of fishery scientists.

Understanding the impact of other ecosystem components on fish populations of concern is equally critical to properly place seal consumption estimates into the context of prey population dynamics. For example, capelin and fisheries are important drivers of cod condition, mortality and abundance off eastern Newfoundland—while predation by seals has not been found to significantly impact northern cod stock levels. In contrast, the collapse of southern groundfish stocks in the Gulf of St. Lawrence coupled with high levels of grey seal predation appears to have created a predator pit, where grey seal predation may be limiting the recovery of cod, hake and skate—even in the absence of fishing.

Rates of predation on salmonids and amounts consumed by pinnipeds

Rates of predation and amounts consumed have be calculated at different scales and species using different data sets and assumptions[U,V,W,X,Y].

One study postulates that the currently stable harbour seal population may be much higher today than it has been for several millennia when seals were harvested by First Nations[W].

This study further concludes that three lines of evidence point to seals as a potential cause of increases in first-ocean-year mortality rates: correlative, diet, and seal behavior[W]:

1. There is a significant linear correlation between first ocean year mortality rate and seal abundance, for average mortality rates estimated from coded wire tagging for indicator chinook and coho stocks, as expected if seals take juvenile salmon incidentally while foraging for other prey.
2. Increases in mortality rate predicted from estimates of total juveniles eaten based on seal energy requirements and diet composition data are highly uncertain, but agree broadly with the increases estimated from correlation studies.

3. Estimates of potential mortality rate based on seal foraging behavior (swimming speeds, reactive distances, foraging times) also predict the mortality rate increase apparent from correlations.

Increases in mortality rates of coho are consistent with the increase that occurred in seal abundance. However, chinook stocks show highly variable responses to seal abundance with the dominant lower Fraser (Harrison) chinook showing about half the change in mortality rates seen in other Georgia Strait indicator stocks[W].

Some seal diet data has been interpreted to show that predation of salmon is not concentrated in estuarine areas, but is spread over the first ocean summer as juvenile salmon disperse widely over the Strait of Georgia and are exposed to predation by seals from both estuarine and non-estuarine haulout sites[W]. However, concern has been expressed that these data from Belle Chain are not representative of non-estuary sites. Scat collection sites in the San Juan Islands may also be similarly biased.

Most of the uncertainty in assessing the impact of seals on salmon is due to uncertainty in the small proportions of juvenile salmon found in seal scats. Small proportions of salmon in the seal diet extrapolate to high predation rates due to the energetic requirements of harbour seals, their high numbers, and the small body size of juvenile salmon in the spring and summer months [U].

Current estimates of numbers of coho and chinook consumed are sensitive to assumptions about the size of juvenile salmon being consumed, as well as the number of prey (hatchery and wild) that are available and vulnerable to seals after freshwater and post-release mortality has occurred[U,V]. The estimated numbers of salmon eaten would be significantly lower if the sizes of juveniles they are eating are larger than currently assumed[U,V]. In contrast, estimates of consumption would be higher if freshwater and post-release mortality is higher than currently assumed. Research is underway to improve these estimates.

A second model[U], using the same diet data, estimated that seals consume 24% of the juvenile chinook in Puget Sound and 44% of them in the Strait of Georgia. For coho, the model estimates that seals eat 35% of the juvenile coho in Puget Sound and 55% of them in the Strait of Georgia[U]. Thus, predation rates for juvenile chinook and coho appear to be lower in Puget Sound than in the Strait of Georgia[U].

It is important to note that there is high uncertainty and disagreement around these estimates, and they are subject to change as new data are incorporated and model assumptions are refined.

A field study used acoustic telemetry to assess predation of steelhead in Puget Sound and Hood Canal since 2006[X]. It found an annual variation in survival of smolts ranging from 6% to 38%[X]—and concluded that there appears to be a negative relationship between presence of seals and this early marine survival of steelhead smolts.

Other factors influencing juvenile steelhead survival include ocean temperatures, anchovy recruitment, and presence of alternative prey for seals to feed on. Predation by killer whales on seals may also affect steelhead survival rates by influencing seal behaviour and their foraging locations[X].

The harbour seals feeding in Puget Sound and the Strait of Georgia likely have different foraging ecologies because of basin-specific differences in habitat and prey availability[U]. Current models do not account for the movement of seals and salmon between these two regions. A Salish Sea-wide model of the seal population may improve current model formulations that are based on each region being a closed spatial box.

Steller sea lions also consume salmon smolts. While smolts comprise a miniscule part of the diet in terms of biomass, the consumption represents large numbers of smolts[Y]. However, the impact on chinook stocks is probably minimal when viewed in the context of the number of smolts produced, and the number of smolts dying before attaining adulthood[Y].

Preliminary analyses indicate that Steller sea lions are an important predator of adult chinook in British Columbia. Total chinook consumption, mainly by northern resident killer whales and Steller sea lions, has increased dramatically over the last four decades, while chinook fishery catches have declined. Increased consumption of chinook by predators may explain the declining exploitation rates in chinook fisheries [Y].

Cowichan focal area—rates of predation

The Cowichan River is a well-studied system with populations of seals and sea lions preying on juvenile and adult salmonids. For the past decade (since 2009), returns of chinook to the Cowichan have increased[Z]. Possible explanations for the increase include reduced marine exploitation, increased wild fitness (reduced hatchery releases), freshwater habitat restoration, and increased marine survival. Pre-fishery abundance is not yet as high as historic levels, but the trend is positive. Removing seal predation on salmon might further increase returns of adult fish [Z].

Four haulouts used by seals that feed in the Cowichan estuary were scanned in 2016 and 2017 for the presence of PIT tags (implanted into chinook smolts prior to release in Cowichan Bay and Sansum Narrows). A total of 18 tags were detected up to 40 km from the estuary. These 18 tags were from a wide range of tagging sites suggesting that it was not just recently tagged and more vulnerable fish that were consumed [Z].

Juvenile chinook from the Cowichan River appear to be resident in the Gulf Islands through September, and are more likely to stay in the southern Salish Sea for at least the first winter rather than emigrate. This means that they have continued exposure to pinniped predation. Mortality rates appear to be about 40% during the fall and early winter. Pinnipeds may account for at least 18% of mortality during this time of year based on acoustic tagging data [AA]. It is not known what factors account for the remaining mortality [AA].

Pinniped diet analysis shows the proportion of salmon in the diet of seals sampled in the estuary is low in the spring (juveniles of all species) and increases throughout the fall (predominantly adult chum). The relative importance of chinook, coho, and chum varies considerably from season to season, and from year to year. The proportion of juvenile chinook in the harbour seal diet has declined since 2012 from a high of ~6%, to a low of almost zero in 2018[BB]. Juvenile chinook averaged ~2% of the spring and summer diet from 2013-2017[BB]. These percentages apply to the small number of seals that feed in the Cowichan estuary and cannot be extrapolated to the entire Salish Sea population of harbour seals. Diets vary by type of site (estuary versus non-estuary) and by regional differences in habitat that support different types of fish.

Other predators of juvenile salmon that have not been studied as intensively as seals include trout, sculpins, mergansers, river otters, raccoons, and Pacific great blue herons. Significant numbers of PIT tags were detected at a heron rookery near Cowichan River suggesting the birds consumed 1-3% of tagged smolts released in the Cowichan River annually from 2014-2018 [DD]. Over 95% of the tags recovered in the Cowichan Bay heronry were from river-released fish, as opposed to fish tagged in Cowichan Bay—suggesting that predation by herons likely occurs in the lower river and estuary prior to bay residency

Smaller smolts are more susceptible to heron predation, likely as a result of slower migration speeds, slower predator evasion, and possible exclusion from refuge habitats by larger smolts when predation is occurring [DD].

Tags were evenly distributed under the nests at the Cowichan Bay heronry, suggesting that most herons prey on salmon smolts [DD].

Factors that affect pinniped predation of salmonids

Artificial lighting and man-made structures may facilitate predation by seals on juvenile salmon. Significant mortality has been documented at the Hood Canal floating bridge where the migration of steelhead smolts is slowed and the mortality is particularly high (up to 50% of the smolts arriving at the bridge)[FF]. Indirect evidence from temperature and depth tags indicate that steelhead are being consumed by harbour seals at or very near the Hood Canal Bridge, and this predation appears to account for most of the mortality[FF]. Higher numbers of seals occurred near the bridge during one of the two years of study—but densities were fairly uniform between locations (near and far from the bridge) in the second year. If seals are responsible for most of the mortality, it is likely caused by very few seals based on the relatively low density of seals near the bridge.

The presence of transient killer whales may also affect the rate at which salmon are consumed by changing the haulout and hunting behaviours of the seals and sea lions they are targeting[EE]. Seals may no longer be able to feed in areas where the risk of predation is highest. Transient killer whales were rarely seen in the Salish Sea prior to 2000, and are now seen hunting for marine mammals on a daily basis.

Ecosystem considerations

There are at least three ecosystem models being built by three teams of researchers that can be used to assess food web interactions and the potential consequence of reducing the abundance of pinnipeds on the ecosystem.

Individual-based, spatially- and temporally-explicit ecosystem models that simulate the whole life cycle of modelled species can reproduce reasonable diet compositions and achieve good understanding of pinniped impacts on prey species.

Such ecosystem models can be used to project potential future dynamics of fish species and the Salish Sea ecosystem under future changes of climate and management strategies with trade-offs between conflicting objectives across management sectors being considered.

The models are in development, but data limitations may affect each model's ability to accurately model the system and therefore to predict the effect of potential management actions.

The Strait of Georgia is an ideal area for assessing the top-down effects of pinniped predators on their prey. Pinniped predation has increased ~20-fold since 1970, and the diet is rather simple (being dominated by two species, herring and hake, which comprise distinct Strait of Georgia stocks) [II].

The increase in pinniped abundance appears to have resulted in higher mortality of herring, particularly in older age-classes, presumably because they have higher energy content. The age- and size-composition of hake has also shifted toward younger, smaller fish. Size-selective predation by pinnipeds may be driving declines in size-at-age of older herring and hake[II].

Seals may have displaced hake as the predominant herring predator in the Strait of Georgia. During the 1970s and early 1980s when pinniped populations were depleted, there was a large biomass of older, larger hake that preyed on juvenile herring and hake. As pinniped populations recovered, the biomass of older, larger hake was depleted, which reduced predation on juvenile herring and hake, and resulted in improved recruitment[II]. Herring biomass has remained at high levels despite the increased consumption by pinnipeds.

