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Abstracts

Listed by last name of the presenting speaker:

Growth of Bristol Bay and Yukon River, Alaska chum salmon in relation to climatic factors and inter-specific competition

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Questions remain about how ocean climate shifts influence salmon survival and abundance. Recent studies have documented trends toward smaller adult salmon, but these questions are difficult to examine because sampling salmon at sea is difficult and few long-term time series exist. We present results of recent studies designed to test hypotheses related to how climatic factors affect growth of chum salmon in western Alaska and whether interactions with Russian pink and Asian chum salmon have affected the growth of these salmon. We created indices of growth for age 0.3 and 0.4 Bristol Bay and Yukon River chum salmon by year (mid-1960s-2006) by measuring annual growth. We examined the relationship between growth and sea surface temperature (SST) as well as the effect of Russian pink and Asian chum salmon abundance on growth. Generalized linear modeling indicated a significant positive correlation of the Aleutian Low Pressure

Index and SST on the first year of growth and a negative correlation of SST, Russian pink salmon abundance, and Asian chum salmon abundance on the third year of growth for Yukon River fish. We found a positive correlation of SST on the first year of growth and a negative correlation of pink and Asian chum salmon abundance and SST on the third year of growth for Bristol Bay chum salmon. Use of a general additive model yielded similar results. These studies provide examples of how scale measurements can be used to reconstruct salmon growth trends in the ocean to test problematic hypotheses.

The poor return of sockeye salmon to the Fraser River in 2009 resulted from exceptionally poor survival in the early marine period

R. Beamish, R. Sweeting, C. Neville, R. Thomson and D. Preikshot

In 2007 there was an exceptionally large number of sockeye salmon smolts produced in the Fraser River drainage. When these juveniles entered the Strait of Georgia, they experienced extremely unfavourable rearing conditions that affected all other juvenile Pacific salmon and young-of-the-year Pacific herring. Juvenile coho and chinook salmon that survived to mid July had poor growth and a high percentage of empty stomachs. Adult coho salmon returning in the next year (2008) had the poorest marine survival on record. Catches of juvenile chum salmon in 2007 were the smallest in the 11 years of surveys and the adult returns in 2010 were exceptionally poor. Age 0+ Pacific herring survived very poorly and had the lowest abundance in the 14 years of surveys. The resulting recruitment to the fishery in the Strait of Georgia was very poor. An estimate of juvenile sockeye salmon abundance in mid July 2007 indicated that only approximately 3.9% of the smolts produced in fresh water had survived. The synchronous response of all juvenile Pacific salmon and Pacific herring indicates that prey abundances in the Strait of Georgia in the spring of 2007 were exceptionally low. Thus, the exceptionally poor return of sockeye salmon in 2009 most likely resulted from exceptionally poor early marine survival in the Strait of Georgia in 2007.

Winter Ichthyoplankton Biomass: Predictor of Summer Prey Fields and Ultimate Survival of Juvenile Salmon?

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Summer diets of juvenile coho and Chinook salmon are primarily made up of late-larval and early-juvenile winter-spawning fish taxa that are undersampled in plankton nets and large fish, so we have no measurements of the availability of these prey to juvenile

salmon. We investigated whether the biomass of fish larvae in the winter and early spring could serve as a proxy for the spring-summer biomass of juveniles to create an index of food available to young salmon. We examined winter (January-March) ichthyoplankton abundance estimates from the Newport Oregon Hydrographic line from 1998-2010 as a potential indicator of future feeding conditions for young salmon in the marine environment. The proportion of the total ichthyoplankton biomass that are considered common salmon prey fluctuated from a low of 13.9% in 2006 to 95.0% in 2000. The relationship between the abundance of fish larvae in winter and subsequent coho salmon survival based on the Oregon production index (OPI) was found to be highly significant ($r^2 = 76.0$, $p = 0.002$). This relationship was positive although not significant for spring Chinook salmon ($r^2 = 23.0$, $p = 0.13$), but when we removed the outlier year 1999, the relationship improved significantly ($r^2 = 54.0$, $p = 0.02$). Finally, the relationship for fall Chinook salmon was positive and significant ($r^2 = 30.0$, $p = 0.03$). Annual winter larval fish composition showed high overlap with juvenile salmon summer diets during both May and June. Larval fishes appear to be a good indicator of ocean conditions and we believe they can be a useful and cost-effective performance indicator of future survival juvenile salmon, and can provide an early indicator of shifts in the availability of food resources for juvenile salmon.

