*Abstracts for oral presentations are in chronological order by session.*
*Abstracts for poster presentations are included at the end of the file.*

## Predation Workshop, Tuesday, February 27th

### Predation ecology and juvenile Chinook salmon

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The role of predation in structuring ecosystems along the California Current is becoming more evident. As predator populations recover following the enactment of Federal protections 40 years ago, the impact they have on forage communities (e.g., anchovy, sardine, herring) and fisheries (e.g., salmon) is notable. To date, the majority of studies examining predation ecology and its impacts on the ecosystem have been reliant on building an understanding of prey composition, models of cumulative bioenergetic demands, and the temporal-spatial associations of predators and prey. Predation is inherently an individual-level event. For predation to be successful, several distinct processes must all occur: a predator must a) encounter, b) attack, and c) capture the prey. Each of these processes is complicated by several physical and environmental factors that make documenting and understanding predation difficult, yet can have profound impacts on the population-level impact of predation. *Encounter*: In a system as large as the California Current, spatial overlap between predator and prey is hardly universal. Both predators and prey have evolved strategies to optimize spatial and temporal overlap to maximize survival. Many predator species (hake, tuna, sharks) can migrate hundreds to thousands of kilometers annually. Similarly, many stocks of salmon, such as interior Columbia River Chinook salmon, migrate just as far. Few studies examine how variability in predator behaviors impact prey taxa interannually and seasonally.
*Attack*: Predators can be highly selective among prey types, sometimes actively avoiding a less abundant prey source until some threshold of prey abundance. On the other end of the spectrum, as prey become highly abundant, predator swamping can reduce the probability of attack on any given individual, which can also have impacts at the population level.
*Capture*: Most studies looking at predator capture success have shown some level of size selectivity. Larger prey, and those in better condition, are better able to evade capture, either behaviorally or through gape limitations of the predator. Size- or condition-dependent biases in survival can not only impact population-level abundance, but evolution of traits such as size at age, migration timing, and fecundity. The study of predation on Pacific salmon should explicitly identify mechanisms for each of these trophic processes. Moreover, this must all be pursued in the context of a varying environment and preyscape.

**A Look at Predation by Piscivorous Marine Fishes on Juvenile Salmon.**

**<u>Gregory K. Krutzikowsky</u>**

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The Oregon Nearshore Strategy lists marine survival as one of the limiting factors for a number of population segments of salmon called state management units by the state and evolutionary significant units or distinct population segments by the federal government. The mechanisms affecting marine survival are also listed as a data gap. It has been hypothesized that piscivorous marine fishes are a primary source of marine mortality for Pacific Northwest juvenile salmon. I will present information collected off the mouth of the Columbia River from 1998 to 2004 designed to investigate that hypothesis. This work was headed up by the late Robert Emmett as part of his doctoral dissertation. I will discuss results of this work including information on the abundance and distribution of pelagic piscivorous fishes in this area during spring/early summer, nocturnal feeding of Pacific hake (*Merluccius productus*) and jack mackerel (*Trachurus symmetricus*) and the implications for juvenile salmon predation, as well as some of the challenges involved in conducting this work. I will also touch briefly on further modeling work that Dr. Emmett pursued on this topic as part of his dissertation.

**Ocean avian predation on Columbia River salmon populations – what we know, what we don't know, and next steps to improve our knowledge**

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In 2003, NOAA Fisheries began to systematically strengthen our understanding of the early marine survival of juvenile salmon by looking at one potential source of ocean predation – seabirds. A four-step approach to addressing predation asked the following: (1) which predator species are present during the early marine period? (2) of these predators, which are abundant enough for a potential population-level impact? (3) when and where do salmon populations overlap in space and time with those predators? and (4) to what extent, if any, does salmon consumption by seabirds impact population-level impact salmon survival? We now know that common murres (*Uria aalge*) and sooty shearwaters (*Ardenna grisea*) are two abundant seabirds whose distributions overlap with at least 6 ESU/DPS groups of juvenile Columbia River Chinook salmon during May and June. Results from at-sea surveys, satellite telemetry, and models of predator-prey distributions demonstrate these predators are attracted to and aggregate in the Columbia River Plume region, a nearshore habitat directly affected by freshwater discharge from the river and a region through which all outmigrating juvenile salmon must pass to successfully enter ocean habitat. However, quantitative diet data for murres or shearwaters in the Plume region necessary to inform bioenergetic models or other theoretical approaches used to estimate salmon predation are presently unavailable. Ball-park estimates based on sparse diet data, as well as results from other systems where data are available, both suggest predation impacts may be significant. If we assume times and locations of highest predator-prey overlap also represent times and locations of highest potential mortality risk, then the next logical step is to quantify predation events in the field and estimate realized predation mortality. Completing the final steps in assessing population impacts of predation requires integrating new empirical data with theoretical approaches to quantify predation mortality.

**Examining Predation on Juvenile Salmonids in a Larger Predator-Prey Context: Avian Predators in the Columbia River Estuary**

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Levels of predation on juvenile salmonids by two species of avian predators in the Columbia River estuary, Caspian terns and double-crested cormorants, have been substantial over the past two decades. Assessments of impacts have included both estimates of the number of individuals consumed using bioenergetics methods and the proportion of species or populations consumed using analyses of PIT tag recoveries at bird colonies. Despite relatively good documentation of direct predation impacts, we lack information on functional relationships and the broader ecological context, which has limited projections of potential changes in predation under altered management or climate regimes. To address these information gaps, we compared avian predator diets to independent measures of prey fish availability from purse seine sampling within the estuary, during a six year period of data overlap (2007 – 2012). Caspian terns appeared to take salmonids in rough proportion to *absolute* availability, whereas cormorants appeared to take salmonids in proportion to their *relative* availability in the Columbia River estuary, not their absolute abundance. Changes in absolute abundance of alternative prey, both marine and freshwater/estuarine forage fishes, influenced how much cormorants relied on salmonids as prey but not terns. Using Ivlev's selectivity index, we found that terns consistently selected for steelhead, salmon, smelt, and surfperch and against stickleback and clupeids. Cormorants moderately selected for salmonids, sticklebacks, and surfperch, and consistently selected against smelt and clupeids. Selectivity for anchovy was variable (periods of selection for and against) for both species. As plunge divers, tern foraging is constrained to the top meter of the water column, whereas cormorants, as pursuit divers, are capable of exploiting the entire water column. We conclude that foraging behavior and physiology likely play an important role in determining how much predator species rely on salmonids under varying availability of alternative prey.

**Competing tradeoffs between increasing marine mammal predation and fisheries harvest of Chinook salmon**

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Many marine mammal predators, particularly pinnipeds, have increased in abundance in recent decades, generating new challenges for balancing human uses with recovery goals via ecosystem-based management. We used a spatio-temporal bioenergetics model of the Northeast Pacific Ocean to quantify how predation by three species of pinnipeds and killer whales (*Orcinus orca*) on Chinook salmon (*Oncorhynchus tshawytscha*) has changed since the 1970s along the west coast of North America, and compare these estimates to salmon fisheries. We find that from 1975 to 2015, biomass of Chinook salmon consumed by pinnipeds and killer whales increased from 6,100 to 15,200 metric tons (from 5 to 31.5 million individual salmon). Though there is variation across the regions in our model, overall, killer whales consume the largest biomass of Chinook salmon, but harbor seals (*Phoca vitulina*) consume the largest number of individuals. The decrease in adult Chinook salmon harvest from 1975-2015 was 16,400 to 9,600 metric tons. Thus, Chinook salmon removals (harvest + consumption) increased in the past 40 years despite catch reductions by fisheries, due to consumption by recovering pinnipeds and endangered killer whales. Long-term management strategies for Chinook salmon will need to consider potential conflicts

**Effects of Sea Lion Predation on Willamette River Winter Steelhead Viability**

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California sea lions (CSL) began to regularly appear at Willamette Falls in the mid-1990s. A rigorous monitoring program began in 2014, revealing that CSL have consumed an average of at least 5300 salmonids per year in the immediate vicinity of Willamette Falls. At the same time, winter steelhead, which are listed as "threatened" under the federal Endangered Species Act, have declined in abundance. We conducted a population viability analysis of Willamette River winter steelhead to quantify extinction risk under current CSL predation rates, and the effect of removing CSL on steelhead extinction risk. The North Santiam population of winter steelhead has a 0.64 probability of extinction over 100 years if the 2017 predation rate by CSL is perpetuated, but probability of extinction drops to 0.015 if CSL are absent. Other steelhead populations in the Willamette River showed qualitatively similar responses to CSL. Though many assumptions were needed to perform this work, the results suggest that CSL can extirpate winter steelhead populations, which has already occurred at "Ballard Locks" Washington. Removing CSL from Willamette Falls would greatly improve extinction risk.