Herring and hake stocks are currently dominated by younger, faster-growing fish that are more productive. However, this has had negative implications for fisheries that tend to target older, larger fish with higher market value[II].

Predation is usually framed as a negative consequence for prey populations. However, predators can benefit the overall health of prey populations by removing sick and unhealthy individuals that may compete with others or spread disease.

As pursuit divers, pinnipeds are likely to be more successful at capturing individuals that are in poorer condition (slow, weak, sick, stressed) compared to those that are larger and healthier. Juvenile fish that are predated may be more disease-agent challenged. A study in BC of fish-eating seabirds (rhinoceros auklets) found this to be the case[lJ]. The juvenile salmon eaten by the birds carried a higher diversity of infectious agents at higher loads compared to fish that were caught using a trawl net.

Preliminary results of one ecosystem model also indicate the vulnerabilities of chinook and coho to seal predation may be relatively high, lending additional support to hypotheses that disease and physiological stressors may be playing an important role.

Appendix D: Participant Presentation Summaries

The following synopses of workshop presentations were provided by participants, and have been edited for style.

Day 1 – Pinniped Abundance, Distribution, Sex and Age Composition, and Seasonal Movements

A. Pinniped Abundance and Distribution in Washington (*Scott Pearson & Steve Jeffries, WDFW*)

Harbour seals in the Salish Sea:

- In general, Salish Sea harbor seal stocks healthy and robust
- In US, for management purposes, NOAA recognizes 3 inland WA harbor seal stocks: Hood Canal Stock, Southern Puget Sound Stock, Northern Washington Inland Waters Stock
- Under MMPA, WA stocks within OSP range (MNP to "k")
- In BC, no stock designations but S of Georgia harbour seal "stock" reached carrying capacity or "k" by late 1990s or early 2000s
- Evidence for stability to decline in inland WA harbor seal abundance
- Predation on harbour seals by Bigg's killer whales may be reducing numbers
- Haulout composition varies seasonally by age and sex

Steller sea lions in the Northwest

- WA and BC SSLs belong to the Eastern Distinct Population Segment (EDPS) which ranges along the west coast of North America from Southeast Alaska to central California
- EDPS was delisted under the ESA and is not designated as depleted under the MMPA
- Between 1972 and 2017, over its range, the EDPS has increased from 12,000 to 79,000
- The Optimum Sustainable Population (OSP) range for SSLs has not been estimated
- SSLs in the Salish Sea originate from rookeries in AK, BC, WA, OR and CA
- In the NW, SSL abundance varies seasonally with peak counts on rookeries during summer breeding seasons
- In WA, between 1972 and 2017, SSL abundance increased from 500 to over 2,000
- During fall, winter and spring SSLs become seasonally abundant where there is sufficient prey biomass that may include herring, hake and adult salmon

California Sea Lions in the Northwest

- CSLs in OR, WA, BC and SEAK originate at rookeries in the Channel Islands in CA (and most likely rookeries in Mexico waters as well)
- Between 1975 and 2014, the CSL population in US waters, increased from an estimated 88,924 animals to 257,606
- The US CSL stock was estimated to be within its OSP range (between MNPL and k)
- CSL abundance varies seasonally with very few in NW waters during summer when they are on rookeries in CA and Mexico
- In late summer/early fall, 60,000 to 80,000 adult and subadult male CSLs disperse north from their rookeries into waters off OR, WA, BC and SEAK
- CSL counts in the WA waters have increased from just a few (rare) to over 3,000 between 1972 and 2018
- During fall, winter and spring SSLs become seasonally abundant where there is sufficient prey biomass that may include herring, eulachon, anchovy, hake and adult/juvenile salmon
- Predation by CSLs (and SSLs) on ESA listed salmon (adults and juveniles) in the Columbia River is significant

B. Steller Sea Lions: An Important But Unrecognized Salmon Predator (*Peter Olesiuk, Pacific Eco-Tech*)

- The Eastern Population of Steller sea lions has increased dramatically in recent years. In BC and SE Alaska, which accounts for ~80% of pup production, total and pup numbers on rookeries have increased 5-fold since 1960. The number of breeding sites has grown from 4 to 12. The population is now well above the levels that occurred when the first assessment was conducted in 1913, which was prior to any large-scale kills.
- During the summer breeding season, abundance in BC is estimated to be 35,600 – 39,200 as of the most recent published survey in 2013. These estimates were obtained by applying multipliers derived from life tables to pup counts, and by estimating the proportion of non-pups at sea and missed during surveys based on satellite telemetry and archival tags.
- During winter, abundance in BC increases to 48,500 due to an influx of animals from the south displaced northward from CA and OR by migrating California sea lions, and by an influx of animals from the north dispersing from the large rookery at Forrester Island in SE Alaska.
- Steller sea lions have emerged as significant predators, and now likely consume more fish and more salmon than any other predator, including humans.

C. Pinniped Abundance & Distribution: Strait of Georgia and Coastal British Columbia overview: Data limitations, strengths & weaknesses of DFO datasets (*Sheena Majewski & Strahan Tucker, DFO*)

<u>Summary of trends</u>

Harbour seals

- Rotational aerial surveys undertaken every 5-10 years throughout BC
- Low tide surveys timed towards the end of the pupping season (summer)
- Visual scan of entire coastline, reefs
- B.C. population update scheduled for 2020 (surveys flown 2014-2019)
- The last coast wide assessment (Olesiuk, 2010) estimated 105,000 Harbour seals distributed throughout B.C. with slowing population growth rate
- The highest density occurs in the Strait of Georgia; the most recent estimate of abundance (based on surveys flown in 2014) was ~39,000 (stable since early-90's)
- Next survey planned for August 2019; coordination with WDFW for combined Salish Sea assessment
- Telemetry based haulout curves used to refine survey parameters (Olesiuk 2010); new deployments of GPS satellite tags are currently underway in Strait of Georgia

Steller Sea Lions

- Aerial surveys undertaken at the end of the pupping season (June 27-July 9) for total breeding population assessments
- Range wide surveys for the Eastern population conducted on a 4 year interval in coordination with US counterparts
- Latest population estimate (2013) in BC waters: 33,000-39,000 animals in summer rookeries and haulouts, approx. 48,500 animals in winter, showing continued increase
- Last range-wide survey was in 2017; updated abundance estimates scheduled for early 2020

California Sea Lions

- Breeding season surveys done outside of B.C.
- Relative overwintering <u>counts</u> updated opportunistically from fall/winter SSL surveys
- Counts of CSL observed during 2016/17 survey are scheduled to be finalized fall 2019

<u>Strengths</u>

- Coverage: coast wide surveys designed to estimate abundance of total population

- Regular standardized surveys allow assessment of trends, range expansions and support development of more intensive local studies
- Coordination of surveys for trans-boundary populations
- Longer term dataset (1970s)
- Multi-species perspective
- Use of abundance surveys to inform design and support interpretation diet studies

Weaknesses/Considerations

- Current Steller sea lion surveys not specifically designed to capture growing CSL overwintering population in B.C. (correction factors to estimate abundance, large groups of swimmers, expanding range)
- Current Harbour seal surveys occur in summer and are spread over multiple years; not designed to capture animals in rivers/estuaries, on log booms; haulout patterns influenced by disturbance and predation
- Survey correction factors (is haul-out behavior of seals the same outside the SOG); how to deal with log booms and estuaries haulout patterns influenced by disturbance and predation
- Very resource intensive; are there more effective ways of estimating/monitoring populations and diet
- Relatively little information on genetic stock structure and life-history data
- Need better coordination with NOAA and WDFW for transboundary stocks
- No information on abundance and potential impacts of Northern fur seals and elephant seals (and other marine mammal species) on fish stocks of interest
- Use of haulout data to design and interpret diet studies

Challenges

- available resources vs. frequency and coverage
- survey correction factors
- lag time between surveys and publication
- Increase winter surveys to support diet work
- Log booms?

Opportunities

- Increased frequency of index site surveys outside of SOG for harbor seals to validate trends
- Species specific (i.e. need dedicated CSL)
- Some of our plans-WCVI index site, drone program, further CF
- Integration with existing data eg NIMML brand resights, UBC diet work, past DFO pinniped datasets and other species data
- Anticipating questions

Day 1 – Pinniped Diets and Diet Trends: Seasonal and Inter-Annual Year Variability; Sex-Based Variability; Specialization

D. **Pinniped diets in Washington State (*Scott Pearson, Steve Jeffries, Austen Thomas, Monique Lance & Bill Walker, WDFW*)**

- Important analytical and methods considerations when reconstructing pinniped diet:
  - Representative sample is critical
  - Sampling should be designed to address the specific question being addressed.
  - Sample size considerations (recommend considering the take home messages in Trites and Joy
  - Representative of appropriate time and space
  - Not uncommon to have > 35 species of prey consumed by pinnipeds in a given area
  - However, only 3-15 species are typically common (represent ≥5% of the diet)
  - The uncommon prey are likely being consumed opportunistically or represent secondary prey (the prey found in the GI tract of the targeted prey)
  - Need very large sample sizes of scat (generally > 90 scats per haulout and

time period (e.g., month)) when trying to enumerate prey items less than 5% of diet.
    - Salmon smolts/juveniles often represent less than 5% of diet
    - Important to propagate uncertainty in dietary estimates upwards in any modelling exercise.
    - Different techniques (e.g., DNA and hard parts) give very different answers on a sample-by-sample basis but are strongly correlated given an adequate sample sizes for a given space and time.
    - DNA provides greater prey species resolution but only hard-part analysis provides prey age/size information. As a result, it is critical to use these two types of information in an integrative fashion
    - Only DNA can provide information on the sex of the pinniped that deposited the feces
- Four large efforts to assess harbor seal diet in Puget Sound – these have resulted in a number of government and peer-reviewed publications
    - Hood Canal Project (1998-2005) – Frequency of occurrence information from scat
    - Puget Sound (1995, 1997, 2004) – Frequency of occurrence information from scat
    - San Juan Archipelago (2005-2008) – Frequency of occurrence, stable isotopes, and fatty acids
    - S. Puget Sound (2016-2018) – Frequency of occurrence and DNA from feces
- Some take home information from these studies:
    - Harbor seals have a very diverse diet. Critical components = clupeids, gadids, cottids, and sandlance (year-round), adult salmon (summer/fall)
    - Highly variable diet in space and time (year, season, annual and regional differences along with time-space-season interactions)
    - Sex and size differences in diet (females more nearshore, larger individuals more offshore)
    - Clustering analysis suggests some diet specialization among individuals or these results are also consistent with specialized foraging bouts but don't know if individuals might switch from one particular specialization strategy to another or to a more generalist approach because individuals were not identified molecularly.
    - Different techniques for reconstructing diet (QFASA, Stable isotopes, frequency of occurrence) can lead to slightly different results.
    - Our most recent approach using frequency of occurrence information in concert with DNA information allows us to estimate the juvenile and adult salmon portion of the diet (and its associated uncertainty) by species.
    - This study also found the diet to be highly diverse (over 57 species of fish and cephalopods) and that juvenile salmon represented are relatively small portion (generally less than 5%) of the overall diet.