Quantifying habitat correlates for salmon in coastal waters

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Marine survival of Pacific salmon is highly influenced by the physical and biological environment in coastal waters. Yet, predictions of salmon survival and spatial distribution are often tenuous due to the dynamic aspect of the coastal environment. Moreover, managing a migratory species like Pacific salmon is made more difficult by the transient nature of their habitat use. Expanding on previous analyses, we used generalized linear models to characterize habitats that are correlated with the presence of salmon to improve our understanding of how salmon respond to local cues during migration. We used catch data from an ongoing surface trawl survey (1998 through 2010; over 1000 trawls) along Washington and Oregon coastlines to model spring Chinook salmon habitat correlates. Input variables included water depth, secchi depth, salinity, chlorophyll a concentration, and water temperature. All of the environmental variables except salinity were highly significant in predicting our salmon catch (count) distribution. However, we found that spatial information was explicitly required in the model in order to predict the spatial distribution of salmon and we present multiple ways

of incorporating spatial information into the model. We also describe some model specifications, such as zero-inflation, that dramatically improved model fit.

Are post-smolts running on empty? - Migration and survival in the Atlantic

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Atlantic salmon (Salmo salar) spawning returns to Maine, USA, rivers continue to decline despite intensive restoration programs. Most management and research efforts have focused on freshwater life-stages and conservation of freshwater habitat. Little is known about the marine phase of post-smolts but recent work suggests a potential bottleneck at this life-stage. In this presentation, we use dynamic modeling to examine growth and survival of post-smolts as they migrate through the Gulf of Maine to the Scotian Shelf. We couple an ocean circulation model and a bioenergetics model to explore post-smolt energetic costs during this migration over observed ranges of hydrographic variability. The model can serve as a template on which we can layer other hypothesized factors (e.g., shifting predator and prey fields, climate change scenarios) to evaluate their relative importance, singularly or interactively.

Size-dependent Survival of Columbia River hatchery and naturally reared Chinook salmon (Oncorhynchus tshawytscha) during early marine residence: A PROPOSAL

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Although many aspects of their freshwater migration are now better understood, the mechanisms that regulate the survival of Chinook salmon (Oncorhynchus tshawytscha) during the marine phase are less clear. There is growing evidence that climate-induced changes in productivity and trophic processes (i.e. bottom-up and top-down) influence the success of a year class. In addition, it has been hypothesized that marine survival is largely determined during the first summer at sea and that predation-mortality shortly after fresh water emigration is related to the size and growth of migrants. Several studies have related larger size at fresh water emigration to the survival of adults; however it is not clear if, or when, size-dependent selection occurs. Otolith microstructure, microchemistry, and genetic stock identification have been used to determine origin and

stock-specific size and timing of fresh water emigration. Therefore, for my M.S. thesis I propose to use these methodologies developed in the Central Valley of California, British Columbia, and the CR basin to investigate size-dependent mortality in naturally and hatchery reared upper CR summer/fall individuals that emigrated in 2007 to 2010. I will examine fish collected at three time periods and locations: (1) the mouth of CR estuary during summer and in (2) June and (3) September during their first summer at sea off the coasts of Oregon and Washington to test if size-dependent mortality occurs over specific time-periods during the migrants first summer at sea.

Spatial and trophic overlap of marked and unmarked Columbia River Basin spring Chinook salmon during early marine residence with implications for competition between hatchery and naturally produced fish

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Ecological interactions between natural and hatchery juvenile salmon during their early marine residence, a time of high mortality, have received little attention. These interactions may negatively influence survival and hamper the ability of natural populations to recover. We examined the spatial distributions and size differences of both marked (hatchery) and unmarked (a high proportion of which are natural) juvenile Chinook salmon in the coastal waters of Oregon and Washington from May to June 1999-2009. We also explored potential trophic interactions and growth differences between unmarked and marked salmon. Overlap in spatial distribution between these groups was high, although catches of unmarked fish were low compared to those of marked hatchery salmon. Peak catches of hatchery fish occurred in May, while a prolonged migration of small unmarked salmon entered our study area toward the end of June. Hatchery salmon were consistently longer than unmarked Chinook salmon especially by June, but unmarked salmon had significantly greater body condition (based on length-weight residuals) for over half of the May sampling efforts. Both unmarked and marked fish ate similar types and amounts of prey for small (station) and large (month, year) scale comparisons, and feeding intensity and growth were not significantly different between the two groups. There were synchronous interannual fluctuations in catch, length, body condition, feeding intensity, and growth between unmarked and hatchery fish, suggesting that both groups were responding similarly to ocean conditions.

Pelagic Food Web Ecology in Puget Sound: Implications for Chinook Salmon

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Recent evidence for strong size-selective ocean survival and the importance of juvenile rearing in the pelagic zone of Puget Sound by ESA-listed Chinook salmon should sharpen our focus on processes that affect growth and mortality during this critical period. Over the last decade, inter-annual, seasonal, and regional differences in growth of juvenile Chinook were primarily attributed to differences in feeding rate (a surrogate for food availability). Much of the variability in feeding rate corresponded directly to the variable consumption of crab larvae, insects, and amphipods. The observed high, but variable feeding rate, coupled with strong size-selective mortality, suggests that competition could affect growth during pelagic rearing, and thus reduce ocean survival. The question becomes: what is the relative importance of competition between hatchery and wild Chinook, versus other species of salmon, herring, or other forage fishes? During the critical summer growing season, herring dominated the biomass of the shallow pelagic fish community, and exhibited extensive diet and spatial overlap with juvenile Chinook and other salmon. A bioenergetic analysis indicated that herring consumed 10-47 times more biomass of the key prey resources eaten by Chinook during this critical growth period. These results suggest that any assessment of the marine carrying capacity for salmon will need to account for the population and feeding dynamics of all major daylight planktivores, especially herring. Determining factors that affect growth performance during this critical period will clarify the role of the Puget Sound food web in supporting production and survival of Chinook and associated pelagic species.