## Wednesday, February 28th

**Ocean Salmon Research: "Oh, Bother" (keynote)**

**<u>Nancy D. Davis</u>**

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From a salmon researcher's point of view, how far offshore does one have to follow salmon in the ocean to decide that's far enough to understand salmon ocean ecology? I will attempt to shed some light on this question based on some previous research and opinion. Information repositories will be highlighted that exist based on information from earlier studies that might provide insight for new comparative studies. Renewed interest in salmon ocean research has created fresh opportunities, and possibilities for advancing these initiatives are suggested.

## SESSION I: Basin-scale Processes

**The Life and Hard Times of Pacific Salmon: Chapter 3 – The Ocean**

Nathan F. Putman[1,2], Michelle M. Scanlan[1], Amanda M. Pollock[1], and **<u>David L. G. Noakes[1]</u>**

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Salmon have very difficult lives, defined by their philopatric anadromous life history patterns. Their biology, their management and their conservation are defined by the predictable accuracy and precision of their migration. Their behavior is remarkable because their movements are performed without error, and in the absence of experience or interactions with their parents or older conspecifics that have previously carried out such migrations. Their first movements (Chapter 1) are required to emerge from the redd where they were buried by their mother, into the open water of the stream or river. The second great movements (Chapter 2) take juvenile smolts from fresh water into the ocean. Movements in the ocean (Chapter 3) are the most extensive and until recently the least understood salmon movements. A number of mechanisms have been proposed to account for the ocean movements of salmon, ranging from random drift in ocean currents to various complex orientation responses. I will review our recent research on geomagnetic navigation in salmon as our hypothesis for ocean movements. We have shown that salmon are able to detect geomagnetic cues soon after hatching, and can use that information to direct their emergence from the spawning gravel. Juveniles use geomagnetic information to determine their current location, and to compensate for experimental displacement from their oceanic locations. Adults use geomagnetic information to navigate directly back to their home stream location at spawning time. Salmon possess the ability to detect geomagnetic cues and use that information to navigate without prior experience, so we are now investigating the basis for that ability and how it develops during ontogeny.

### Do pink salmon affect the structure of the North Pacific ecosystem and contribute to declining Chinook salmon populations in Alaska?

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Pink salmon have never been more abundant than now. During 2005-2015, pink salmon abundance averaged nearly 500 million fish with peak abundances of ~650 million fish in 2009 and 2011. Pink salmon are especially abundant in odd-numbered years, reaching 76% of all Pacific salmon in peak years. Here, we briefly examine the hypothesis that pink salmon have strongly influenced pelagic ecosystem structure of the North Pacific Ocean and Bering Sea. First, high abundances of pink salmon are shown to cause a trophic cascade by reducing the abundance of zooplankton, which in turn leads to a greater abundance of phytoplankton (zooplankton prey). Second, seabirds near the Aleutian Islands that consume similar prey as pink salmon experience reduced foraging and reproductive success when pink salmon abundance is high. Third, a range of evidence indicates pink salmon affect growth, age at maturation, and survival of sockeye salmon. We present preliminary new findings showing how ocean conditions differentially mediate the effects of competition with pink salmon on survival of sockeye salmon ranging from British Columbia through Bristol Bay, Alaska. Finally, we examine recent evidence of pink salmon interactions with Chinook and coho salmon, suggesting that high abundances of pink salmon may be contributing to the decline of Alaskan Chinook salmon.

**Distinct chemical fingerprints in Chinook salmon reflect their marine distribution and feeding**

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Persistent organic pollutants (POPs) can serve as chemical tracers, revealing the foraging habitats of mobile marine species for which such information is often lacking. These man-made pollutants resist degradation from environmental or metabolic processes, accumulating and magnifying in higher trophic levels. Marine environments have distinct POP patterns based on historic inputs, and animals foraging for extended periods of time can accumulate POPs in proportion to their availability in those environments. Pacific salmon may be exposed to POPs in freshwater and estuarine habitats but acquire most of their adult body burden at sea where almost all growth occurs. Here, we used multi-dimensional scaling to analyze the relative proportions of four POP classes in adult Chinook salmon from populations originating from northern British Columbia to northern California. The relative abundance of four POP classes among these populations provided distinct chemical fingerprints of their exposure to contaminated prey related to the geographical distribution of the contaminant sources. For example, levels of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) were highest in salmon that originated from and resided in Puget Sound, followed by Puget Sound-origin populations that migrated to the ocean, and were lowest in populations from northern British Columbia, distant from urban areas. Dichlorodiphenyltrichloroethane (DDT) levels were highest in California Chinook salmon that feed off California and Oregon coasts, reflecting greater use of that pesticide in that region. The marine distributions inferred from these distinct chemical fingerprints were consistent with independent assessments of the migration patterns and distribution of the populations. The chemical fingerprints identified here may therefore help elucidate marine distribution patterns of other salmon species, other Chinook salmon populations, and individuals within populations. Additionally, these chemical fingerprints can also reveal foraging habitats of salmon predators because the fingerprints in the predators will reflect those of their prey.

**Atlantic salmon: Assessments through the estuary and beyond**

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A major hurdle to Gulf of Maine Atlantic salmon Distinct Population Segment (GOM DPS) recovery and persistence is low marine survival. Efforts over the last two decades (e.g., analysis of historic tagging data, in-river trapping, diet analysis, telemetry) have begun to characterize a suite of risks incurred during seaward and early marine migration. Smolts are now migrating and entering the ocean earlier than in the past, likely in response to climate shifts. During migration, in-river dams are (and remain) a site of high acute mortality. In addition to direct mortality, sub-lethal effects (e.g., delay and injury) are implicated in further risk during the estuary transition. Hatchery sourced smolt performance is incongruent with wild reared fish. Upon seawater entry, post-smolt diets differ between wild and hatchery fish in coastal waters during this critical growth period. In the ocean, smolts migrate quickly towards the Labrador Sea, residing in the GOM is less than a month, traveling in colder and less saline waters. GOM post-smolts mix with northern populations once on the Scotian Shelf. At summer feeding grounds off West Greenland, diets have also changed over the last decades, likely related to climate driven shifts in the Northwest Atlantic. A phase shift in the 1990s diminished prey quality and availability. This shift remains constraint on the productivity and recovery of many Atlantic salmon populations. Together, these observations present a daunting level of uncertainty and challenge for the recovery of the species but also provide some guidance in addressing marine loss for GoM Atlantic salmon populations.

## SESSION II: Salmon in Estuaries

### Characterizing juvenile Chinook salmon residency and early growth in the lower Fraser River estuary

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The Harrison River is a tributary of the lower Fraser River system which produces the highest proportion of fall-run, ocean type Chinook salmon (*Oncorhynchus tshawytscha*) in the Salish Sea. Ocean type Chinook, which emigrate to estuarine and marine waters within the first year, may be more dependent on nearshore habitats than stream type individuals during their first year of ocean residency. Using a combination of genetic and otolith analyses, we assessed the stock-specific utilization of three habitat types in the lower Fraser estuary by emigrating Chinook. In 2016 and 2017 we surveyed 20 sites across the lower estuary, sampling 3,240 juvenile Chinook salmon and collecting 838 tissue samples for genetic stock identification. We caught the majority of all salmon in brackish marsh habitat in both years, despite large differences in seasonal flows, temperatures and previous escapement. Overall, we captured juvenile Chinook from 18 different populations, with stream-type populations generally captured in very low numbers. The dominant stock in our catch was identified as Harrison and were ocean type, arriving the earliest near the end of March, and present the longest until mid-July in 2016 and mid-June in 2017. We retained a subsample of Harrison stock juveniles from 2016 and assessed entry timing and estuarine growth prior to capture using visual and chemical analyses of the otoliths via LA-ICP-MS. Preliminary results from otolith analyses show diverse entry and residency times among individual Harrison fish, demonstrating a broad spectrum of behaviours within an ocean type population. Our results will improve our understanding of the importance of estuarine to the early marine survival of these Chinook populations and provide some insight into life history trade-offs for ocean type juveniles.