E. **Food Habits and Diet Overlap of Steller and California Sea Lions in Northwest Washington State (*Jonathan Scordino, Makah Tribe*)**

- The Makah Tribe studied California and Steller sea lion diets for two purposes: 1) to better understand the role of the sea lions in ecosystem to inform ecosystem-based management and 2) to evaluate if California and Steller sea lions compete for the same prey.
- 776 Steller sea lion scat and 262 California sea lion scat were collected from haulouts in Northwest Washington from 2010-2013 during all months for Steller sea lions and during spring through fall for California sea lions.
- All hard parts found in scat were identified to the lowest taxonomic level possible. Salmonid bones were further classified by

size to small (roughly a first ocean salmon, i.e. smolt), medium (larger than small up to about 1 kg), and large (>1 kg, assumed to be returning adult salmon).

- A representative bone of each salmonid size class from each scat was genetically analyzed to determine species of salmonid.
- Both California and Steller sea lions had diverse diets with 58 prey taxa identified representing 27 prey families of fish and cephalopods.
- Common prey (>5% split-sample frequency of occurrence (SSFO)) were in ranked order for the two sea lions pooled: rockfish species, unidentified clupeid, skate species, spiny dogfish, Pacific hake, Pacific sardine, Pacific herring, and coho salmon.
- Steller and California sea lions had significant diet overlap with Morisita-Horn Index values of 0.82 in spring, 0.65 in summer, and 0.83 in fall (index values greater than 0.6 are considered significant).
- Sea lions preyed upon salmonids in all seasons. Steller sea lions had SSFO of salmonids of 15% in winter, 12% in spring, 6% in summer, and 14% in fall. California sea lions had SSFO for salmonids of 11% in spring, 12% in summer, and 13% in fall.
- The majority of bones identified as salmonids were of the medium size class. Steller sea lions had a large portion of bones identified as small (smolt/first ocean year) in the winter and spring. California sea lions predated on more large (adult sized) salmon than Steller sea lions.
- Genetic tests revealed that coho was the most commonly consumed salmonid species with 5% SSFO in Steller sea lions and 5.7% in California sea lions. Chum were the next most frequent. Chinook composed 0.8% SSFO of Steller sea lion diet and 0.9% of California sea lion diet. We were unsuccessful at amplifying 15.2% of salmon bones analyzed resulting in an SSFO of 2.2% for Steller sea lions and 1.2% for California sea lions.
- The greater occurrence of coho than other salmonid species was consistent across size classes and seasons analyzed.
- A large pink salmon year in 2011 resulted in a 1% SSFO increase of salmonid consumption as compared to 2012. In 2011, pink salmon were the third most common salmon species consumed after coho and chum.
- The high frequency of salmon observed in both sea lion diets is of note because the study area is not near any large salmon bearing rivers.
- Observed consumption of species of concern (i.e. rockfish and salmon) was greater than in a previous study that detected Pacific hake in a much greater portion of diet. This finding suggests that considerations of Pacific hake abundance is important for reducing impacts on salmon and rockfish by sea lions for ecosystem-based management.
- Modelling is needed to evaluate the impact of sea lions on sensitive and economically important species like salmon and rockfish. Modelling is also needed to evaluate how impacts on these sensitive and economically important species would change if aboriginal groups hunted sea lions as they did pre-European contact.

F. Harbour seal diet quantification methods (*Austen Thomas,*)

- Choice of diet estimation method can strongly influence consumption estimates
- SSFO overestimates prey eaten in low proportion and underestimates prey eaten in high proportion
- We developed a new method with DNA metabarcoding, using sequence percentages as an index of proportional consumption: Relative Read Abundance (RRA)
- Biases in RRA exist but do not strongly influence diet estimates at the population

level, when averaging a large number of samples
- Life stage of prey consumption is really important, especially for salmon.
- Small percentages of seal diet can equate to large numbers of juvenile salmon consumed
- We merged data from seal scat DNA and prey bones to estimate salmon prey species, proportion of seal diet, and life stage (Juvenile vs Adult)
- > 1200 scat samples analyzed using the method from 3 estuary sites and one non-estuary site
- Adult salmon eaten were predominantly Chum and Pink
- Juvenile salmon eaten were predominantly chinook, coho, and Sockeye
- We hypothesize seals are selecting for juvenile salmon of species that emerge from rivers larger (1+yr), and thus fit the search image similar to a herring forage fish
- Otolith data support that seals consume juvenile salmon in the 10-16cm range in the spring/early summer
- Buffer prey such as other forage fishes may be very important for juvenile salmon survival in this temporal window
- There is concern that our data are skewed because of the focus on estuaries. This may lead to overestimation of juvenile salmon consumption
- Other published data from the San Juan Islands suggest similar levels of juvenile salmon consumption in a non-estuary area. Those data also indicate high levels of juvenile chinook predation relative to other salmon species
- Chad Nordstrom presented data beyond 2012-13 in which the juvenile salmon proportion of seal diet in Cowichan is much lower
- Fluctuations in seal diet interannually are likely driven by differences in the number of juvenile salmon available to seals from year to year, and availability of alternative prey
- Seal diet % alone is not very meaningful in terms of prey impacts. The numbers are only informative when converted to a number of prey consumed, and finally expressed as a percentage of the total juvenile salmon mortality
- You need to know how many fish were in the system to understand seal impact, and this fluctuates from year to year. <u>Don't expect seal diet % to be a static number.</u>

G. Pinniped diets: spatial, temporal and sex-based variability (*Strahan Tucker, Sheena Majewski, Chad Nordstrom, Wendy Szaniszlo, DFO*)

- Presentation provides an overview of DFO's scat sampling 2015-2018 and results to date (analysis is not yet complete for all datasets) and plans to build on and expand these datasets.
- DFO has 3 primary scat-based diet datasets: 1) spring through late fall multispecies collections in the Strait of Georgia, 2) focal 4 season collections for Steller sea lions on the WCVI (with opportunistic sampling of California sea lions), and 3) opportunistic, non-breeding season collections for Steller sea lions.
- Results are proportional diet estimates based on genetics analysis. Results to date suggest high inter- and intra-specific variability in diets. Diets are highly variable between seasons and years and at both regional (West Coast Vancouver Island vs. Strait of Georgia) and sub-regional (haul out or estuary vs non-estuary) spatial scales.
- For harbour seals, we have integrated sex markers permitting differentiation between males and females. In all seasons and locations, diets varied significantly by sex. In part the difference is due to males consuming more salmon. The sex ration is highly skewed towards males. We speculate there is a sex bias in haul out behaviour-but results certainly suggests that diet data is biased towards males.

- The proportion (range across all pinniped samples: chinook:0-4.4%; coho: 0.1-4.3%) and occurrence (total scats of all pinniped samples: chinook 140 of 2035; coho 83 of 2035) of chinook and coho salmon was low overall with the majority of occurrences representing <20% of total diet composition.
- The Pinniped Research Program continues to make monthly collections of samples for diet analysis at key index sites around Vancouver Island (Strait of Georgia, Queen Charlotte Strait, WCVI). Further, we hope to contribute to a performance evaluation of the DNA diet metabarcoding approach to evaluate the efficiency, sensitivity, specificity and repeatability of the platform to validate the identification of species and limits of detection.

H. Reconstructing a century of coastal productivity and predator trophic position in WA with archival bone (*Megan Feddern, Gordon Holtgrieve, Eric Ward, NOAA*)

- Early results from harbor seal bone analysis: diet/trophic position snapshots over a 100 year period
- Baseline productivity estimated from compound specific isotope analyses (CSIA) is correlated with upwelling, and higher in inland waters – likely because of human inputs of nitrogen in these areas
- The estimated trophic level of seals appears to have declined 1970-1990, and may have increased since – because of sparse samples in recent years, these more recent trends are uncertain
- Trophic level appears to be higher on the coast compared to inland waters
- Harbour seals are estimated to feed lower on the food chain with increased upwelling

I. Are diet estimates reliable (*Peter Olesiuk*)

- Split Sample Frequency of Occurrence, which has been widely adopted for reconstructing diets from scat contents, is based on the concept of biomass reconstruction when it is not possible to accurately estimate the number of prey consumed in a meal. SSFO appears to provide reliable estimates for fish prey when compared to volumetric estimates in northern fur seals.
- Recent captive studies, when corrected for publication errors, indicate that SSFO gives results comparable to Biomass Reconstruction. In contrast, Biomass Reconstruction using N_{min} as a proxy for the number of prey consumed tends to exaggerate the importance of larger prey species consumed in small numbers such as adult salmonids.
- Serious bias can occur when extrapolating diet from a small number of unrepresentative sites. For example, the 4 sites selected by Thomas et al. (2016) for salmon predation studies, which have been widely used to estimate diet in the Salish Sea and have been incorporated into ecosystem models, do not appear to be representative of salmon consumption when compared to the other 54 sites sampled in the 1980s (Olesiuk et al. 1990).
- Researchers are encouraged to collect scat samples broadly and throughout the year, and to incorporate weighted stratification schemes to account for seasonal and geographic differences in diet and shifts in the distribution of animals.