Population-specific variation in growth of yearling Columbia River Chinook salmon during early ocean residence as indicated by levels of the hormone insulin-like growth factor-1 (IGF-1)

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Growth of juvenile salmon during early ocean residence is a determining factor in their long-term survival to adulthood. Assessing growth rates of juvenile salmon along the coast of Washington and Oregon is of great interest in order to better predict smolt-to-adult return (SAR) rate, especially for imperiled Columbia River Chinook salmon. The development of a robust biomarker of growth, the hormone insulin-like growth factor-1 (IGF-1), has allowed for the ability to assess growth in juvenile salmon captured at sea. The IGF-1 hormone is a protein released by the liver to directly stimulate cell division and growth in somatic tissues in fishes. The level of IGF-1 measured in the blood plasma is positively correlated with instantaneous growth such that IGF-1 level is an informative

and robust index of growth in juveniles caught in their first 2-3 months at sea. In this study, IGF-1 levels in juvenile Chinook caught along the Washington and Oregon coast in May and June from 2000 to 2009 were assessed. Variation in IGF-1 level is examined in relation to population, year, fish size, catch location, and month. Significant inter-annual differences were found, similar to earlier results presented on coho salmon. In addition, population-specific differences in IGF-1 levels were apparent, requiring us to examine population-specific IGF-1 levels in regard to fish size, catch location, and month. Finally, the mean June IGF-1 levels of yearling upper Snake/Columbia River spring Chinook salmon were found to be correlated with adult returns of spring Chinook salmon to Bonneville Dam. These results suggest that the early marine growth of these important populations of Chinook salmon is related to adult survival and that IGF-1 levels of these fish may be used to predict adult returns.

Ocean dispersal of stocks of juvenile CWT Chinook and coho salmon off Oregon and Washington, 1998-2009.

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First ocean year dispersal of juvenile CWT Chinook and coho salmon off OR and WA varied by stock group and by age of fish. Dispersal of three stocks of yearling Chinook salmon -- upper Willamette spring, mid-upper Columbia River (CR) spring, and Snake R. spring/summer -- was rapidly northward, so that by June these groups were most abundant off northern WA and by August and September were absent south of Canada. Conversely, subyearling lower CR and mid-upper CR fall Chinook salmon first appeared in our catches in June, and increased in abundance by August and September, when the lower CR falls were mainly distributed off WA and the mid-upper CR falls were distributed off both WA and OR. Both yearling and subyearling upper CR summer and Snake R. fall Chinook salmon were widely distributed north and south of the CR. Yearlings were caught in May, June and September and subyearlings in June and September, although both yearling CR summers and subyearling Snake R. falls were most abundant in June off WA. A few yearling coastal OR/WA Chinook salmon were caught in May and June, but by September subyearling coastal Chinook salmon were distributed along every transect. The distribution of both CR and coastal OR yearling coho salmon shifted to the north between May and June, and by September catches were greatly reduced. BC and Puget Sound Coho were found only in June and September off WA.

Mobile Receivers: Releasing the mooring to 'see' where fish go

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Much has been learned from the large scale deployment of acoustic tags on aquatic species and associated networks of riverine and marine receivers. While quite effective in the linear environment of river systems, marine receivers are limited in their ability to provide spatial information on fish movements and distributions due to a combination of costs, logistics, and lack of off-shore technology. At the same time, each year millions of dollars worth of tags are being released into the aquatic environment with extended battery/transmission life and no potential for detection beyond coastal arrays. Here we explore new methods of tracking acoustically tagged species in the marine environment. A new acoustic receiver, the Vemco Mobile Tag (VMT), has been miniaturized, enabling it to be carried by larger marine organisms. In combination with satellite and archival tag technology, VMT's were deployed on northern elephant seals beginning in the fall of 2009 to monitor acoustic tags during their migrations across the Northeast Pacific. Early results include acoustic detections of great white sharks, salmon and other tagged elephant seals. We also propose several alternative directions for future effort: 1.) analyzing the growing number of passive acoustic survey recordings of ultrasonic marine mammal vocalizations for acoustic tag detections, 2.) working with acoustic technology providers to develop hull-mounted receiver systems that could be deployed on the thousands of ocean going vessels around the world and 3.) integrating acoustic receiver technology into the thousands of moored and drifting oceanographic buoy arrays.