**Large-Scale Dam Removal and Ecosystem Scale Nearshore Restoration: Learning from the Elwha Nearshore**

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Dam removal is an emerging tool for ecosystem and fisheries restoration. Nearshore restoration implications of dam removal are however not well understood. Located on the north Olympic Peninsula, the Elwha River and nearshore are undergoing an unprecedented restoration event with the removal of two large in-river dams. The project is estimated to deliver 16 million cubic meters (mcm) of material to the marine environment within five years of dam removal. The delivery is significant ecologically. The Elwha nearshore is a critical component of the Salish Sea, used by no fewer than six U.S. Federally-listed salmon species and numerous forage fish. The Elwha nearshore is impaired ecologically due to extensive shoreline armoring and in-river channelization and dams. To date approximately 60-80 percent of predicted sediment has been delivered to the sediment-starved Elwha nearshore. In this paper we present updates of a series of basic long term studies of the nearshore ecological response of fish use to Elwha dam removals. This work informs ecosystem restoration science and management with a series of specific nearshore recommendations for developing future watershed ecosystem restoration projects, including dam removal, and minimizing/preventing future nearshore ecosystem degradations thru understanding of how the nearshore functions. We also provide an overview of emerging linkages of the nearshore restoration event for the larger Elwha and Salish Sea ecosystem.

**Longitudinal variation in growth of Snake River Spring Chinook salmon in the Columbia River System: from Bonneville Dam to the Pacific Ocean**

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Juvenile Snake River Spring Chinook salmon may migrate up to 700 km through both the Snake and Columbia Rivers to enter the ocean through the Columbia River Estuary. In 2016 and 2017 juvenile Snake River Spring Chinook salmon were captured and sampled for blood plasma in freshwater via tow net in April and May in three regions downstream of Bonneville Dam (Rooster Rock, Willow Grove, and Steamboat), in the Columbia River estuarine waters in April and May via purse seine, and in marine waters of the Columbia River Plume in May exclusively via fishing trawl. Blood plasma concentration of insulin-like growth factor-1, or IGF-1, is an index of instantaneous growth in juvenile fishes and was used herein to assess growth. Variations of IGF-1 concentration between sampling regions may be indicative of differences in use of a given region for feeding and subsequent growth. In 2016 differences in mean IGF-1 concentration were observed within the May freshwater samplings sites from upstream to downstream; whereas in 2017 there were not differences in mean IGF-1 concentration among freshwater sampling sites. In both 2016 and 2017 mean IGF-1 concentration was significantly higher in marine sampling sites as compared to freshwater sampling sites. Thus far, these results indicate that growth does vary downstream from Bonneville Dam to the ocean. Further analyses including differences in fork length and stomach fullness and content will be included to address the observed differences in IGF-1 concentration.

**Making connections to habitats: Feeding ecology of juvenile salmonids during emigration**

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In the lower Columbia River and Estuary (LCRE), salmon recovery efforts have focused on wetland restoration. Although wetland residence by sub-yearlings has been well documented, it is less clear how important these habitats are for rapidly migrating species such as yearling Chinook salmon. Our ultimate goal was to determine if foraging habits changed as salmon moved through the LCRE, which extends from the lowermost mainstem dam (Bonneville) to the mouth of the estuary. As part of a collaborative effort to evaluate ecological benefits of restoration actions for threatened Chinook salmon in the Columbia River basin, we examined stomach fullness (relative indicator of feeding success), diet composition, and primary producers supporting salmon, along with stable isotope signatures ($\delta^{13}C$ & $\delta^{15}N$) of tissues (fin and muscle) with relatively fast turnover rates (7 –10 d). In 2016 and 2017, juvenile salmon were collected from three riverine sites using a tow net and at the mouth of the estuary using a purse seine. This presentation will focus on summarizing and comparing feeding habits of the Snake River Spring stock across both years. Initial results indicate, on average, salmon collected in 2017 had greater stomach fullness (2016 = 0.86 ± 0.43 SD; 2017 = 1.15 ± 0.53 SD) and higher richness of prey taxa (2016 = 4.25 ± 2.48 SD; 2017 = 6.25 ± 3.57 SD) in their diets compared to those collected in 2016, with the greatest stomach fullness and prey richness occurring at the two uppermost estuary sites. Salmon consumed a greater biomass of insects in 2017 compared to 2016, with dipterans occurring in 60-100% of the diet samples across all sites. Further analysis of carbon sources of salmon tissues and stomach contents will provide additional insight on potential benefits and food web linkages to wetland habitats.

**Transported Snake River salmon and steelhead: survival indices across life stages show signs of carryover effects**

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The Juvenile Fish Transportation Program of the Snake and Columbia rivers is a mitigation strategy to help increase survival and number of adult returns of ESA-listed salmon and steelhead. Although direct survival has been nearly 100% during barge transportation, smolt-to-adult return (SAR) rates of transported fishes are sometimes lower than those of in-river migrants. Transportation can be beneficial or detrimental to SARs depending on the environmental conditions, the time of year, species, rear-type, and biological and physical fish conditions. These patterns suggest that the juvenile hydrosystem migration can have negative “carryover effects” on the performance and survival in later life stages. Understanding these carryover effects can help determine ways to improve SARs of transported fishes. In our current review and synthesis of research related to the transportation program and survival patterns of Snake River salmon and steelhead, we: 1) estimated survival indices within and across life stages in a Bayesian approach to a Cormack-Jolly-Seber mark-recapture model, 2) highlighted findings from recent literature in context of direct and carryover effects, 3) discussed transportation-related decisions, and 4) identified critical uncertainties. Preliminary results showed that many patterns of annual and seasonal survival indices changed after a court order of increased spill (2006-2015), compared to those in years prior (1998-2005). Juvenile survival increased, but adult conversion rates decreased or remained unchanged. Annual patterns of these survival indices were most variable in fall Chinook, followed by steelhead, and then spring/summer Chinook salmon. Seasonal patterns of transport to run-of-river SAR ratios for spring/summer Chinook and steelhead showed more variable types of patterns starting around 2005. We discuss how determining the direction and the relative impact of factors on survival at each life stage – under various combinations of river and ocean conditions – would help clarify when and how the transportation program can be effectively improved.

## SESSION III: Salish Sea Salmon

### An overview of environmental drivers impacting juvenile Puget Sound chinook and coho salmon: preliminary results from the Salish Sea Marine Survival Project

**Michael Schmidt[1*]**, Iris Kemp[1], Alan Chapman[2], Barry Berejikian[3], Correigh Greene[4], Chris Ellings[5], Chris Harvey[4], Christopher Krembs[6], Dave Beauchamp[7], Erik Neatherlin[8], Jan Newton[9], Joe Anderson[8], Josh Chamberlin[4], Julie Keister[10], Ken Warheit[8], Lance Campbell[8], Mike Crewson[11], Neala Kendall[8], Neil Banas[12], Parker MacCready[10], Paul Hershberger[7], and Sandie O'Neill[8]

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In 2014, Long Live the Kings (LLTK) and the Pacific Salmon Foundation launched the Salish Sea Marine Survival Project: an interdisciplinary US-Canada research collaboration to determine the causes of poor juvenile Chinook, coho, and steelhead survival in the Salish Sea. Four years later, over 200 scientists representing multiple disciplines are engaged; 60 federal, state, tribal, nonprofit, academic, and private entities are participating; more than 80 studies have been initiated; and 18 articles have been accepted for publication in peer-reviewed journals. This presentation provides an overview of Salish Sea Marine Survival project findings and ongoing research focused on Puget Sound chinook and coho salmon. Survival patterns of Salish Sea chinook and coho populations vary independently from coastal populations and indicate that early marine conditions within the Salish Sea are important to overall marine survival. Qualitative network modeling suggests anthropogenic pressures and food web alterations within the Salish Sea impact salmon survival and abundance. Salish Sea chinook and coho populations

are impacted by a combination of bottom-up and top-down environmental drivers. Contaminant levels in urban river systems and throughout the Puget Sound marine environment exceed adverse effects thresholds for juvenile chinook. Size and lifestage at marine entry and growth within Salish Sea waters correlate with marine survival for some populations. Crab larvae and forage fish such as herring and Pacific sand lance are important diet components; fish prey provide a growth advantage in northern regions of Puget Sound. A zooplankton monitoring program was initiated to better understand relationships between prey availability, prey quality, and salmon growth and survival. Predation pressure on Salish Sea salmon populations has increased over time; affiliate research efforts have estimated as much as a nine-fold increase in consumption of Chinook by harbor seals in Puget Sound since the 1970s.