Day 1 – Pinniped Prey Abundance, Trends and Availability to Pinnipeds in Salish Sea

J. Trends in abundance and distribution of gadids and clupeids in Puget Sound and coastal waters (*T. Essington, E. Ng, D. Lowry, L. Kuehne, C. Greene, T. Francis, E. Ward [presenter]), M. Schmidt, P. Dionne, T. Sandell, NOAA*)

- Overall, groundfish trends from the School of Fisheries (UW) and WDFW trawl surveys are stable – species are different in their variability, synchrony of recruitment dynamics, etc.

- Spatially, the distribution of gadids is highest in northern Puget Sound, around the San Juan Islands
- Looking at gadids, clupeids, and perch, there is a slight increase in trophic level of this community since 1987 – though when all fish are combined (including more numerous spotted ratfish and English sole), these trends appear to be reversed with a decline in trophic level in recent years
- The largest herring stock in Puget Sound (Cherry point) has largely declined, as have several of the smaller ones. The overall abundance of herring seems relatively stable in recent years because of an uptick of the Hood Canal stock.

K. **A very brief overview of herring, forage fish and gadids in the Strait of Georgia (*Sean MacConnachie, Jaclyn Cleary, Jennifer Boldt, Linnea Flostrand, Sean Anderson, DFO*)**

Herring Migratory Patterns

- General migratory pattern is for age 2+ herring to move out of SOG post spawning (April/May) and move into the west coast feeding areas
- Juvenile herring are thought to remain within the Strait of Georgia for the first year

Strait of Georgia herring: stock trends and reference points

- Herring biomass is assessed using SCUBA surveys, and formerly surface surveys, assessing the volume and density of eggs deposited during the spawning season.
- Generally spawn distribution has changed over time with increased volumes of spawn over a smaller spatial scale.
- Herring biomass in the SOG are at high time levels.
- Since the early 1970 fishery has focused on roe, and more recently food and bait has increased.
- Increased interactions with seine fleet and California and Steller Sea lions has been documented in recent years.

Juvenile Herring Sampling

- An annual survey has been conducted from 1992-2018 (except 1995).
- The sampling is conducted a night using a small purse seine (183 x 27 m).
- The survey is conducted at fixed stations throughout the strait of Georgia.
- The survey results inform the stock assessment for herring.
- Although CPUE has decreased in recent years, body condition has improved.

Anchovy

- Anchovy are intercepted during the juvenile survey.
- Population appears to be growing in recent years.

Eulachon

- Two indices of abundance are collected for Eulachon
  - On the WCVI small mesh multispecies bottom trawl survey is conducted annually using a fixed station survey design.
  - The other relative index of abundance is an Eulachon egg and larval study conducted on the Fraser River from 1995 to 2018 Fraser River

L. Trends in Salish Sea Pacific salmon (and data complexity in Northeast Pacific chinook salmon) (*Cameron Freshwater, DFO*).

- Five Pacific salmon, as well as steelhead trout, spend at least some portion of their marine lifespan in the Salish Sea.
  - Species, and populations within species, exhibit consistent differences in their duration of residence within the Salish Sea, their trends in abundance, and the data available to evaluate management or conservation status.

- Species with limited residence within the Salish Sea
  - Generally highly abundant as juveniles (May-Sep), then rear offshore in Gulf of Alaska until their return migrations (late summer to late fall).
  - Modest hatchery influences and relatively simple fisheries that are mostly near-terminal and commercial.
  - Sockeye salmon
    - Generally 1-2 years of freshwater residence.
    - Dominant stock aggregate in region spawns in Fraser River, which is relatively data-rich.
    - Status evaluated using trends in productivity (log recruits per spawner); productivity has declined in recent decades and return abundances have become more variabile and synchronized among stocks within the aggregate.
  - Chum and pink salmon
    - Migrate to the marine environment shortly after emergence.
    - Although return abundances appear to be more variable, populations within the Salish Sea have not exhibited consistent declines.
- Species with protracted residence within the Salish Sea
  - Months to multiple years of
  - freshwater residence
  - Historically components of certain stocks remained resident within the Salish Sea for their entire life cycle
  - Relatively large hatchery contributions and more complex fisheries management due to mix of recreational and commercial fisheries that occur throughout marine residence (i.e. not solely near-terminal)
  - Coho salmon
    - Data on survival is relatively patchy and derived from indicator stocks (mostly hatchery)
    - General decline in Fraser River with Interior Fraser coho of particular concern
    - Recent return to Salish Sea residence after ~20 year absence.
  - Chinook salmon
    - Substantial life-history variation that can most broadly be defined by freshwater residence
    - Stream-type/yearling: at least one year of freshwater residence; offshore distribution; minimal interactions with southeast Alaskan and northern BC fisheries
    - Ocean-type/subyearling: weeks to months of freshwater residence; majority of Salish Sea populations; continental shelf distribution; considerable interactions with non-terminal fisheries
    - Estimates of status must account for changes in hatchery contributions, differential natural mortality rates, and impacts of multiple fisheries
- Chinook salmon data
  - Smolt-to-age 2 survival
    - Derived from coded wire tag (CWT) returns that are largely deployed in hatchery fish (in BC)
    - Assume fixed natural mortality rate after age-2 to calculate first marine year survival
    - Assume marked fish have representative survival of unmarked fish
  - Escapement
    - Confounds wild and hatchery fish in systems where both are present and doesn't account for changes in management strategy (e.g. exploitation rate, hatchery practices)
    - Different suite of indicator stocks than age-2 survival rates
  - Common trends in survival and escapement identified using Bayesian dynamic factor analysis
- Trends in chinook salmon smolt-to-age 2 survival
  - Divided into four life history-region groupings

  - Northern yearlings – survival peaked 1990-2000, followed by modest decline
  - Salish Sea yearlings – generally stable survival
  - Salish Sea subyearlings – high survival in 1970s followed by stable, but low survival
  - Southern subyearlings – three distinct survival stanzas, high in 1970-80s, moderate 1980-90s, and low since
- Trends in chinook salmon escapement (Salish Sea only)
  - Subyearlings – divergent trends with certain systems increasing in recent years (e.g. Cowichan)
  - Yearlings – precipitous decline since early 2000s
- Changes in chinook salmon demography
  - Consistent, range-wide declines in abundance and size-at-age of oldest age classes
  - May be associated with size selective predation, fisheries, or hatchery practices
- Conclusions
  - *Generally* populations with shorter periods of freshwater residence and smaller size at marine entry have better status
  - Declines in status of species appear uncoupled – chinook in late 70s, coho in late 80s, sockeye in late 90s
  - Differences between survival and escapement difficult to disentangle with current data, but suggest uncoupling which warrants caution when interpreting status
  - Recent anomalies should be considered
    - Increased escapement of Vancouver Island chinook salmon; declines in escapement of Fraser Springs
    - Return to Salish Sea residence of coho salmon

M. Salish Sea Marine Survival Project: ecosystem indicators development (*Kathryn Sobocinski, Correigh Greene, Joe Anderson, Mara Zimmerman, Neala Kendall, Michael Schmidt* [presenter])

- Recent work on Chinook and coho salmon and steelhead trout has shown a decline in the marine survival of many Salish Sea populations that was not evident in populations from coastal regions (Zimmerman et al. 2015, Ruff et al. 2017, Kendall et al. 2017).
- The causes of this decline in marine survival are likely complex, and may include bottom-up processes that drive prey availability, top-down processes, including increasing abundances of predators such as harbor seals that may be exacerbating mortality, as well as a multitude of anthropogenic factors such as habitat loss, contaminants, and hatchery management practices that may contribute to disease, reduced fish condition, and ultimately increased mortality. The cumulative effects of these factors are unknown.
- While the three species with observed declines in marine survival have different life-histories, and are therefore subjected to variable pressures at multiple scales, there are some commonalities in factors explaining marine survival over the 40-year time period from the late 1970s to present.
- We developed hypotheses related to predation, competition, environmental variation, and anthropogenic impacts to frame our analysis and to identify a suite of factors that was best at explaining variation in survival time series for populations in Puget Sound, WA, USA. From these hypotheses, we generated time series of available and relevant data to use as indicators for each hypothesis. We used generalized additive modelling to describe variation in survival with multiple covariates at ocean, regional, and local scales. We used smolt-to-adult return ratios (SAR) as the response variable; updates to the survival dataset using the methods of Ruff et al. (2017, Chinook) and

Zimmerman et al. (2015, coho) allowed for analysis up through ocean entry year 2015. For each hypothesis we generated multiple generalized additive models and used best subsets model selection to identify the combination of indicators explaining the most variance in salmon marine survival.

- In general, hypotheses related to freshwater delivery performed poorly, while those related to predation, competition, and water quality explained more variance (30-40% for the best models).
- For Chinook, the factors with strongest support included sea surface temperature in Puget Sound, spring river flow in Puget Sound, seal abundance, subyearling Chinook hatchery release date, and yearling coho hatchery release date. For all except water temperature, the relationship between marine survival and the indicator was negative.
- For coho, the variables with the most support included North Pacific Index in the summer (negative relationship with SAR), spring precipitation (negative relationship with SAR), stratification in the Strait of Juan de Fuca (parabolic relationship), the CV of Chinook subyearling hatchery release date (positive relationship with SAR, where the greater the variation in release date, the higher survival is), maximum spring temperature (negative relationship with SAR), seal abundance (negative relationship with SAR), summer NPGO (positive relationship with SAR), and Strait of Georgia herring abundance (positive relationship with SAR). These variables collectively hint at numerous causes of decreased survival for all three species of interest, from unfavorable ocean conditions, to increased predation and prey limitation.
- For all three species investigated, seal abundance was an important explanatory variable. The seal abundance time series shows a rapid increase until the early 1990s when the population has been more steady (B. Nelson and S. Pearson, pers. communication). To explore the relationship between seal abundance and survival further, we evaluated univariate relationships between each species and seal abundance and found that for all species the relationship was negative. However, for steelhead trout and coho salmon, seal abundance explained much more variance in the data (22% and 30%, respectively) that it did for Chinook salmon (<8.6%). It is important to note that the methods for estimating SAR (survival) varied among the three species, which may account for some of the differences in observed relationships.
- Seal abundance seems to be one contributing variable for explaining declines in marine survival. However, depending upon the species, other indicators are also important. Lack of data for some potentially important ecological variables (for example, young of the year forage fishes in Puget Sound) may limit the explanatory power of our models related to marine survival.