Interactions between conservation measures and the environment lead to unintended consequences for an endangered species: Pacific salmon in the Columbia River basin

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Conservation management of depleted species requires understanding of dynamic processes influencing individual survival; failure to account for the interaction of selection processes and management interventions can result in unintended outcomes that undermine recovery efforts. In the Columbia River basin, various conservation and restoration efforts have largely failed to increase the production of threatened Pacific salmon (*Oncorhynchus* spp.) populations. Here we considered (1) how inter-and intra-annual variability in marine environmental conditions affect survival of Chinook salmon (*O. tshawytscha*) during their time in the ocean; and (2) how those effects depend on whether the salmon are of hatchery or wild origin, and whether they migrated to sea naturally or were transported downstream around various hydroelectric dams. We used

data from more than one million fish individually-tagged from 1998-2006 to evaluate the probability of an individual fish returning as an adult in relation to its life-history, migration route, and a suite of environmental factors including river flow, water temperature, coastal upwelling, and the abundance of predator, forage fish, and prey. We found that current efforts to transport salmon downstream strongly favor hatchery-origin fish, and may hinder the survival of wild-origin Chinook. We further found that, except for select periods when river flow is particularly low, wild fish that traveled downriver through the hydropower system had higher overall survival to adulthood than their transported counterparts. We also found evidence that competition and predator aggregation negatively affects survival, and that the effects vary with fish density and a variety of climatic conditions. Our results have broad implications for conservation of salmon as well as other species in other systems, and they highlight the importance of considering the interacting effects of both anthropogenic and natural factors on the long-term viability of at-risk species.

ENSO induced harmonic oscillations of marine survival (HOMS) of BC sockeye salmon populations: Forecasting adult sockeye returns in HOMS way.

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The hypothesis that ENSO variations induce harmonic oscillations in sockeye marine survival (i.e. the harmonic oscillating marine survival or HOMS hypothesis) has served as the conceptual basis for a highly successful pre-season forecasting method (the survival stanza method or SStM) that has been used to predict variations in smolt-to-adult return rates (SARs) and annual returns of Barkley Sound sockeye salmon for more than twenty years. Sea-entry years associated with La Nina-like conditions (cold ocean) result in above average SARs while those associated with El Nino-like conditions (warm ocean) result in below average SARs. Examination of time series SARs for several additional sockeye stocks originating from the Fraser River, Smith Inlet and the Columbia River indicates that ENSO variations, anticipated by sea surface temperature changes, appear to induce predictable changes from higher to lower marine survival for all stocks. Thus, for the stocks considered here, a clear majority of La Nina-like sea entry years are accompanied by elevated SARs relative to proximal values observed in non-La Nina years. Conversely, a clear majority of sea-entry years exhibiting El Nino-like conditions are accompanied by depressed SARs relative to proximal values observed in non-El Nino years. This knowledge may be used to improve future forecasts of marine survival and total return variations for these stocks and, at this writing, we anticipate that the 2008 through 2009 sea entry years (2010-2011 return years) will be accompanied by relatively high marine survival for sockeye stocks migrating through south and central coast waters of BC. By contrast, these stocks are likely to exhibit an average to below average SAR for juvenile sockeye migrating seaward in 2010 (returning principally in 2012-2013). Finally, although ENSO induced changes in SARs are exhibited by all stocks, they fail to provide a sufficient explanation for single year return anomalies exhibited by some stocks (e.g. the anomalously low return of Fraser sockeye in 2009) or for differences in longer

term production trends observed among stocks (e.g. increasing production for Columbia sockeye but decreasing production for Fraser sockeye).

Regional and inter-annual variation in the feeding behaviour and trophic dynamics of juvenile pink and chum salmon

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Pink and chum salmon are the most heavily stocked species of salmon; hatcheries on both sides of the Pacific produce billions of fry every year that they release into the ocean. In addition, many pink and chum stocks have been increasing while other species of salmon have been decreasing or exhibiting unpredictable returns. In order to understand the implications of hatchery stocking and the possible causes for increased returns, it is essential to understand the feeding behaviour of these two species. It is especially important to examine the critical time that juveniles spend in the coastal marine environment when a large proportion of marine mortality occurs. Stable isotopes of carbon and nitrogen were used to compare the trophic level and food source of juvenile pink and chum salmon in several years of contrasting ocean conditions. Stable isotopes of zooplankton were also examined in order to determine the baseline isotope signatures for each region where salmon were collected. Previous research has found that the feeding strategies of adult pink and chum salmon appear to differ, which would reduce competition for resources between the two species. It has yet to be determined if these different feeding strategies occur also among juvenile salmon. Preliminary results indicate that there is a large degree of overlap in the diets of juvenile pink and chum salmon, but this can vary significantly in years of contrasting ocean conditions.