**An overview of environmental drivers impacting juvenile Puget Sound steelhead: preliminary results from the Salish Sea Marine Survival Project**

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In 2014, Long Live the Kings (LLTK) and the Pacific Salmon Foundation launched the Salish Sea Marine Survival Project: an interdisciplinary US-Canada research collaboration to determine the causes of poor juvenile Chinook, coho, and steelhead survival in the Salish Sea. Four years later, over 200 scientists representing multiple disciplines are engaged; more than 80 studies have been initiated; and 18 articles have been accepted for publication in peer-reviewed journals. This presentation provides an overview of Salish Sea Marine Survival project findings and ongoing research focused on Puget Sound steelhead. Although most (80%) Washington, Oregon, and British Columbia steelhead populations declined in abundance during the mid-1980s, Salish Sea populations experienced the most severe declines and their survival patterns are distinct from coastal and lower Columbia River populations. Juvenile steelhead experience high mortality within Puget Sound: across 13 populations studied from 2006-2009, less than 20% of steelhead entering Puget Sound waters survived to the ocean. Early mortality is driven more strongly by processes in the lower river and marine waters than by intrinsic effects of population or freshwater-rearing. In some Puget Sound estuaries, the parasite *Nanophyetus salmincola* is present at levels that may reduce swimming performance or directly cause mortality. Contaminants in the Nisqually River also negatively impact steelhead health. Compromised fish may be more susceptible to predation, which is likely the immediate cause of most juvenile steelhead mortality within Puget Sound. Harbor seal populations in Puget Sound have nearly tripled since the 1980s, and scat analyses indicate seal predation on juvenile steelhead. Other potential steelhead predators include harbor porpoises and cormorants. Over the past three years, early marine survival of Puget Sound steelhead has more than doubled, spurring new research around predation dynamics and factors that may mitigate or exacerbate predation on steelhead populations.

**Using salmon to sample the Salish Sea: diets of recreationally harvested Chinook and Coho Salmon as an ecosystem monitoring tool**

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In addition to their economic, social and cultural importance, Chinook and Coho Salmon are key players in the Salish Sea ecosystem. They are at times dominant predatory fish in epipelagic waters and are important prey for marine mammals. Chinook Salmon in particular are critically important as the primary prey of the endangered Southern Resident Killer Whales. An extensive body of recent and current research has investigated declining juvenile marine survival of these species. Surprisingly, data on the diets of adult Chinook and Coho Salmon in the Canadian Salish Sea (Straits of Georgia and Juan de Fuca) are sparse, with no published work since the 1980s and a total lack of information on winter diets. We are seeking, in partnership with recreational anglers, to develop a low-cost, ongoing program to sample Chinook and Coho Salmon diets throughout the year from around the Canadian Salish Sea. We report results of our pilot year (2017) which indicate regional and seasonal variation in Chinook Salmon diet and corroborate recent observations of forage fish dynamics. This program has the potential to complement existing and future fishery-independent surveys in elucidating natural and anthropogenic changes in the Salish Sea.

**Sockeye salmon (*Oncorhynchus nerka*) smolt migration patterns through coastal British Columbia assessed by acoustic telemetry**

**Stephen D. Johnston[1]**, Scott G. Hinch[2], Christine F. Stevenson[2], Andrew G. Lotto[2], Nathan B. Furey[2], David W. Welch[3], Erin L. Rechinsky [3], Aswea D. Porter[3]

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Sockeye salmon (*Oncorhynchus nerka*) smolts originating from the Fraser River migrate north 170 km to the Discovery Islands (DI) where they need to utilize one of three major migratory routes (Discovery Passage (DP), Sutil Channel (SC), and Desolation Sound (DS)) to reach the open Pacific Ocean. To investigate marine routes that Fraser River smolts take during their coastal migration, 58 individuals were captured in the DI, surgically implanted with VEMCO V4 (180 kHz) tags, then transported and released ~17-km south the DI subarrays. This study is the first to capture, tag, and release sockeye salmon smolts with acoustic transmitters exclusively in a marine environment. An additional 303 individuals implanted with either V4 or V7 (69 kHz) tags were released at Chilko Lake, 840 km from the marine release site. Segment-specific apparent survival (AS) of marine and river released smolts (n= 101) was 56.4% from DI subarrays to Johnstone Strait (JS) subarrays (106 km), where all corridors converge and is 140 km from the open ocean. Smolts that experienced DP (n = 32) averaged 1.92 $\pm$ 0.71 days to reach the JS subarrays, travelled at 40.3 $\pm$ 13.23 km $d^{-1}$, and route-specific AS rate was 72% per day. Smolts that selected the SC route (n = 49), experienced an AS rate of 85% per day and averaged 5.28 $\pm$ 2.09 days to reach JS subarrays, travelling at 23.6 $\pm$ 10.93 km $d^{-1}$. DS was the least selected route (n = 14), with an AS rate of 94% per day, mean travel time was 12.14 $\pm$ 6.74 days, and smolts averaged 12.84 $\pm$ 6.87 km $d^{-1}$. This study presents the variability in sockeye smolt migration patterns among routes and has highlighted the potential increased rate of migration with specific route selection, which has the potential to increase survival along this migration segment.

**Fine-scale migration dynamics of juvenile salmon in the Discovery Islands of British Columbia**

**Brett T. Johnson[1]**, Chrys Neville[3], Brian P. V. Hunt[2,1,4]

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Juvenile sockeye salmon move through nearshore coastal habitats during the early marine phase of their migration. Whether certain sockeye stocks, age or size classes are segregated horizontally or vertically through these habitats is poorly understood but has important ecological implications. For example, fine-scale migration dynamics may affect foraging conditions, competitive interactions, predator encounter rates, and interactions with aquaculture facilities. Fine-scale migration dynamics may also affect representativeness of juvenile salmon sampling, which may in turn bias interpretation of early life history and fish health reporting. To investigate this we compare seine catch data from two different vessels capable of accessing different habitats in Okisollo channel in the Discovery Islands (British Columbia). A 300 m by 20 m purse seine was set in waters greater than 30 m deep and a 46 m by 9 m net was set in waters greater than 10 m deep to collect juvenile salmon. We used genetic stock ID to estimate catch proportions of sockeye from different watersheds and measured stock specific length frequencies. Chilko Lake sockeye dominated the catch in both habitats though the proportion caught in shallow water was less (22.4%) than in deep water (37%). Stellako River sockeye catch proportion was greater in deep water (17.8%) compared to shallow water (2.6%). Sockeye caught in deeper waters were on average 9.2 mm longer (95 % CI: 2.1 mm – 16.3 mm) than fish caught during the same week in shallow waters (paired t-test, $t = 3.01$, df = 7, $p < 0.2$). These results suggest that fine-scale habitat segregation occurs as a function of fish length which varies between stocks and life histories, and that to obtain a representative sample, integration of samples across habitats is required. Finally, we discuss potential ecological implications of these findings in our study area.

## SESSION IV: Growth and Survival

### Multivariate time series analysis to evaluate trends in marine survival across multiple species

**Kathryn Sobocinski[1,2]**, Correigh Greene[1], Eric Ward[1]

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Recent work on marine survival in Chinook and coho salmon and steelhead trout has shown a decline in marine survival in the Salish Sea that was not evident in coastal regions. For Chinook, the decline was not explained well by oceanographic patterns, and for coho, regional-scale indicators were suggested as important in understanding survival. Recent work on the development of indicators of Puget Sound steelhead survival has shown that predator abundance and patterns in hatchery releases, as well as oceanographic conditions, are informative in predicting marine survival. While the three species of focus for the Salish Sea Marine Survival Project have different life-histories, and are therefore subjected to variable pressures at multiple scales, this current analysis aims to answer three questions: 1.) Are there similarities in survival trends among the three species? 2.) Do regional patterns in survival emerge when survival trends are evaluated concurrently across the three species? 3.) Does release strategy (timing and size) of hatchery fish confer a survival advantage, and if so, is this consistent across all species? To evaluate survival time series, we used multivariate time series analysis with multiple groupings (species, spatial, and release strategy) to identify commonalities among species. Observed commonalities will aid in the development of indicators of survival for coho and Chinook by focusing efforts on appropriate spatial or temporal attributes. A hypothesis-driven approach similar to that recently employed for the development of indicators of steelhead survival will be used to relate coho and Chinook to environmental, biological, and anthropogenic factors determining survival for Salish Sea populations.

**Using Scale Analysis to Estimate Early Marine Growth: A Biological Indicator for Forecasting Salmon Survival**

**Andrew Claiborne[1]**, Lance Campbell[1], Joe Anderson[1], Marisa Litz[1], and James Losee[1]

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In this study, we used scale analysis of returning adults to examine the relationship between early marine growth and survival for three Puget Sound and two coastal populations of Chinook salmon (*Oncorhynchus tshawytscha*). In total, we examined scales from 2,603 individuals over 7 outmigration years characterized by relatively poor, average, and good survival from 1976 to 2008. We observed no evidence of a relationship between growth and survival for fish returning to the north Washington coast (Quillayute River). However, we observed a positive relationship between growth during the first year at sea and survival for adults returning to the Skagit, Green/Duwamish, and Puyallup Rivers. In addition, we examined the utility early marine growth as a biological indicator of marine survival for Chinook salmon originating from Tumwater Falls hatchery on the Deschutes River in Puget Sound. A forecasting model using early marine growth of the earliest returning hatchery fish (age $2_1$) was used to estimate total adult returns, and performed better then sibling and recent year average approaches. These results support previous research that factors influencing early marine growth (i.e. prey abundance and quality) are important to the survival of Puget Sound Chinook salmon. In addition, early marine growth may be a useful biological indicator for pre-season forecasting of some Chinook salmon populations in Puget Sound.