N. Enumerating availability of juvenile chinook and coho salmon to pinnipeds in Puget Sound (*Joseph Anderson & Benjamin Nelson, NOAA*)

- Hatchery-produced chinook salmon (~10X) and coho salmon (~2X) numerically dominant compared to naturally-produced fish.
- Naturally produced chinook salmon have a protracted, six month migration from January through July. Natural-origin chinook salmon are initially small (~ 45 mm) but show consistent growth beginning in April, and eventually reach sizes of ~ 60 - 100 mm by July.
- Hatchery produced chinook salmon predominantly released in mid-May and exhibit long term trend toward synchronization of release dates.
- Naturally-produced and hatchery-produced coho salmon smolts both migrate approximately mid-April to mid-May.

- Seems likely that pinnipeds consume resident chinook and coho salmon that rear year-round in Puget Sound rather than migrate to the Pacific Ocean, but the abundance of these life-histories types is not commonly estimated.

O. Juvenile salmon in the Strait of Georgia (*Chrys Neville, DFO*)

- DFO has been conducting surveys to study the abundance, distribution and early marine condition of juvenile salmon in the Strait of Georgia since 1998. The surveys are conducted in the early summer (late June/early July) and fall (September/October) using mid-water trawl gear fished at variable depths from the surface to 60m. During each survey a standard track line is fished that covers the nearshore and deep water regions of the strait from Campbell River in the NW to the Canada/US border in the south. Other regions (inlets, Gulf Islands, Juan de Fuca Strait, Discovery Islands, Puget Sound) dependent on vessel time and research questions .
- Juvenile from all species of Pacific salmon use the Strait of Georgia as an important early marine rearing area. The period of residence varies by species and sometimes stocks but ranges from 6-8 weeks to several months. Some individuals/stocks remain resident in the Strait of Georgia through their first marine winter or longer. The majority of coho and Chinook salmon remain and rear in the Strait of Georgia until fall or later. Conversely, most Fraser River sockeye salmon rear in the strait for 6-8 weeks and then migrate north over a narrow time window (weeks) north through Johnstone Strait. Refer to Beamish (2018), Neville and Beamish (2018), Neville et al (2017), Beamish et al (2016), Neville et al (2015), Chittenden et al (2009), Beamish et al. (2010).
- Over the 20 year time series of the surveys there have been changes in the abundance of the juveniles between years. The changes are not consistent between species.
- With the exception of Pacific herring, juvenile Pacific salmon are the dominant fish in our daytime catch in the surface 75m of the Strait of Georgia in June through October.
- The dominant salmon species in the Strait of Georgia in the summer are chum salmon and pink salmon in even years. Chum salmon is typically 2-10 times more abundant than Chinook or coho salmon. In the fall, these species are still common but are more similar in number to coho and Chinook salmon.
- The size of the juvenile salmon in late June is similar between most species. The average length over the past 10 years ranged from 11 to 13 cm for Chinook, chum, pink and sockeye salmon. Coho are typically 3-5cm larger during this time period. There has been an increasing trend in length of chinook, coho, chum and pink salmon in the summer months over the past 6-8 years. The size of juvenile sockeye is confounded by cycle year so does not follow this same trend.
- The abundance of juveniles in the surveys has been related to returns for some species. For example, the abundance of coho salmon in the fall is related to subsequent returns to southern BC the subsequent year (Beamish et al. 2010).
- Juvenile coho salmon are caught in all regions of the Strait of Georgia in both surveys although catch rates are typically higher in the northern regions (Texada north) in the fall survey. Acoustic tagging studies indicate that when these fish migrate out of the strait in the late fall, the majority of them will move through Juan de Fuca Strait (Chittenden et al. 2009).
- Coho salmon historically utilized the Strait of Georgia both as juveniles and as sub-adults. Distribution changes occurred in the 1990s and this species was mostly absent from the region during their spring of second marine year. However, in recent years, sub-adult coho

have returned or have overwintered in the Strait of Georgia and have been available to sport fishermen in the spring. The reason for the change in behaviour has not been identified. However, the abundance of coho salmon in the fall survey has increased since 2009. Associated with this increase has been an increase in the size of the individuals. A hypothesis is that these fish remain in inside waters over the winter as they have sufficient energy stores to successfully remain over the winter months (Neville and Beamish, 2018).

- Juvenile Chinook salmon are found throughout the Strait of Georgia. However, there are stock specific rearing areas for many stocks where the majority of the stock will remain and rear. Over the last decade, the Chilliwack/Harrison Chinook salmon rear primarily in US water of San Juan Islands and northern Puget Sound and represent only a small percentage (~5%) in the Canadian survey region (C. Neville unpublished data).
- The abundance of Chinook salmon is often similar between the early summer and fall survey. However, the stock mixture changes due to an influx of South Thompson Chinook summer in mid-summer (July). The resulting decline in abundance of other stocks is primarily due to mortality within the Strait of Georgia as there is no evidence of large movements of these fish out of the Strait of Georgia until fall (Chittenden et al. 2010, Beamish 2019).
- The CPUE of Chinook salmon in the early summer survey has remained consistent over the past eight years suggesting that early marine mortality has not changed or has decreased (if the number of juveniles entering the ocean has declined due to declining escapement).
- We have evidence that the return abundance of UPFR and MUFR Chinook salmon is strongly related to the abundance of these juveniles in July (r^2= 0.87). Our speculation is that this is a result of the growth during the early marine residence in the SOG with fish that grow faster having increased survival (Neville unpublished data). We interpret this that a bottom up effect is more controlling adult abundance than top down effects.
- The catch rates of Chinook salmon in Puget Sound are consistently higher than in the Strait of Georgia (2-10x higher) in both the summer and fall. It is expected that the variation is due to the physical differences with broader and more open waterways in the Strait of Georgia than in Puget Sound. Puget Sound would be more similar to the Discovery Island region where catch rates can be very high for sockeye, pink and chum in mid-June. These habitat differences need to be considered if comparing potential predation pressures between the regions (Neville unpublished data).
- Chum and pink salmon are found throughout the Strait of Georgia in both the summer and fall surveys. The odd/even cycle of pink salmon means very low catches in odd years and high catches in even years. Stock DNA for these two species is not as refined as for other salmon species and only identifies regions rather than stocks (e.g. Fraser River). Therefore, we have limited stock specific information for these species. Catches in the fall indicate that a component of the fish that entered the Strait of Georgia remain within this inland sea, however, we also encounter these fish in other regions including WCVI, QCS, Johnstone Strait, and north.
- The early marine period of Chinook salmon from the Cowichan River have been studied extensively over the past decade as a focus of the Pacific Salmon Foundation Salish Sea Research Program. This stock remains very localized in the region with catch rates remaining highest adjacent to the river through August. However, faster growing and predominantly hatchery fish can be observed in other regions including Desolation Sound by mid-summer (C.

Neville unpublished data). Returning adults are being examined to determine if the increased escapement over the past decade to this system is dominated by these faster growing, wild Chinook salmon.

- Within the Cowichan estuary (2013-2016) chum salmon, Pacific herring, stickleback, pink salmon and squid have either been in similar or greater abundance to juvenile Chinook salmon. Typically, chum salmon are at least twice as abundant as the Chinook salmon. The size of these two species is similar by June (C. Neville unpublished data).
- The catch and abundance of juvenile salmon in the Strait of Georgia over the past decade shows no evidence of increasing predation pressure as the abundance of all species has either been steady or increasing. There is evidence of shifts in conditions of the juveniles with changes in ocean climate over this time period.

Day 1 – Pinniped Foraging Behavioural Diversity, Size Selectivity, and Spatial and Temporal Differences in Predation Pressure on Salmonids

P. Seasonal changes in harbor seal and sea lion behavior and abundance in Northwest waters (*Steve Jeffries, WDFW*)

<u>Harbor seals</u>

- Haulout space and/or food do not appear to be limiting factors for Salish Sea harbor seal populations
- Composition of harbor seals on haulout sites varies seasonally by age, sex and location during pupping season, annual molt and availability of prey
- Relatively small number of scats are deposited on haulouts compared to number of animals hauled out (i.e. most scats deposited in the water)
- Male and female harbor seals have different diets
- Males eat more salmon than females
- Predation on harbor seals by Bigg's killer whales has increased in last 10 years and may be reducing numbers and changing haulout behaviors

<u>California sea lions</u>

- Between 1975 and 2014, the CASL population in US waters, increased from an estimated 88,924 animals to 257,606
- CASLs in OR, WA, BC and SEAK originate at rookeries in the Channel Islands in CA (and most likely rookeries in Mexico waters as well)
- CASL abundance varies seasonally with very few in NW waters during summer when they are on rookeries in CA and Mexico
- In late summer/early fall, a wave of 60,000 to 80,000 adult and subadult male CASLs disperse northward from their rookeries into waters off OR, WA, BC and SEAK
- CASL counts in the WA waters have increased from just a few (rare) in 1972 to over 3,000 in 2018.
- During fall, winter and spring CASLs become seasonally abundant where there is sufficient prey biomass that includes herring, eulachon, anchovy, hake and adult/juvenile salmon
- Predation by CASLs (and SSLs) on ESA listed salmon (adults and juveniles) in the Columbia River during the spring is significant
- The US CASL stock was estimated to be within its OSP range (between MNPL and k)

<u>Steller sea lions</u>

- Between 1972 and 2017, the EDPS has increased from 12,000 to 79,000
- Between 1972 and 2017, in WA, SSL abundance has increased from 500 to over 2,000
- SSLs in the Salish Sea originate from rookeries in AK, BC, WA, OR and CA
- In the NW, SSL abundance varies seasonally with peak counts on rookeries during summer breeding seasons with

relatively small numbers in the Salish Sea at this time

- During fall, winter and spring SSLs become seasonally abundant where there is sufficient prey biomass that may include herring, hake and adult salmon
- WA and BC SSLs belong to the Eastern Distinct Population Segment (EDPS) which ranges along the west coast of North America from Southeast Alaska to central California
- EDPS was delisted under the ESA and is not designated as depleted under the MMPA
- The Optimum Sustainable Population (OSP) range for SSLs has not been estimated

Q. Using new technologies to quantify juvenile salmon predation in the Salish Sea (*Austen Thomas, Hassen Allegue, Chad Nordstrom, Andrew Trites*)