Stock-specific ocean distribution of Chinook salmon catch in 2010

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In 2005, anticipating fishery restrictions on the harvest of Klamath River Chinook salmon, a collaboration of commercial fishermen, scientists, and seafood marketers initiated Project CROOS (Collaborative Research on Oregon Ocean Salmon) to explore the potential of genetic stock identification (GSI) to provide fisheries managers with

more robust and timely information about stock distributions in the hope of providing managers with a new tool to avoid weak stocks. In 2007 a similar project was initiated in California. Fishermen recorded the location of each fish caught using GPS, collected fin clips (for GSI) and scales (for aging), fish length and other information. Data were used to map changing distributions, by stock, throughout the fishery. In 2010, a collaboration of Oregon and California fishermen and agencies (the West Coast Salmon GSI Collaboration) conducted a coordinated sampling effort weekly from May through September from Cape Falcon south to Santa Barbara. In areas closed to commercial fishing, samples were collected by contracted commercial vessels using a catch and release protocol. This effort has provided the first synoptic, fine-scale data set of Chinook catch distributions in the area south of the Columbia River plume. Data were assembled in a central data base where they are associated with supporting data sets including oceanographic data, satellite observations, and coded-wire tag data. These data will be accessible to scientists, fishermen, fishery managers, processors, marketers, and the general public. A web site, www.pacificfishtrax.org, is being developed as a portal to these data. Early analysis shows clear spatial and temporal patterns of stock-specific catch rates and may allow the reconstruction on a coarse scale of stock-specific migration patterns.

A Bayesian network incorporating genomic information into in-season management of Fraser River sockeye salmon

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The physiological condition of a sockeye salmon (Oncorhynchus nerka) has important implications on the success of its journey to its natal spawning ground. Recently, functional genomics has been used as a tool to assess the physiological condition of sockeye salmon and predict their fate as they return to the Fraser River in British Columbia, Canada. In this study, we examine how information from genomics could play a role in the in-season management of Fraser River sockeye salmon. That is, could we make better management decisions if we could use genomics to assess the physiological condition of sockeye salmon prior to their freshwater entry? To achieve this goal, we use a Bayesian network methodology to develop an influence diagram that formalizes the in-season decision-making process concurrently with representing the natural history of the salmon. Bayesian networks are useful tools for sharing information with stakeholders and non-scientists because of their graphical representation. An application of the Bayesian network to the 'Summer' run-timing group demonstrates that in some cases genomics information can be useful in adjusting in-season spawning escapement estimates. This work also highlights that presenting new tools such as genomics through Bayesian networks can facilitate understanding of the management

process for all parties concerned, and ultimately lead to the acceptance and uptake of novel techniques in resource management.

Impacts of Potential Climate Change on the Ocean Thermal Habitat of Pacific Salmon

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Historical SST observations for the 20th century and projections from 18 climate models (GCMs) used in the IPCC's Fourth Assessment Report were regridded to a reference 2^ox2^o resolution and corrected for biases relative to historical observations. Based on high-seas salmon surveys that began in 1956, reference temperature thresholds and associated isotherms were defined as the coldest (northern) and warmest (southern) limits within the North Pacific and Arctic Basins for sockeye (O. nerka), chum (O. keta), pink (O. gorbuscha), coho (O. kisutch), and chinook (O. tshawytscha) salmon, and steelhead (O. mykiss). Historical July and December habitat range and areas were quantified as examples of, respectively, summer and winter habitats for the warm (1925-46 and 1977-1997) and cool (1947-76) eras of the Pacific Decadal Oscillation (PDO) to evaluate the impacts of natural inter-decadal climate variability. We used the thirty-year average centered on the decade of the 1980s (1970-1999) as our historical reference period. Thirty-year averages centered on the 2020s (2010-2039), 2040s (2030-2059), and 2080s (2070-2099) were used to evaluate the potential changes ocean distributions and habitat areas for Pacific salmon under three IPCC scenarios of lower (B1), medium (A1B), and higher (A2) greenhouse gas emissions using multi-model averages of the available GCM SST output fields. Our results show that projected 21st century changes in July reference habitat for all species, and December reference habitat for sockeye salmon, were much larger than those observed in the historical time-frames. Projected reductions in reference habitats were greatest for chinook and sockeye salmon.

Growth of juvenile Chinook salmon: a model comparison between estuaries and adjacent sandy beach surf-zones

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During summer, juvenile Chinook salmon are present in estuaries, adjacent sandy beach surf-zones and the coastal ocean. Although early marine residence is considered an

important period, there is little information on the role of surf-zones as a habitat for juvenile Chinook salmon. As part of a larger project to evaluate the role of surf-zones, we modeled and compared potential growth rates of juveniles in two Oregon estuaries and adjacent surf-zones during 2008 – 2010. Because estuaries are considered a nursery habitat for juveniles, we hypothesized they would present higher growth rates than surf-zones. We used locally obtained data on water temperature, diet and prey energetic content to predict growth rates in each of these habitats across years, assuming maximum consumption rate. On average, potential growth rates were 15% higher in surf-zones than in estuaries. Across years, growth rates were similar between 2008 and 2009 (<1% difference), but were 5% lower in 2010 when compared to 2008 or 2009. Among sites, the surf-zone south of Coos Bay had similar growth rates as the surf-zone south of Alsea Bay (<0.01% difference), and Alsea Bay had 4% higher rates than Coos Bay. Instances of higher growth rate were associated with lower temperatures and higher prey energetic content. In both habitats, potential growth rates declined over time, however rate of decline varied annually at each habitat. Results presented in this study suggest sandy beach surf-zones can act as an alternative habitat for juvenile Chinook salmon during years in which conditions are sub-optimum in the estuary.