**Growth and survival of coho salmon are related in the Northern California Current: sometimes**

**Brian Beckman[1],** Cheryl A. Morgan[2], and Meredith Journey[1]

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Coho salmon have a relatively simple marine life history, juveniles enter the ocean in the spring at 1.5 years of age and adults return to freshwater in the fall after 18 months of marine rearing at age 3. As such, it is relatively easy to identify years in which differences in ocean conditions may have led to variation in marine survival of these fish. A long-standing hypothesis suggests that variation in marine survival of coho salmon is related to marine growth of juveniles soon after ocean entry. We have tested this hypothesis by measuring growth of juvenile salmon in June, soon after ocean entry, in a ocean survey conducted off the Oregon/Washington Coast since 2000 (2000 – 2017). In this presentation we report on juvenile abundance, juvenile growth and adult coho salmon returns over this time period. In addition, we examine relationships between these salmon metrics and common ocean indices, including temperature, up-welling, sea level height, PDO and NPGO. We report on a disruption of previous relationships between PDO, growth and survival of coho salmon in the years 2014 – 2015. In particular, we found abundant food resources and high growth of juvenile salmon during and after the blob, an unexpected result during periods of warm ocean temperatures.

**Salmon and people in a changing world: Introducing the International Year of the Salmon**

**Madeline Young** and Mark Saunders

North Pacific Anadromous Fish Commission, Suite 502, West Pender Street, Vancouver, BC, Canada V6C 3B2

Wild salmon face enormous challenges as they migrate from rivers and estuaries of the Northern Hemisphere to the global ocean and back. With increasing social and environmental change, an effort beyond the capacity of any one group or country is needed to raise awareness, address knowledge gaps, and find new approaches to conservation and management. The International Year of the Salmon (IYS) is a multiyear hemispheric-wide partnership to catalyze and intense burst of outreach and research on salmon led by the North Pacific Anadromous Fish Commission (NPAFC) and the North Atlantic Salmon Conservation Organization (NASCO). The target year for research and outreach is 2019, with some activities beginning before and others continuing through to 2023. To affect real change and ensure a shared future for salmon and people, we aim to separate the high-level aspirational goal of the IYS—*'salmon and people are resilient in a changing world'*—from those that we can measurably achieve through our collective actions. Teams of experts will be brought together under each IYS theme (status of salmon, salmon in a changing salmosphere, new frontiers, human dimension, information systems and outreach and communication) to consider innovative ideas for projects that will bring about measurable change. One exciting telemetry concept, termed "ROAM" proposes to use existing SOFAR (Sound Fixing and Ranging) technology in reverse to track salmon through the majority of their marine migration. Another example project, dubbed "Salmon Connections" aims to quantitatively describe and predict salmon production in the ocean within a model framework that will facilitate regional comparisons between and within oceans. Scoping workshops for these innovative ideas are planned for March and May 2018, respectively. Beyond these targeted outreach and research projects, there is something for everyone in the IYS. The IYS aspires to bring together youth, Indigenous Peoples, researchers, fishermen, managers, policymakers, and the interested public to collaborate at the local, regional, and hemispheric levels to make a difference for salmon and people in a changing world.

## Thursday, March 1st

**Puddles (keynote)**

**Skip McKinnell[1,2]**

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That we are convening the 19th Annual Salmon Ocean Ecology Meeting is unremarkable as you can only learn so much by focusing attention on your favourite river or estuary before you need to look up to see what is happening around you. The SOEM and the regional-scale research that it facilitates has become the primary forum for that dialogue. In my own work, the regional context of the SOEM was at least partly responsible for the work of Meredith Journey and colleagues; allowing them to get the data to test the Trophic Gauntlet Hypothesis although they probably didn't set out with that in mind. They discovered that there is a part of the ocean where salmon go hungry. Are there more? This talk will splash around in a few of the bigger puddles of the SOEM's history with an eye trained down the road for the next big one to really get your boots wet. Keep on forecasting.

**Moving forward in a sea of studies on salmon ocean ecology (keynote)**

**Elizabeth M. Phillips[1]**

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Research over the last two decades has provided valuable insights on spatial distributions, movement patterns, diet, and growth of salmon while at sea. The demonstrated influence of ocean conditions on salmon survival highlights the interdisciplinary nature of salmon ocean ecology research. Much of this work comes from successful collaborations between fisheries scientists and resource managers, researchers at academic institutions, and groups working across state and national borders. Despite these significant advances, many questions about salmon ocean ecology remain unanswered. In my view, species interactions, including competition and predation, and the population-level impacts of these ecological relationships require further work. Multidisciplinary research approaches that integrate technologies and long-term datasets are also critical to the understanding and management of salmon during their marine phase. I will use my research experiences to demonstrate the types of collaborative projects that can contribute to and advance knowledge and understanding of salmon ocean ecology. I hope that my perspective will stimulate discussions of current and future research projects and collaborations that will contribute to salmon and ecosystem management goals.

## SESSION V: Salmon Management

### Using Genetic Stock Identification Data to Improve the Science and Management of the West Coast Chinook Troll Salmon Fishery

**Gil Sylvia**[1] and Michael Banks[1]

Coastal Oregon Marine Experiment Station, Oregon State University, Hatfield Marine Science Center, Newport, Oregon

Since 2006, Project CROOS (Collaborative Research on Oregon Ocean Salmon) and the West Coast Salmon GSI (Genetic Stock Identification) projects have conducted comprehensive research to understand West coast Chinook salmon migration behavior and to find approaches that would help industry target strong Chinook stocks while reducing bycatch of weak stocks. This collaboration has included salmon troll fishermen, agency scientists and managers, and universities in California, Oregon, and Washington. A unique feature of the project are partnerships and contracts with more than 200 fishermen in collecting fine scale temporal and spatial data. The genetic, fisheries, and oceanographic data are shared and housed in an integrated data base and accessed through a variety of portals depending on the use and required permissions. Data has been used to understand migration patterns of different stocks as well as fishing behavior across both large scale and fine scale space and time. The focus of this presentation will ongoing development of visualization and analytical techniques and recent research on 1) variability of stock patterns in relating to oceanographic conditions, 2) comparison of stock patterns using GSI data compared to coded wire tag data, and 3) bioeconomic analysis using coded wire tag and GSI data. The presentation will conclude with a discussion of planned future work including development and testing of salmon fishery management portals and evaluating application for in-season management.

**Tracking the status of salmon populations and their habitats in British Columbia using the Pacific Salmon Explorer**

**Eric Hertz[1]**, K. Connors[1], E. Jones[1], L. Honka[1], K. Kellock[1], and B. Riddell[1]

[1]Salmon Watersheds Program - Pacific Salmon Foundation, #300-1682 West 7th Ave, Vancouver, BC V6J 4S6

Salmon play an important role in the economy, ecology and culture of the west coast of North America. However, the lack of centralized, standardized, and easily accessible data on the state of salmon populations, and threats to them, impedes efforts to make informed, transparent, and evidenced-based management and conservation decisions. In an effort to provide broader public understanding of salmon data in British Columbia (BC), the Pacific Salmon Foundation has embarked on a major initiative to synthesize, and make openly available, the best available information on salmon populations and their freshwater habitats in BC. Drawing upon these experiences, we illustrate how government datasets can be used to monitor and assess the state of salmon populations and their habitats. We provide open, standardized, and reproducible information on a suite of indicators of salmon population condition including estimates of freshwater production, spawner abundance, harvest, trends in abundance, run-timing, population productivity, and assessments of biological status. This biological information is coupled with remote-sensed data that is used to quantify cumulative pressures on freshwater salmon habitats. All of this information is made available to the public through the Pacific Salmon Explorer (www.salmonexplorer.ca), an online data visualization tool that allows users to explore salmon-related information through a series of interactive maps and figures, as well as download source datasets. While initially developed for northern and central BC, the PSF is now scaling the Pacific Salmon Explorer up to all salmon-bearing watersheds in BC. Our novel approach provides a synoptic overview of the status of salmon populations and their habitats in BC, and highlights areas where data gaps exist and where more research is needed.