- There are clear issues with estimating numbers of juvenile salmon eaten based on seal scat analysis.
- We set out to develop an alternative method to estimate juvenile salmon consumption by seals.
- We developed a head-mounted PIT tag scanner for seals that scans the seals mouth during foraging to detect PIT tags implanted in juvenile salmon.
- The scanners are accelerometer activated, so they only turn on when a seal does a head-strike to capture fish.
- Tank trials with a captive wild seal were used to develop a sampling algorithm that detects 100% of juvenile salmon eaten in a large tank.
- We deployed 20 devices on seals near the Big Qualicum River, 9 on seals captures in the estuary and 11 on seals from nearby rocky reef sites.
- ~37,000 coho PIT tagged, 19,000 12mm tags, 18,000 23mm tags, 384,000 total smolts, Released May 4, 2015.
- Seal-mounted scanners lasted 2 – 6 months in terms of battery life.
- Predation occurs mostly in evening/night. 31 Total PIT tag detections. All in the estuary.
- We limited the consumption estimate expansion to only the estuary seals. Consumption likely occurred outside of the estuary but the probability of a tagged seal and tagged smolt interacting is very low outside of spatial constriction of the estuary.
- Consumption peaked 4 days after smolt release, at ~50 smolts per seal, per day.
- This equates to ~1.0 kg/day or 50% of the seals daily consumption.
- 96 seals in estuary, 23,786 total smolts eaten, 6.19% of smolt release.
- Hassen Allegue's work on the same animals indicates the seals responded to the pulse of 384K coho smolts, but did not show a foraging response to 3 million ocean-type chinook juveniles.
- Overall these data support the idea that seals mainly target larger juvenile salmon >10cm, while mostly ignoring the small ocean type Chinook.
- Diet data in the SoG suggest the ocean-type Chinook may be eaten later (June/July) when they grow into the seal prey size window (10-16cm).
- These data also support the idea that seal predation in estuaries comprises a relatively small portion (~6% of the out-migrating coho) of the overall seal-related mortality calculated from scat data (30 – 40%).

R. Pinniped foraging behavioral diversity, size selectivity, and spatial and temporal differences in predation pressure on salmonids (*Strahan Tucker, Sheena Majewski, Chad Nordstrom, Wendy Szaniszlo, DFO*)

- DFO is undertaking initiatives to address elements of foraging patterns and further define the spatial and temporal variability in predation pressure on salmonids.
- New deployments of GPS satellite tags on harbour seals are currently underway in Strait of Georgia. This is a multiyear project

with deployments anticipated in other areas of BC. While the primary objective and impetus of these deployments is to provide an updated and precise estimate of haul-out correction factor for population estimates, half of our tags provide more discrete information on distribution and foraging behavior.

- Propose to obtain higher level resolution of harbour seal population structure than currently available through microsatellite analysis. Harbour seal population structure (and sex ratio characterization) will be valuable for stock assessments as current resource management demands related to US MMPA require the delineation of population management units. Current work on characterizing diet composition with metabarcoding will be complemented with this technique. The development of an amplicon panel will be used for high-throughput and cost efficient screening of scats that have been characterized for diet content to identify sex, repeat sampling of the individual animals and assignment to source population.
- Developing a drone program to address variation in haul-out counts. Undertake frequent drone survey of index haul out sites to address variation in total counts, species composition and size-class composition

S. Harbour seals: predation on chinook & coho smolts (*Hassen Allegue and Andrew Trites, UBC*))

- Little attention has been given to understanding where, when and how harbour seals prey on salmon smolts, and the extent to which it might be opportunistic or specialist feeding behaviour by a few or many individual seals.
- We documented the spatiotemporal foraging behaviour of harbour seals in the Salish Sea by equipping 17 seals with GPS loggers and Daily Diary tags—and tracking them before and after the release of thousands of coho and chinook smolts from the Big Qualicum Hatchery.
- Comparing the foraging behaviours of smolt specialists with non-specialist seals revealed 4 different foraging strategies. One consisted of seals (17.6%) that only fed on coho smolts and ignored chinook in the river mouth, while a second group of seals (17.6%) appeared to target larger fish that preyed on chinook smolts near the river mouth. The two other seal groups did not feed at the river mouth in association with the concentrated numbers of smolts, but either remained resident (52.9%) and fed near their main haul-out sites, or were transient (11.8%) and left the study area all together.
- Our results suggest a high degree of individual foraging and diet specializations—and show that a small number of seals were specialized in consuming coho smolts (primarily at dusk), but did not appear to respond to the large pulse of the smaller bodied chinook smolts.

Day 1 – Perspectives on Pinniped Impacts on Commercially and Culturally Important Prey Species in Eastern Canada

T. Fisheries Interactions in Atlantic Canada (*G. Stenson & M. Hammill, DFO*)

- Concerns about the impact of seals on commercial fish species have been raised for many decades. However, questions about the impact of grey and harp seals on Atlantic cod stocks in eastern Canada increased with the collapse of cod in the early 1990s. Many of these cod stocks have not recovered. Considerable research has been carried out to determine the impact of seal predation on cod. From our experience dealing with these questions we have found the following:
- Consumption is a marine mammal issue – Impact is a fish issue
- Abundance is a major driver of consumption estimates. However, the estimates for harp and grey seals are

relatively well know and precise. Also mammal populations generally do not show large interannual variation.

- There considerable temporal and spatial variability in diets. Sensitivity analyses indicate that uncertainty in the diet accounts for most of uncertainty in the consumption estimates.
- Seasonal distribution of predator and prey are important to quantify to account for the entire population; this is often a major data gap
- Energy requirements will vary over the year, particularly for capital breeders, and given seasonal variation in diets, it can significantly change estimated consumption of individual prey species.
- Things (e.g. diet, body size, distribution) change over time!
- 'Impact' depends upon the population dynamics of the prey species. Therefore it is critical to bring 'fish people' into the discussion to estimate how much of M (natural mortality) can be attributed to seal predation and how much is attributed to other factors
- Understanding the impact of other ecosystem components is critical in order to place seal predation into the context of prey population dynamics
- The factors influencing the dynamics of different stocks can vary so the important drivers may differ
- Capelin and fisheries have been found to be an important driver of cod condition, mortality and abundance off eastern Newfoundland; predation by seals was not found to have a significant impact on Northern cod stock levels.
- In the southern Gulf of St Lawrence, the collapse of the groundfish stocks coupled with high levels of grey seal predation has created a predator pit, where grey seal predation is limiting recovery of cod, hake & skate, even in the absence of fishing..

Day 2 – Rates of Predation on Salmon and Steelhead and Amounts Consumed by Pinnipeds in Salish Sea and Coast

U. Quantifying impacts of harbour seal predation on chinook and coho salmon in the Salish Sea (*Benjamin Nelson, UBC*)

- Even small proportions of salmon in the seal diet can imply high predation rates. While there is still uncertainty around several of the key parameters in the bioenergetics models presented here, the results do show that diet percentage and the magnitude of predation rates should not be conflated. In other words, it is possible that small percentages of juvenile salmon in the seal diet could result in high predation rates, due to the large energetic requirements of harbour seals, their high abundance, and the small size of juvenile salmon in the spring and summer months. Further, the predation rates are a function of how many prey are available to seals in a given year, which means it is critical that accurate estimates of hatchery and wild/natural juvenile salmon are known to make a plausible estimate of predation/consumption.
- Predation rates for both chinook and coho are comparable between the Strait of Georgia and Puget Sound basins. While the predation/consumption rates for both species are different, they do appear to be comparable in magnitude. We estimated the mean consumption of juvenile chinook in the Puget Sound was 24%, and 44% in the Strait of Georgia. For coho, the mean consumption estimate was 55% in the Strait of Georgia, and 35% in the Puget Sound. It is important to note that there is high uncertainty around these estimates, and they are subject to change as we continue to incorporate new data, and refine assumptions in the model.
- Predation rates are sensitive to model assumptions. Through sensitivity testing, we have concluded that current consumption estimates for both species in both basins are sensitive to assumptions

about the size of juvenile salmon being consumed, in addition to the number of prey that are available/vulnerable to seals after freshwater/post-release mortality has occurred. Larger prey size would lower estimates of consumption, while higher freshwater/post-release mortality would increase estimates of consumption. We are currently working with collaborators at Washington Dept. of Fish and Wildlife to improve these estimates.

- The Puget Sound and Strait of Georgia are different, but, they're also similar. While seals in both basins likely have different foraging ecology because of factors like habitat and prey availability, it is important to note that seals in these two regions—in addition to salmon—are likely to move across international boundaries, which is not accounted for in the current modelling frameworks. For example, seals that haul out in the San Juan Islands in the north Puget Sound certainly forage in the southern Strait of Georgia, and vice versa. Additionally, we know from coded-wire tag data and trawl surveys that juvenile chinook and coho salmon from Puget Sound are routinely captured in the Strait of Georgia. Therefore, a Salish Sea-wide model of the seal population may be an improvement over current model formulations that assume each region is essentially a closed spatial box.

V. Impact of harbour seals on chinook (*Joseph Anderson, Scott Pearson and Steve Jeffries, WDFW*)

- Our bioenergetic models estimating consumption of Puget Sound juvenile Chinook salmon by seals (see Ben Nelson presentation) are highly sensitive to assumptions regarding body size of juvenile salmon prey consumed.
- Ongoing work uses hard part analysis to quantify body size of prey consumed.
  - Otoliths and vertebral bones hold the most promise for developing salmonid species-specific relationships between body size and hard part morphological measurements.
  - Concern over bias against small sized fish due to more rapid digestion of hard parts in the seal gut than larger sized fish. But two captive field studies suggest the opposite bias, one for California sea lions and the other for harbour seals.
  - Initial results suggest seals consume Chinook salmon ranging from 50 to approximately 450 mm. Ongoing effort to identify prey size preferences, given possible methodological biases in sampling.
- Expressed as a proportion of the total available smolts, our estimates of seal consumption of Chinook salmon smolts (see Ben Nelson presentation) is 5 – 70 %, with a mode of approximately 25%.
  - By comparison, total smolt to adult rates for Puget Sound natural and hatchery chinook salmon are approximately 0 – 1.5%. Thus, ≥ 98.5% of Puget Sound Chinook salmon smolts die prior to adulthood, and our estimates of seal consumption account for approximately 25% of that mortality.
- Efforts to express estimated consumption of juvenile Chinook salmon in terms of adult salmon are fraught with uncertainty and major assumptions.
  - The level of compensatory mortality among juvenile salmon is a major source of uncertainty. In other words, if seal consumption of Chinook salmon were somehow reduced, we do not know how many of the "saved" smolts would survive to adulthood, and how many would be consumed by another predator or succumb to another source of natural mortality. The Puget Sound food web is simply too complex for confident predictions. We suggest that at least some level of compensatory mortality is likely if the seals are eating unhealthy or less vigorous fish.
  - Similarly, rates of marine mortality before and after exposure to seals are

another source of uncertainty in estimating the impact of seal consumption of juvenile salmon on the abundance of adult salmon.