Juvenile salmonid migratory behavior at the mouth of the Columbia River and within the plume

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Juvenile spring and fall Chinook salmon and steelhead tagged in the Columbia River with small acoustic transmitters (0.43 g in air) were detected on a sparse array of Juvenile Salmon Acoustic Telemetry System (JSATS) autonomous receivers in the Columbia River plume in an effort to inform survival study experimental design. The 20 receiver 'box-shaped' array had ~3 km internode spacing with the terminus sub-array, with six receivers, being about 15 km from the mouth of the river, along the 100 m contour. The north and south sub-arrays, with seven receivers each, were about 22 km apart and were perpendicular to the coast line. A total of 1,680 unique JSATS-tagged juvenile salmonids were detected on the plume array between 5 May and 8 August 2010. Travel rates of juvenile Chinook salmon were slower upon ocean entry when compared to in-river movement rates. Juvenile steelhead travel rates increased upon ocean entry. Most (86%) Yearling Chinook salmon and steelhead (96%) moved from the mouth of the river to plume array in 3 days or less, while 74% of the subyearling Chinook salmon traveled the same distance in 3 or fewer days. Eight percent of the yearling Chinook salmon took more than 6 days to move from the river mouth to their last detection on the plume array while only 1% of the steelhead took more than 6 days to cover that distance. Subyearling Chinook salmon spent more time between the mouth of the river and their final detection on the plume array, with 20% taking more than 6 days to traverse this area. Several subyearling Chinook salmon were detected on the plume array and then back inside the river mouth, apparently associated with tidal currents. Tagged yearling Chinook salmon

and steelhead were primarily detected on the terminus array, with more of the remainder being detected on the southern sub-array than on the northern sub-array prior to May 18, 2010. In the latter half of May, more yearling Chinook salmon and steelhead were last detected on the northern sub-array than on the southern sub-array; however the majority continued to be last detected on the terminus sub-array. Before May 18, about 27 and 47% on the yearling Chinook salmon and steelhead, respectively were last detected on the southern sub-array. May 18 and later, 14 to 18% of each species was last detected on the southern sub-array. The distribution of tagged yearling Chinook salmon last detected moving north and south were skewed toward deeper waters farther off-shore in comparison to steelhead and subyearling Chinook salmon. Subyearling Chinook salmon were more often last detected on the northern sub-array (55%) and southern sub-array (23%), than they were on the terminus sub-array (22%). The 2010 pilot scale JSATS array deployment in the Columbia River plume was successful in terms of providing the necessary behavioral information to enable the design of a robust survival study of juvenile salmonids exiting the Columbia River.

Early marine growth and overwinter mortality during the first ocean year of juvenile Chinook salmon in Quatsino Sound, British Columbia.

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Evidence suggests that the variability in recruitment of adult Pacific salmon is related to smolt survival during the first ocean year. Specifically, the early marine life stage and first marine winter may be two critical periods of high mortality. Early marine mortality has been attributed to predation and size-dependent factors. The second period of high mortality during the first winter may be due to energy deficits and failure to reach a certain size by the end of the growing season. Our study assessed the effect of early marine growth and energy accumulation on overwinter mortality in juvenile Chinook salmon from Marble River, Quatsino Sound, B.C. Juvenile salmon were collected during November 2005 and 2006 (fall) and March 2006 and 2007(winter). Fish size and energy density data showed no evidence of size-selective overwinter mortality between fall and winter fish in both 2005-2006 and 2006-2007 and CPUE data for both years dropped by approximately 80-90% between fall and winter indicating high mortality. Otolith microstructure analyses showed significantly similar circulus increment widths during the first four weeks after marine entry. Similarities in increment width indicated early marine growth did not differ between fall and winter fish in 2006 and 2007. These observations show that mortality during the first month and first winter at sea may not be size-dependent for juvenile Chinook salmon in Quatsino Sound.