**Experimental capture and handling of chum salmon elucidates genomic responses and physiological thresholds to inform best practices for improving bycatch survival in purse seine fisheries**

**Katrina V. Cook[1]**, Scott G. Hinch[1], Maryann S. Watson[2], David A. Patterson[3], Kristi M. Miller[4], Andrea J. Reid[5], Steve J. Cooke[5]

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Identifying how different components of capture influence the condition of released fish can help in developing more specific guidelines and best handling practices. Using an experimental approach, we modified the severity of capture stressors in commercial purse seine fisheries for Pacific salmon, and monitored indices of injury and reflex impairment in chum salmon (*Oncorhynchus keta*), a species commonly released from these fisheries. Study fish were held for 5 or 10 days to observe the latent effects of capture. Modeling of changes in injury and reflex impairment sought to disentangle the relative effects of modified capture stressors to individual physiology and the role of sex and maturity. Thresholds in physiological responses to time pursed in the net and air exposed on deck were also evaluated. Injury progressed during holding, was more extensive in females, and accelerated faster in less mature fish. Blood indicators of stress and exhaustion revealed physiological thresholds in response to capture stressors. Analyses of the temporal variation in expression of stress and immune genes reveal that injury sustained during capture can have lasting effects to individual health and condition.

## SESSION VI: General Contributions I

### An update on the Newport Hydrographic Line and Ocean Indicators as Predictors of Salmon Returns

**Kym C. Jacobson[1]**, Jennifer L. Fisher[2], Samantha M. Zeman[2], Jesse F. Lamb[3], Brian J. Burke[4], Cheryl A. Morgan[2], William T. Peterson[1]

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At the 2010 Salmon Ocean Ecology Meeting in sunny Santa Cruz, Bill Peterson first introduced new ecosystem indicators for salmon returns from bi-weekly collections of zooplankton on the Newport Hydrographic Line (NH line). Since then, the May-Sept copepod species richness anomalies and northern and southern copepod species biomass anomalies have been among the 16 basin-scale, regional, and local ecosystem indicators in our stop light chart. These metrics have also been important in models used to predict annual salmon returns to the Columbia River Basin. In this talk, we provide an update on the NH line ecosystem indicators, the stop light chart, and recent model predictions for salmon returns to the Pacific Northwest. Our data suggests that the anomalously warm ocean conditions that persisted on the shelf off the Pacific Northwest from fall 2014 through spring 2017 have dissipated, but may continue to impact Pacific Northwest salmon returns for several years.

**Effects of harbour seal predation and hatchery competition on the productivity of Chinook salmon in the Pacific Northwest**

**<u>Benjamin Nelson</u>**, Carl J. Walters, Andrew W. Trites, Murdoch K. McAllister

University of British Columbia

Predation risk and competition among conspecifics significantly affect survival of juvenile salmon, but are rarely incorporated into models that predict recruitment in salmon populations. Using densities of harbour seals (*Phoca vitulina*) and numbers of hatchery-released smolts as covariates in spatially-structured Bayesian hierarchical stock-recruitment models, we found significant negative correlations between seal densities and productivity of Chinook salmon (*Oncorhynchus tshawytscha*) for 14 of 20 Chinook populations in the Pacific Northwest. We also estimated that changes in numbers of seals since the 1970s were associated with a 74% decrease (95% CI: -85%, -64%) in maximum sustainable yield in Chinook stocks. Hatchery releases were significantly correlated with Chinook productivity in only one of 20 populations. Changes in the abundance of hatchery smolts since the 1970s were associated with an average increase in maximum sustainable yield of 9% (95% CI: -6%, 25%). Our findings are consistent with recent research on predator diets and bioenergetics modeling that suggest harbour seal predation on Chinook smolts are linked to significant reductions in marine survival in parts of the eastern Pacific. Forecasting, assessment, and recovery efforts for salmon populations of high conservation concern should thus consider including biotic factors, particularly predator-prey interactions.

**Individual variation and population-specific strategies shape juvenile sockeye salmon migration phenologies**

**Cameron Freshwater[1,2]**, Marc Trudel[1,2,3], Terry D. Beacham[2], Stéphane Gauthier[4], Stewart C. Johnson[2], Chrys-Ellen Neville[2], and Francis Juanes[1]

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Migration phenology can influence individual fitness, moderate population dynamics, and regulate the availability of ecosystem services to other trophic levels. Phenology varies within and among populations, and can be influenced by conditions individuals experience both prior to departure and encounter en route. Yet studies that assess how intrinsic and extrinsic factors interact to influence variation in migratory phenologies across ecological scales are limited due to logistical constraints associated with tracking large numbers of individuals from multiple populations. We used two natural tags, DNA and otolith microstructure analysis, to estimate the relative influence of individual traits (life history strategy, body size at departure, and growth during migration), population-specific strategies, and interannual variability on the phenology of marine migrations in juvenile sockeye salmon *Oncorhynchus nerka*. We show that the timing and duration of juvenile sockeye salmon migrations were correlated with both life history strategy and body size, while migration duration was also correlated with departure timing and growth rates during migration. Even after accounting for the effect of individual traits, several populations exhibited distinct migration phenologies. Finally, we observed substantial interannual and residual variation, suggesting stochastic environmental conditions moderate the influence of carry-over effects and population-specific strategies. Given evidence that intraspecific diversity can stabilize ecological systems, conservation efforts should maintain migratory variation among populations by preserving locally adapted phenotypes, while also regularly assessing variation within populations, which may buffer systems from environmental stochasticity.

**Integrated biogeochemical approaches to full salmon life history analysis**

**Brian P. V. Hunt[1,2,3]**, Boris Espinasse[1,3], Evgeny A. Pakhomov[1,2,3]; Wade D. Smith[1,2]

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A growing suite of biogeochemical methods is making it increasingly possible to retrieve detailed information on salmon life history across a wide range of spatial and temporal scales. In this paper we outline available methodologies, drawing on case studies from British Columbia that apply biogeochemical approaches to inform feeding biology, nutritional health, and migration dynamics of salmon across all life history phases. Bulk and compound specific analysis of tissue carbon and nitrogen stable isotopes provide insights into trophic level, niche width, and the organic matter sources that underpin salmon food webs. Soft tissues turnover rates confer a time integration of approximately 1-6 months, while hard tissues (otoliths, scales and bones) can be used to interpret trophic ecology over the lifespan of a fish. These interpretations of trophic ecology are complemented by analysis of fatty acids, which has the additional value of informing prey quality and fish nutritional status. The suitability of hard tissues for stable isotope analysis makes possible the reconstruction of long-term records of trophic ecology using sample archives collected by aging laboratories; while correlations of carbon, nitrogen and oxygen isotopes with environmental parameters can be used to provide insights into high seas distribution patterns. Finally, analysis of trace elements in otoliths using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) provides a powerful tool for analyzing migration dynamics through elemental signatures of coastal to offshore habitat.

## SESSION VII: General Contributions II

### Trophic relationships among juvenile salmon during cool and warm periods in Southeast Alaska

**<u>Emily Fergusson</u>**, Jim Murphy, and Todd Miller

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Marine growth and survival of juvenile Pacific salmon (*Oncorhynchus* spp.) has been linked to marine temperatures and feeding conditions during their first few months in the ocean. Evidence from the Bering Sea, Prince William Sound, and Southeast Alaska (SEAK) suggest that the juvenile salmon prey community is responsive to environmental change, and that these changes are reflected in their species richness, abundance, and nutritional quality. Therefore, understanding what salmon consume under varying environmental conditions is important to understanding how their growth and survival is affected by climate change. For over 20 years, the Alaska Fisheries Science Center has been monitoring seawater temperatures, zooplankton abundance, and the diets of juvenile salmon in Icy Strait, AK, a major fish migration corridor in northern SEAK. Here, we used multivariate statistical methods to examine how the diets of juvenile pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) salmon in Icy Strait responded to shifts in seawater temperature and zooplankton abundance during the summer months of 2013-2017. During this five-year period, water temperatures shifted from a cool phase in 2013 to a warm phase in 2014-2016, then back to a cool phase in 2017. Overall, the diet composition and prey diversity varied within and between zooplanktivorous (pink, chum, sockeye) and piscivorous (coho) salmon species, with the exception of 2015 which showed euphausiids as the overwhelmingly dominant prey in all four species. The dominance of euphausiids in 2015 was also observed in zooplankton samples, showing their overall presence in the system at that time. In other years, pink, chum, and sockeye salmon consumed more gastropods, hyperiids, and gelatinous-bodied prey while coho consumed mainly decapod and fish larvae. The results of this study underscore the importance of incorporating trophic measures into long-term monitoring of pelagic ecosystems.