- Assuming rates of total marine mortality approximately similar to current values, our estimates of juvenile salmon consumed by seals (see Ben Nelson presentation) range from 0 adult salmon (assuming 100% compensatory mortality) to hundreds of thousands of adult salmon (assuming no compensatory mortality). However, if seal consumption of juvenile salmon is on the upper end of our estimated range (i.e., 15-25 million) it seems unlikely that all of that consumption could be replaced by other predators in the absence of seal predation.

W. Evidence of high seal predation impact on chinook and coho salmon in the Georgia Strait (*Carl Walters, DFO*)

- The BC seal population is likely much higher today than it has been for the last several millennia, when seals were harvested by First Nations people
- Three lines of evidence point to seals as a main cause of increases in first-ocean-year mortality rates: correlative, diet, and seal behavior
- There is a strong linear correlation between first ocean year mortality rate and seal abundance, for average mortality rates estimated from coded wire tagging for indicator chinook and coho stocks, as expected if seals take juvenile salmon incidentally while foraging for other prey
- Increases in mortality rate predicted from estimates of total juveniles eaten based on seal bioenergetics and diet composition data are highly uncertain, but agree broadly with the increases estimated from correlations
- Estimates of potential mortality rate based on seal foraging behavior (swimming speeds, reactive distances, foraging times) also predict the mortality rate increase apparent from correlations
- Coho stocks show consistent patterns of increase in mortality rate with seal abundance, while chinook stocks show highly variable responses with the dominant lower Fraser (Harrison) stock showing about half the response seen in other Georgia Strait indicator stocks
- Based on diet data, predation mortality rates are not concentrated in estuarine areas but are spread over the first ocean summer as juveniles disperse widely over the Georgia Strait and are exposed to predation by seals from both estuarine and non-estuarine haulout sites

X. Harbor seal - steelhead interactions in Puget Sound (*Barry Berejikian, Megan Moore, Steve Jeffries, WDFW*)

- Acoustic telemetry research on steelhead trout in Puget Sound and Hood Canal has been conducted since 2006 (with a gap from 2010-2013) and is on-going. Studies have included survival estimation paired with assessments of predation in estuaries, the main basin of Puget Sound, and fine-scale tracking at the Hood Canal Bridge. In 2014 and 2016, harbor seals were instrumented with hydrophones, acoustic tags, and GPS/TDR tags to quantify interactions with tagged steelhead. The following is a very brief summary of findings:
- Steelhead smolt survival through Puget Sound has varied from 6% to 38%.
- Low survival (2014, 6%) was associated with substantial evidence of predation at Rocky haulouts in Central Puget Sound. High survival (2016, 38%) was associated with no evidence of predation at the same haulout areas.
- Evidence of predation by harbor seals in the Nisqually estuary (inferred from tag movement patterns) has increased each year and we speculate that it may be related to increasing presence of transient

killer whales influencing the behavior of harbor seals. Peak transient killer whale presence in south Puget Sound occurs during the spring smolt migration period.

- Warm ocean temperatures (PDO) are conducive to anchovy recruitment in the ocean and survival in Puget Sound.
- Instantaneous mortality rates (-ln(survival) of steelhead smolts are significantly and negatively correlated with PDO (in the year preceding migration) and the one index of anchovy abundance available in Puget Sound.
- It is unknown whether warm ocean conditions have a positive or negative effect on steelhead after they leave Puget Sound.
- The presence of alternative, preferred prey may lessen predation impacts on steelhead
- The Hood Canal floating bridge slows the migration of steelhead smolts and causes significant mortality (up to 50% of the smolts arriving at the bridge). Temperature and depth tags strongly indicate that steelhead are being consumed by harbor seals at or very near the Hood Canal Bridge, and this predation appears to account for the most of the mortality.
- Except for the extreme southern end of range, abundance of most stocks has not declined in the past 6 years.
- Columbia River summer and upriver bright stocks have had recent record high abundance.

Y. Prey requirements and salmon consumption by Steller sea lions in southern British Columbia and Washington State (*Peter Olesiuk*)

- A large-scale assessment in the Pacific Salmon Commission Southern Endowment Area (Cape Caution to the mouth of the Columbia River but not including the River) indicates that Steller sea lions commonly feed on salmon
- Salmon comprised about 12% of the overall diet, and sea lions consumed an estimated 17,500 tonnes of salmon annually. In the Canadian portion of the study area, Steller sea lions consumed about twice the biomass of salmon as caught in commercial fisheries.
- Genetic analyses indicate that Steller sea lions are opportunistic and prey on a wide variety of salmon species. Some of the estimates of salmon consumption by species appear to be ecologically and/or economically significant. For example, Steller sea lions could be consuming almost one million sockeye salmon in the Southern Endowment Area annually, and Steller sea lions appear to consume more adult chinook salmon than the Southern Resident Killer Whales. These estimates need to be peer-reviewed and incorporated into salmon stock assessments.
- Preliminary analyses indicate that at the ecosystem level (SE Alaska to the Columbia River), Steller sea lions are an important adult chinook predator. Total chinook consumption, mainly by killer whales and Steller sea lions, has increased dramatically over the last 4 decades, whereas chinook catches have shown a corresponding decline over the same period. Increased consumption of chinook by predators may explain the declining exploitation rates in chinook fisheries.
- Steller sea lions also consume salmon smolts. While smolts comprise a miniscule part of the diet in terms of biomass, the consumption represents large numbers of smolts. While the numbers may appear to be astronomical, the impact on chinook stocks is probably minimal when viewed in the context of the number of smolts produced, and the number of smolts dying before attaining adulthood.
- Salmon managers should consider incorporating the growing number of salmon removals by predators as part of ecosystem-based stock assessment models. This would allow allocation of the

finite supply of salmon between fisheries and predators and facilitate a discussion of the tradeoffs of various management options (curtailing fisheries versus culling predators versus recovering threatened species).

Day 2 – Rates of Predation And Amounts Consumed – Cowichan Focal Area.

Z. Cowichan River chinook: population trends and survival (*Kevin Pellett, DFO*)

- Chinook escapement to the Cowichan River has been increasing since 2009
- Potential contributing factors include: reduce marine exploitation, increased wild fitness (reduced hatchery releases), freshwater habitat restoration (Stoltz Bluff 2006), increased marine survival
- Escapement methodology has also changed – PIT tag based approach provides a specific run timing curve for each year to accurately expand end of run when fence removed early. We estimate this could account for a ~+35% increase over standardized run timing curves in 2017 and 2018.
- The pre-fishery abundance is still not as high as historic levels but an increasing trend is apparent (slide 10).
- PIT tag based survival work indicates high mortality through first winter
- Paired acoustic/PIT study in 2017 provided both survival estimates as well as proportion of plausible pinniped related mortalities
- Good agreement between PIT based survival estimates and acoustic study results as well as CWT survival to Age 2
- Potential ways to double escapement were explored theoretically. A 7% reduction in mortality after September of the first marine year was equivalent to doubling smolt production or closing all marine fisheries.
- If we take acoustic study results at face value and remove observed seal related mortality during the study period (September to March) escapement would increase 54%. This assumes seal related mortalities are still occurring before and after study period.
- If we assume 18% of all mortalities are due to seals from September of the ocean entry year onwards removing that mortality would increase escapement 255%
- If the window is shifted backwards to June (when fish hit "snack size" 100 mm) an18% reduction in mortality during the marine phase would increase escapement 530%.
- Ground truthing of seal interactions with PIT tagged fish was conducted in 2016 and 2017. 18 PIT Tags were detected on 4 haul outs up to 40 km from the estuary. Each haul out scanned had at least one tag.
- Taking into account relatively small numbers of scats on haul outs, detection probability, proportion of fish tagged and consumption rates the expansion factor could be very high.
- ID's were from a wide range of tagging sites suggesting not just recently tagged fish (more vulnerable) were targeted.
- Acoustic study results indicated most fish exit study area to south – no haul outs have been scanned on this route to date. More effort scanning haul outs in this area is warranted.

AA. 2017 Cowichan chinook salmon acoustic tagging study: pinniped predation implications (*William Duguid (presenter), Erin Rechisky, Aswea Porter, Francis Juanes, Kevin Pellett, and David Welch*

- Caveats: Measuring pinniped predation was not a primary goal of the study; these conclusions are based on the interpretations of Duguid and are subject to revision pending further review of tag detection details prior to publication of results. Select conclusions relevant to pinniped predation:
- We experienced some early mortality likely due to tagging and handling, these fish 12/80 were not included in subsequent mortality estimates

- Residence of Cowichan River chinook salmon in the southern Salish Sea for at least first winter is likely more common than emigration - This means that these fish have continued exposure to Salish Sea pinniped predation through this period
- We unambiguously estimated high (minimum 40%) mortality through fall and early winter
- Due to the behaviour of fish in our study (extensive milling) pinniped predation was challenging to unambiguously determine based on tag movements or final locations; that said, our preliminary estimate is that pinnipeds represented a minimum of 18% of non-tagging related mortality.
- Fine scale movement data confirms that different individual fish within a stock exhibit different fine scale distributional behaviour which may be related to feeding (piscivory vs planktivory). This raises the prospect of growth/survival trade-offs mediated by pinniped predation.
- Suggested areas of required research:
  - Assessment of the relative degree of residence exhibited by different chinook salmon stocks in the Salish Sea... and evidence for changes in residency through time.
  - Winter ecology of juvenile chinook salmon in the Salish Sea: Where, how deep, what diet, what condition, what disease state, and spatiotemporal overlap with pinnipeds
  - Trade-offs between growth and survival - selective implications of harvest and predation?