Early marine residence of spring Chinook salmon: a comparison of growth and migration in two interior Columbia River populations

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Although the influence of large-scale atmospheric processes on salmon population cycles is well-recognized, the mechanisms regulating survival remain elusive. Correlative evidence indicates that factors during early ocean residence are important although the timing of growth- or size-dependent survival is not clear. Furthermore, it is suggested that the timing of marine entrance influences growth and survival although there are few empirical data to robustly evaluate this hypothesis. Much of the information available on coastal migration patterns is based on coded-wire tag returns, which are biased toward hatchery fish. We applied an approach based on variation in otolith structure and chemistry to determine (1) size and timing of freshwater emigration; (2) early marine growth; and (3) migration rate of juvenile spring Chinook salmon from interior Columbia and Snake River populations that were collected off the coasts of Oregon and Washington (1999, 2000, 2002-2004, 2006-2008). Interannual variation in size at emigration from freshwaters displayed only weak positive relationships with subsequent adult abundance. However, size at capture and indicators of recent marine growth were positively related to indices of ocean productivity and future abundance, highlighting the importance of initial marine growth. Individuals from both populations resided in coastal waters for extended periods (~30 d) prior to capture but there was only weak evidence that timing of marine entrance was related to subsequent growth. Individuals entering marine waters later in the summer migrated northward at faster rates, implying seasonal variation in migration patterns. Overall, the evidence indicates that local processes influence growth very early in marine residence and that early growth is positively related to survival.

Genomics insights into the health and condition of out-migrating salmon smolts

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In 2010, we presented new genomic data on the health and condition of Fraser River sockeye salmon smolts and adults. The identification of a genomic signature in adult sockeye salmon predictive of high mortality in the river whether fish were sampled >200 km before river entry, upon entry in the river, or at spawning grounds provided evidence that salmon were already physiologically compromised before they entered the river. The discovery of this same signature before smolts left natal rearing environments, and the decrease in prevalence of this signature in the first 3 months in the ocean indicates that a similar mechanism may be associated with elevated mortality in juveniles in the

ocean. New genomic studies that directly contrast 2007 and 2008 out-migrating sockeye salmon smolts offer new insight into physiological differences in year classes with unprecedented low and high returns to the Fraser River. Preliminary data on the condition of adult returns in 2009 and 2010 will also be presented.

Ocean distribution and habitat associations of subyearling Chinook salmon in the northern California Current

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Subyearling juvenile fall Chinook salmon (also called ocean-type Chinook salmon) were sampled on 30 cruises in June and September 1981-1985 and 1998-2008 in continental shelf waters off the Pacific Northwest. Oceanographic variables measured included temperature, salinity, water depth, and chlorophyll concentration (all cruises) and copepod biomass (1998-2008). Subyearling Chinook salmon were found exclusively in continental shelf waters, usually close to shore, and showed a patchy distribution: half were collected in 2 – 3 trawls each cruise. Variance-to-mean ratios of the catches were high, also indicating patchy spatial distributions. The juvenile salmon were most abundant in the vicinity of the Columbia River and the Washington coast in June; by September they were distributed evenly along the coast from central Oregon north to the tip of Washington State. The geographic center-of-mass of the distribution was off the Washington coast near the northern end of our sampling grid in June, but in September, it had shifted southward and inshore. 80% of the subyearling Chinook salmon were caught from the nearshore zone out to a depth of 78 m (June) but only 49 m in September. Studies off Oregon have found that subyearling Chinook can reside in the surf-zone, thus we may be overestimating the depths they are associated with because we cannot sample inshore of 30 m with our trawl. Abundances were significantly correlated with water depth (negatively; 20 of 30 cruises), temperature (negatively, 11 of 30 cruises), salinity (inconsistent); chlorophyll (positively; 12 of 30 cruises) and copepod biomass (positively; 9 of 19 cruises).

The Gulf of Alaska Project: an Inter-Regional Research Project through which Salmon Ocean Ecology Studies Should be Integrated

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The Gulf of Alaska Project is a newly initiated North Pacific Research Board integrated ecosystem research program focused on identifying and quantifying key processes that regulate the recruitment of five commercially and ecologically important groundfish species in the Gulf of Alaska (GOA). The focal species are Pacific ocean perch, sablefish, Pacific cod, walleye pollock, and arrowtooth flounder; all of which demonstrate different life histories, but experience the same oceanographic conditions during their first year of life. This comprehensive study will contrast regional differences in oceanographic processes during spring, summer, and fall in the southeastern and central GOA, and relate environmental conditions to species specific health, condition, and recruitment. A combination of field work, laboratory experiments, and retrospective analyses will be combined to determine the main drivers controlling juvenile transport to favorable nursery habitat and interannual differences in cohort survival. Despite the fact that this study is focused on juvenile marine fish ecology, many juvenile and maturing salmon were captured in research trawls during the 2010 pilot year. As a result, work has recently been initiated on stock-specific juvenile sockeye salmon distribution and juvenile pink and chum salmon feeding ecology. There are numerous other opportunities for collaboration and coordination with investigators interested in the ecology salmon inhabiting the GOA.

Stock-specific Ocean Distribution and Migration of Sockeye Salmon

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I will briefly review what we know and need to know about ocean distribution and migration of regional stocks of sockeye salmon with emphasis on Fraser R. and Columbia R. sockeye salmon.