**Characterizing the diets of juvenile Fraser River sockeye salmon across ocean regimes in coastal British Columbia**

**Samantha E. James**, Evgeny A. Pakhomov, Brian P. V. Hunt

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Fraser River sockeye salmon (*Oncorhynchus nerka*) have experienced declines in productivity since the early 1990's. It is believed that conditions experienced during the early marine phase are a contributing factor. Juvenile sockeye salmon migrate from the Fraser River through the Strait of Georgia, the Discovery Islands and Johnstone Strait before they reach Queen Charlotte Sound, and continue north to the Gulf of Alaska. It has been hypothesized that the well-mixed waters of Johnstone Strait could be prey-limited, acting as a 'trophic gauntlet' for out-migrating juvenile salmon. The aim of this research is to test this hypothesis, while also comparing the diets in Johnstone Strait to those in a different oceanographic environment, the Discovery Islands. Samples were collected in 2015 through purse-seine surveys conducted from May to July as part of the Hakai Institute's Juvenile Salmon Program. Additional samples were taken in 2017 to characterize their diel feeding habits. Diets in the Discovery Islands consisted mainly of *Oikopleura* and smaller calanoid copepods (<2mm), while diets in Johnstone Strait consisted predominantly of calanoid copepods >2mm. The Stomach Fullness Index was highest at the most southern and northern sampling sites, suggesting higher quantity of prey in the northern Strait of Georgia and Queen Charlotte Strait. Furthermore, the low fullness index (<1%) within the Discovery Islands and Johnstone Strait suggests that juvenile sockeye may have been prey-limited in these areas. Juvenile sockeye salmon were found to have fuller stomachs in the late afternoon, with the lowest fullness observed in the early morning. Our initial results support the trophic gauntlet hypothesis and illustrate the spatial variability of sockeye salmon diets across this region of their out migration. These data can be used to shape our understanding of factors driving growth and survival during the early marine phase, and ultimately the productivity of Fraser River stocks.

**Historical variation in condition-at-age of returning Sockeye Salmon (*Oncorhynchus nerka*) with climate and Pink Salmon abundance in two British Columbian rivers**

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There is mounting evidence that scale-dependent climate patterns significantly impact the marine growth and survival of salmon populations in the Pacific Ocean. Sockeye Salmon are influenced by inter and intraspecific interactions as well as environmental factors, however these effects are likely time and stock specific. To address the role of biotic and abiotic variables in determining salmon size, we used historical (1914-1943) data of length (mm), weight (g) and age of Sockeye Salmon from the Nass River and Rivers Inlet, British Columbia, Canada to examine how large-scale oceanographic conditions influence condition-at-age of returning Sockeye Salmon. These populations provide a useful comparison since Nass River Sockeye Salmon are still harvested commercially, while the Rivers Inlet stock collapsed in the mid-1990s. We used generalized additive mixed models to explore possible relationships between condition-at-age and three climatic variables: Pacific Decadal Oscillation (PDO), sea surface temperature (SST), and the Aleutian Low-Pressure index (ALPI), as well as competition with Pink Salmon. Preliminary results suggest a different response in condition-at-age to climate variables in the Nass and Rivers Inlet. The condition-at-age of the dominant age class of Nass River Sockeye Salmon (age 2.2) increased in response to increasing PDO values, and decreased in response to increasing ALPI scores. Conversely, condition-at-age of the dominant age class in Rivers Inlet (age 1.3) decreased in response to increases in both PDO and ALPI. Further exploration of the climatic and biotic forces influencing Sockeye Salmon in these two populations will contribute to the understanding of historic and future population trends.

**Impact of two anomalously warm years on juvenile steelhead diet composition and morphology in the northern California Current**

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Juvenile steelhead *(Oncorhynchus mykiss)* enter the northern California Current from the Columbia River and Northwest coastal rivers and include several populations listed under the US Endangered Species Act. However, relatively little is known about the response of these populations to interannual variability in ocean conditions. In 2015 and 2016, anomalous ocean conditions, called the warm 'Blob,' persisted in the northern California Current, increasing ocean temperatures by >2.5°C. To determine how steelhead respond to annual shifts in temperature, we compared juvenile steelhead diet composition, stomach fullness, size, and body condition across a 16 year time-series (2001-2016). This time-series included both the Blob-influenced years as well as other warm, cold, and average temperature years. Steelhead from 2015 and 2016 exhibited some of the poorest body conditions and largest sizes in the time-series. In contrast, steelhead from 2010, an El Nino-influenced warm year, exhibited unusually high body condition and stomach fullness, but were quite small. Steelhead diet composition varied between warm and cold years and between warm and average years, with steelhead consuming more insects, juvenile rockfish, and rare and unidentified fish in warm years. Unusual taxa were consumed in both 2015 (salps) and 2016 (juvenile smelts). These findings highlight the potential for warm ocean years to influence the diet composition and morphology of declining Columbia River steelhead populations and may lead to a better understanding of what affects survival of juvenile steelhead in the early marine residence.

**Spatial dietary patterns and feeding dynamics of juvenile spring Chinook salmon in the Northern California Current Ecosystem**

**Elizabeth A. Daly[1]** and Richard D. Brodeur[2]

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[2]Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Newport, Oregon

Yearling Chinook salmon primarily enter the ocean from the Columbia River in spring and migrate through coastal Washington and Oregon waters for several months. We looked at spatial diet differences to help us identify regions where key prey were eaten and any environmental linkages that might explain the patterns observed. Interannual changes in the diets in May and June were the strongest driver of diet change relative to any other factor examined, including ocean condition (cold, warm, El Niño), latitude, individual station, inshore/offshore distance, or hour of the day of sampling. Although interannual changes over the 19-year study period (1998-2016) had the strongest influence on variations in the diet community, diet changes in May were all stronger than in June. Location (based on bottom depth or latitude), temperature, hour of the day, and year were the top factors that related to diet composition changes of individual prey consumed. For example, rockfish were increasingly eaten by Chinook salmon in the years 2005-15, at stations with higher temperatures, and both south of the Columbia River and north of Grays Harbor Washington. Cottids were eaten more north of the Columbia River, and Pacific sandlance had decreased through time in the diets and were eaten more in the north of the study period in May and more in the mornings in June. Flatfish had increasingly been consumed during the study period. Stomach fullness of the salmon varied based on ocean condition, year, latitude, size of the salmon, time, and bottom depth in varying degrees. There were also spatial patterns to the salmon size and condition factor. Overall, salmon diets showed some spatial patterns as to where specific prey are consumed. Additionally, a few key prey have shifted in importance in the salmon diets during the study period, vary in accordance with ocean conditions.

## POSTER CONTRIBUTIONS

### Effects of Large Infrastructure on the Underwater Visual Environment and Heightened Predation on Salmon in the Salish Sea

**Dave Beauchamp**

USGS-Western Fisheries Research Center, Seattle

Most predatory fish, marine mammals, and birds that eat salmon rely primarily vision to feed. Natural processes and anthropogenic change affect visual conditions underwater which in turn profoundly affect the magnitude of predation risk on juvenile and adult salmon as well as forage fishes and other species in shoreline and pelagic environments. I will discuss the implications of how natural and anthropogenic changes in water transparency and artificial light pollution have significantly increased the predation threat environment for juvenile salmon in the Salish Sea and relate these to some of the major infrastructure projects in the Pacific Northwest. High levels of artificial light pollution are pervasive throughout Puget Sound and the southern portion of the Strait of Georgia. Over the past 30-40 years, increasing light pollution in Lake Washington, a useful surrogate for the greater Salish Sea, has expanded the peak twilight predation periods of juvenile salmon predators from just dusk and dawn to predation increasing throughout the night. Moreover, changing hydrology and water quality due to dams, climate, and land-water use have changed the magnitude, timing, and spatial patterns in water transparency from sediment plumes and plankton blooms. Collectively, these changes in underwater light penetration and transparency have fundamentally changed the predation environment with important implications for marine survival of salmon, functional sustainability of forage fish populations and the services they provide to the broader ecosystem.