BB. Harbour seals consume more adult salmon in estuaries than elsewhere in the Strait of Georgia (*Chad Nordstrom (presenter), Sheena Majewski, Austen Thomas, Strahan Tucker, Andrew Trites*)

- Salmon consumption is variable in space & time
- Site selection (field stage) and how those sites are later summarized (analysis stage) influences prey consumption estimates
- Salmon consumption inside *vs* outside the Cowichan estuary in a single year 'snap-shot' comparison was:
  - major in the fall (primarily adult fish)
  - minor but possibly important in spring (primarily juvenile fish)
- Annual and seasonal variability influenced diet estimates at a longer term site (Cowichan) across a 'time-series' data set (2012-2018) and noted:
  - salmon diet in the Cowichan estuary followed an annual pattern (low proportions in the spring and increasing throughout the fall) BUT
  - the specific seasonal proportion was highly variable year to year as was the species composition during the spring period (chinook/coho dominated in 2012-13 vs Chum in the preliminary 2018 data)
- Overall:
  - Using a single salmon consumption value to assess impacts can be misleading (and authors are encouraged that the current modelling efforts are incorporating variability/uncertainty)
  - Long-term diet monitoring to estimate *consumption* is the key to correctly assessing *impacts* on salmon and other important prey species

CC. Fine-scale catch and effort data with emphasis on southern BC areas (*Wilf Luedke, Bryan Rusch*)

- In the Juan de Fuca area recreational fisheries were restricted beginning in 2009 with greater restrictions starting in 2012 under 'Zone Management' of Fraser spring and summer chinook.
- These restrictions reduced impact on larger age 4 and age 5 wild chinook returning to the Fraser and other areas of the Salish Sea.

DD. Pacific great blue herons: another major predator of outmigrating salmon smolts (*Zachary Sherker (presenter), Kevin Pellet, Jamieson Atkinson, Jeramy Damborg, Andrew Trites*)

- Pacific Great Blue herons are a significant predator of outmigrating salmon smolts, feeding on 1-3% of the tagged smolts released in the Cowichan River annually from 2014-2018. Herons had not been previously identified as a predator of juvenile salmon.
- >95% of the tags recovered in the Cowichan Bay heronry were from river released fish, as opposed to fish tagged in the estuary, suggesting that predation likely occurs prior to bay residency
- The highest levels of heron predation occurred in a critically low flow year (2016). This may be due to the slower migration speeds of smolts in the Cowichan River, reduced access to fish refuge habitat, or a reduced ability to evade heron predation in low water levels.
- Smaller smolts are more susceptible to heron predation, likely as a result of slower migration speeds, slower predator evasion, and exclusion from refuge habitats by larger smolts during predation events.
- Tags were evenly distributed under the nests at the Cowichan Bay heronry, suggesting that most herons take part in predation on salmon smolts.

Day 2 –Factors that Affect Pinniped Predation of Salmonids

EE. Ecosystem Factors Affecting the Early Marine Survival of Puget Sound Steelhead (*Barry Berejikian (presenter), Megan Moore, Steve Jeffries, WDFW*)

- Summary of predation by harbor seals on steelhead in Puget Sound and Hood Canal.
- Acoustic telemetry research on steelhead trout in Puget Sound and Hood Canal has been conducted since 2006 (with a gap from 2010-2013) and is on-going. Studies have included survival estimation paired with assessments of predation in estuaries, the main basin of Puget Sound, and fine-scale tracking at the Hood Canal Bridge. In 2014 and 2016, harbor seals were instrumented with hydrophones, acoustic tags, and GPS/TDR tags to quantify interactions with tagged steelhead. The following is a very brief summary of findings:
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- It is unknown whether warm ocean conditions have a positive or negative effect on steelhead after they leave Puget Sound.
- The presence of alternative, preferred prey may lessen predation impacts on steelhead

FF. Hood Canal bridge assessment: preliminary results (*Megan Moore, Barry Berejikian [presenter]*)

- The Hood Canal floating bridge slows the migration of steelhead smolts and causes significant mortality (up to 50% of the smolts arriving at the bridge). Temperature and depth tags strongly indicate that steelhead are being consumed by harbor seals at or very near the Hood Canal Bridge, and this predation appears to account for the most of the mortality.

Day 2 – Ecosystem Considerations: Indirect Effects of Pinniped Predation on Salmon Mortality, Effects of Disease on Predation Rates, and Questions Surrounding Additive and Compensatory Mortality

GG. Spatial and temporal dynamics of pinniped-prey trophic interactions (*Caihong Fu, DFO*)

- Observations suggest that pinnipeds are generally opportunistic feeders with certain size selectivity. Their diets are dependent on spatial and temporal overlap with prey species.
- Individual-based, spatially- and temporally-explicit ecosystem models that simulate the whole life cycle of modelled species can produce reasonable diet compositions and achieve good understanding of pinniped impacts on prey species.
- Such ecosystem models can be used to project potential future dynamics of fish species and the Salish Sea ecosystem under future changes of climate and management strategies with trade-offs between conflicting objectives across management sectors being considered.

HH. Seals may *not* increase exploitable biomass in the Salish Sea (*Greig Oldford, Villy Christensen [presenter,] Carl Walters, UBC*)

- The presentation described ongoing activities conducted as part of a Pacific Salmon Foundation activity at UBC, which is part of the Salish Sea Marine Survival Project
- A trophic model of the Salish Sea ecosystem from 1966 to 2015 was constructed using Ecopath-with-Ecosim (EwE) software;
- Stock assessments, diet data, abundance trends, and other available data were used for 30 functional groups;
- An age structured approach was used for Chinook and coho salmon to capture important predation changes during the life histories of these species;
- The model included the major predators and prey of Chinook, coho, and harbour seals;
- Several major ecological changes that have been observed were also recreated by the modelling simulation including recovery of the herring population in the Strait of Georgia, an exponential growth of the seal population, and trends in resident killer whale populations;
- A simulated cull of harbour seals was then conducted using the model;
- Results indicated increased abundance of Chinook and coho in the absence of harbour seal predation, especially juvenile fish;
- The model is sensitive to several important factors including the productivity and diet of hake and present and future predation from transient killer whales on seals;
- This model did not replicate results of a previous modelling study on the same ecosystem (Li et al., 2010) which found that the absence of harbour seals may *decrease* abundance of commercial fish species (e.g., hake, Chinook);
- Differences between the modelling results may be accounted for by different hake diet and productivity parameter estimates;
- Future work includes an age-structured parameterization of the model for other species (herring, seal, etc), spatial discretion of the model, primary production models and rigorous sensitivity analyses

II. Top down effects of pinniped predators on prey populations in the Strait of Georgia

(***Peter Olesiuk [presenter], Jake Schweigert and Jaclyn Cleary***)

- The Strait of Georgia is an ideal area for assessing the top-down effects of pinniped predators on their prey. Pinniped predation has increased ~20-fold since 1970, the diet is rather simple, being dominated by two species, herring and hake, both of which represent distinct stocks in the Strait of Georgia.
- The increase in pinniped consumption appears to have resulted in higher mortality of herring, particularly in older age-classes, presumably because they're larger. The age-composition of hake has also shifted toward younger, smaller fish. Size-selective predation by pinnipeds may be driving declines in size-at-age of older herring and hake.
- Seals appear to have displaced hake as the predominant herring predator in the Strait of Georgia. During the 1970s and early 1980s when pinniped populations were depleted, there was a large biomass of older, larger hake that preyed on juvenile herring and hake. As pinniped populations recovered, the biomass of older, larger hake was depleted, which reduced predation on juvenile herring and hake, and resulted in improved recruitment.
- Herring and hake stocks are now dominated by younger, faster-growing fish that are more productive, but this has had negative implications for fisheries that tend to target older, larger fish with higher market value.

IJ. Juvenile salmon growth performance and vulnerability to predation in marine food webs: dynamic links to condition, climate and infectious disease agents (*Strahan Tucker, DFO*)

- Seabirds can be ideal models for predation studies as some species deliver whole fish to their chicks-so a rare opportunity for us to actually observe and characterize the fish which are consumed. Rhinoceros auklets nest at key points along the migration pathways of salmon in BC's Central and Northern Coasts. They are pursuit diver which means that in theory, their prey should be more likely to be individuals in poorer condition (slow, weak, sick, stressed) because are more easily captured. Our juvenile salmon survey was concurrent with sampling at colonies so able to contrast the fish consumed with those available.
- We provided evidence for both size-selective predation and condition based and predation susceptibility of salmon as both size and condition were significantly lower predated salmon than trawl-caught salmon.
- The proportion of salmon that are small and in low condition varied substantially from year to year- a component of this is thought to be due to ecological factors such as prevailing ocean and feeding conditions. The proportion of salmon in low condition was highly correlated to the timing of spring transition.
- Disease can also affect condition. We employed a molecular genetic high-throughput quantitative PCR monitoring platform of 45 different infectious agents known or suspected to cause disease in salmon to see if those that are predated tend to be disease-agent challenged. Predated fish, relative to trawl caught fish, carried a higher diversity of infectious agents at higher loads. We also found an association with 3 different microparasite species.
- We also contrasted seasonal pathogenic infectious agents in life-history variants of juvenile chinook salmon from the Fraser River system through the high-throughput quantitative PCR monitoring platform.
- Life-history variants of Fraser River chinook salmon currently display divergent stock status with yearling stocks generally in decline and sub-yearling stocks doing comparatively well.
- Variants carried a different infectious agent profile in terms of (1) diversity, (2) origin or transmission environment of infectious agents, and (3) prevalence and abundance of individual agents. Differences in profiles

tended to reflect differential timing and residence patterns through freshwater, estuarine and marine habitats.

- Shifts in prevalence and load over time were examined to identify agents with the greatest potential for impact at the stock level; those displaying concurrent decrease in prevalence and high load truncation with time. Of those six that had similar patterns in both variants, five reached higher prevalence in yearling fish while only one reached higher prevalence in sub-yearling fish; this pattern was present for an additional five agents in yearling fish only.
- Similar patterns in diversity are observed in other stocks of non-Fraser chinook salmon utilizing the Salish Sea. At this point we don't know what the fate of any of these individual fish would be and we did not directly establish links between infectious agents and disease. However, these results suggest that agents may play a substantive role in mortality; a component of which may be increased susceptibility to predation.

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