**Using salmon to sample the Salish Sea: diets of recreationally harvested Chinook and Coho Salmon as an ecosystem monitoring tool**

William Duguid[1], Katie Innes[1], Jessica Qualley[1] and **Francis Juanes[1]**

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In addition to their economic, social and cultural importance, Chinook and Coho Salmon are key players in the Salish Sea ecosystem. They are at times dominant predatory fish in epipelagic waters and are important prey for marine mammals. Chinook Salmon in particular are critically important as the primary prey of the endangered Southern Resident Killer Whales. An extensive body of recent and current research has investigated declining juvenile marine survival of these species. Surprisingly, data on the diets of adult Chinook and Coho Salmon in the Canadian Salish Sea (Straits of Georgia and Juan de Fuca) are sparse, with no published work since the 1980s and a total lack of information on winter diets. We are seeking, in partnership with recreational anglers, to develop a low-cost, ongoing program to sample Chinook and Coho Salmon diets throughout the year from around the Canadian Salish Sea. We report results of our pilot year (2017) which indicate regional and seasonal variation in Chinook Salmon diet and corroborate recent observations of forage fish dynamics. This program has the potential to complement existing and future fishery-independent surveys in elucidating natural and anthropogenic changes in the Salish Sea.

**Recent change in the size of juvenile salmon in Southeast Alaska**

**James M. Murphy**, Emily A. Fergusson, and Andrew K. Gray

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The influence of both large- and regional-scale climate conditions on marine ecosystems in Southeast Alaska is reflected in the size and growth of juvenile salmon. Although there is significant concern over impacts of the warm, nutrient poor waters of the North Pacific Blob (2014-2016) on salmon, the average size and energetic condition of juvenile pink, chum, and coho salmon was significantly higher in 2015 and 2016 than the last 20 years of sampling as part of the Southeast Alaska Coastal Monitoring project. Approximately 81% of the annual variation in the size of juvenile pink salmon can be explained by a simple model of spring (May) phytoplankton and temperature (Icy Strait Temperature Index). The same model explains less variation in the size of chum (54%) and coho (45%) salmon. Hatchery rearing practices in chum salmon and freshwater growth of coho salmon may be additional factors that need to be considered in the variation of chum and coho salmon size. Selective feeding, particularly in coho salmon, may also introduce important variation in juvenile growth and size that is not matched to the overall productivity of the marine ecosystem. Primary production (May Chlorophyll-a levels) were significantly higher in 2015 than all other years sampled as part of the Southeast Alaska Coastal Monitoring project. The increase in primary production is believed to be the main factor contributing to the improved marine growth and condition of juveniles in 2015. Temperature increased significantly in inside waters in 2016 along with the Multivariate ENSO (El Nino Southern Oscillation) index. Although it is possible that the North Pacific Blob could also have contributed to the increase in temperatures during 2016, the warm temperatures are believed to be the primary factor contributing to improved growth and condition of juveniles in inside waters of Southeast Alaska in 2016.

**Historical variation in condition-at-age of returning Sockeye Salmon (*Oncorhynchus nerka*) with climate and Pink Salmon abundance in two British Columbian rivers**

**Jacob Weil[1]**, Cameron Freshwater[2], Angeleen M. Olson[3], Will Duguid[1], Skip McKinnell[4] and Francis Juanes[1]

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[3]Hakai Institute, Quadra Island Field Station, Hyacinth Bay Road, Quadra Island, BC, Canada.
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There is mounting evidence that scale-dependent climate patterns significantly impact the marine growth and survival of salmon populations in the Pacific Ocean. Sockeye Salmon are influenced by inter and intraspecific interactions as well as environmental factors, however these effects are likely time and stock specific. To address the role of biotic and abiotic variables in determining salmon size, we used historical (1914-1943) data of length (mm), weight (g) and age of Sockeye Salmon from the Nass River and Rivers Inlet, British Columbia, Canada to examine how large-scale oceanographic conditions influence condition-at-age of returning Sockeye Salmon. These populations provide a useful comparison since Nass River Sockeye Salmon are still harvested commercially, while the Rivers Inlet stock collapsed in the mid-1990s. We used generalized additive mixed models to explore possible relationships between condition-at-age and three climatic variables: Pacific Decadal Oscillation (PDO), sea surface temperature (SST), and the Aleutian Low-Pressure index (ALPI), as well as competition with Pink Salmon. Preliminary results suggest a different response in condition-at-age to climate variables in the Nass and Rivers Inlet. The condition-at-age of the dominant age class of Nass River Sockeye Salmon (age 2.2) increased in response to increasing PDO values, and decreased in response to increasing ALPI scores. Conversely, condition-at-age of the dominant age class in Rivers Inlet (age 1.3) decreased in response to increases in both PDO and ALPI. Further exploration of the climatic and biotic forces influencing Sockeye Salmon in these two populations will contribute to the understanding of historic and future population trends.

**Estuarine pathways of juvenile Chinook salmon in the Columbia River**

**Katherine J. Morrice[1]** and António M. Baptista[1]

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Understanding the extent to which juveniles depend on estuarine habitats is important for conservation, management, and restoration efforts of Columbia River salmon. To address gaps in knowledge of time of residence and patterns of migration of juveniles, we developed and are exploring an Individual Based Model (IBM). The model relies on pre-existing high-resolution simulations of 3D estuarine circulation and on pre-existing characterizations of estuarine habitat (some empirical and some derived from the circulation simulations). The IBM has three main modules: hydraulic transport, fish movement, and bioenergetics. Hydraulic transport involves rigorous numerical tracking of passive particles along 3D simulated flows. Both advection and diffusion are accounted for, and the governing equations are formally derived and well established, with empirical parameterization limited primarily to friction and turbulent mixing. Besides hydraulic transport, fish move in response to behavioral decisions. Multiple behaviors can be explored in the model, including random walks, orientation to positive habitat indicators (e.g., salmon habitat and vegetation cover), and state-based behaviors. The Wisconsin bioenergetics model is used to compute growth of individuals over time, providing an informative link between the individual's physical environment and its growth. We are currently using the model to explore and contrast the estuarine pathways of stream-type and ocean-type juveniles. Preliminary results highlight differences in the extent of habitat and amount of growth experienced. We find river discharge and tides to be strong drivers of estuarine pathways. However, water temperature and the frequency with which salmon occupy regions of optimal habitat are strong drivers of growth. Field data are being compiled for model-data comparisons and to validate and enhance the model.

**Potential effects of salmon shark predation mortality to Chinook salmon productivity in the Bering Sea**

**Kaitlyn A. Manishin**, Peter A.H. Westley, Curry J. Cunningham, Kenneth J. Goldman, and Andrew C. Seitz

Chinook salmon (*Oncorhynchus tshawytscha*) in the Arctic-Yukon-Kuskokwim region are both culturally and ecologically important and their populations have been depressed since 1998. Spawning Chinook salmon also have demonstrated decreases in age-at-maturity and size-at-age. The concurrent decline of several Chinook salmon stocks across the large geographic area of western Alaska, as well as changing life history traits, suggest that the marine environment plays an important role in Chinook salmon productivity and abundance. One potential cause of these perturbations in the abundance as well as size and age structure of this species is increasing marine mortality risk for older life stages. Electronic tags indicate that a considerable proportion of this mortality may be caused salmon shark (*Lamna ditropis*) predation. To understand the role of this predation, we are attempting to elucidate the amount and selectivity of late stage marine mortality required to affect the productivity of Chinook salmon populations. As a first step toward addressing this, we estimated the total annual consumption of prey, including Chinook salmon, by individual salmon sharks. Here, we present preliminary results of an examination of the potential impacts of late stage marine mortality on the productivity of Chinook salmon stocks, using simulation studies with a stage-structured population dynamics model. Finally, to synthesize this ecosystem information, I compare the estimated consumption requirements of salmon sharks and simulated levels of late stage mortality required to alter the abundance and age distribution of a Chinook salmon population.

**Reexamining an assumption about marine mortality of Chinook salmon**

**<u>Andrew C Seitz</u>**, Michael B Courtney, Kaitlyn A. Manishin, Curry J. Cunningham, Peter Westley

It has become dogma that processes in the nearshore environment during the early marine phase of Pacific salmon life history largely govern adult population dynamics. As a corollary, it is widely assumed that the risk of mortality decreases dramatically after the first winter in the ocean, the marine environment is relatively safe thereafter, and that effects in this 'late' marine stage have minimal impacts on population characteristics, including dynamics and life history traits. However, recent evidence of concurrent declines in size-at-age and age-at-maturity, as well as lower-than-predicted returns of older adults suggest that late-stage, potentially selective, marine mortality may be more frequent than currently assumed. To examine this 'late-stage' selective mortality hypothesis, we examined evidence of predation on large Chinook salmon from recent satellite tagging research. Diagnostic evidence of predation was revealed from depth, temperature and light records collected by the satellite tags. Taken as a whole, these data suggest that predation on relatively large adult Chinook salmon by "warm-blooded" and "cold-blooded" predators may be relatively common. These results indicate the need to further investigate late-stage marine mortality of Chinook salmon and its possible effects on the population dynamics and life history characteristics of this species, and Pacific salmon more generally.