Applying Marine Ecosystem Indicators to Forecast Pink Salmon Harvest in Southeast Alaska: The Southeast Alaska Coastal Monitoring Project 1997-2010

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Fourteen years ago the Auke Bay Laboratories of the Alaska Fisheries Science Center launched the Southeast Alaska Coastal Monitoring (SECM) project to study the effects of marine ecosystem dynamics on salmon recruitment in Southeast Alaska

(SEAK). This annual at-sea research has been conducted by monthly surveys (May-August) off government and chartered vessels with surface trawls, plankton nets, and oceanographic instruments in migration corridors used by juvenile salmon. This unique time series of annual SECM ecosystem metrics has enabled salmon forecast models to be developed. In six of the past seven years, SECM pink salmon forecast predictions have averaged within 8% of the actual annual harvests in SEAK (12-59 million). Because juvenile salmon abundance is a primary factor used in these models, the determinate mechanism operating in most years is believed to be early marine mortality of juveniles prior to sampling. However, forecast model accuracy has sometimes been improved by using auxiliary parameters that reflect regional or later ocean basin conditions. SECM survey data is shared with Alaska Department of Fish and Game researchers and the commercial fishing community to ensure biological sustainability of the salmon resource and to allow its optimal economic benefit to be realized in SEAK. Marine ecosystems are complex and difficult to understand, but the SECM research has shown that systematic sampling done on an annual basis--within appropriate time scales--can be applied to better understand mechanisms responsible for salmon recruitment and meet the needs of resource managers and stakeholders.

"Synthesis of evidence about causes of the decline of Fraser River sockeye salmon: Results from the June 2010 Pacific Salmon Commission workshop"

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Recent decreases in abundance and productivity of Fraser River sockeye salmon prompted the Pacific Salmon Commission to hold a workshop on 15-17 June 2010 in Nanaimo, B.C., to evaluate evidence on possible causes of these declines. An Expert Advisory Panel of 11 scientists was created and 25 other experts contributed data regarding the hypothesized causes. This paper will summarize the workshop, including background data on historical patterns that participants were trying to explain. Hypotheses for explaining the serious Fraser sockeye situation included:

1. Predation by marine mammals and/or unreported fishing in the ocean
2. Marine and freshwater pathogens, including parasites, bacteria and/or viruses
3. Oceanographic conditions (physical and biological) inside and/or outside Georgia Strait
4. Harmful algal blooms in the Strait of Georgia and/or northern Puget Sound/Strait of Juan de Fuca
5. Contaminants in the Fraser River and/or Strait of Georgia
6. Freshwater habitat conditions in the Fraser River watershed

7. Delayed density-dependent mortality
8. En-route mortality during upstream migration, plus its effects on fitness of the next generation
9. Competitive interactions with wild and hatchery pink salmon (O. gorbuscha)

After the workshop, the Expert Panel synthesized the information presented and wrote a report (Peterman et al. 2010). The Panel concluded that four sets of hypotheses were the most likely causes of the long-term decrease in productivity of most Fraser River sockeye populations, i.e., numbers 2, 3, 7, and 9 listed above. This paper will also briefly discuss some post-workshop events related to Fraser River sockeye.

Reference

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The Pacific Decadal Oscillation and marine food webs in the northern California Current: variations in source waters which feed the California Current may be the mechanism which links climate change with ecosystem response

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Analysis of hydrographic and zooplankton data collected fortnightly in the coastal upwelling zone off Oregon for the past 15 years have shown that variations in sea surface temperature, salinity, copepod biodiversity, copepod species richness and copepod community structure are correlated with the Pacific Decadal Oscillation. When the PDO is negative (as during the 1970s, 1999-2002 and 2008-2009), cold salty waters from the Gulf of Alaska feed the northern California Current (NCC) and transport lipid-rich copepods to the shelf waters of the NCC; when the PDO is positive (as in 2003-2007), warm fresher waters from offshore and south feed the NCC and transport small, oceanic lipid-poor copepods to the coast. Thus the basin-scale variations in winds that drive the

PDO seem to result in changes in transport that in turn control local food chain structure. Three lines of evidence support the transport hypothesis: we will show from ROMS modeling, from analysis of satellite altimeter data and from analysis of temperature-salinity characteristics of water masses that changes in phase of the PDO are accompanied by changes in source waters which feed the NCC. We argue that to examine how the coastal upwelling ecosystem of the NCC might react to a climate change scenarios, we will need a better understanding of how basin-scale winds and variations in gyre circulation patterns impact source waters which feed the NCC. A combination of ROMS and GCMs should allow examination of future states of the PDO and of regional variations in source waters that feed the NCC.

Forecasting returns of coho and Chinook salmon in the northern California Current: a role for long term observations

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Forecasting ecological phenomena requires a basic understanding of the physical and ecological mechanisms that determine the outcomes which one hopes to predict. Successful prediction of fisheries for example will require at least a modicum of knowledge of where in the ocean the given species lives during all parts of its life cycle, and of processes that determine the recruitment bottlenecks. We have established that juv salmon reside in continental shelf waters during their first summer at sea, thus using data from shelf waters, we now provide predictions of salmon returns based on long-term monitoring of hydrography, plankton and juvenile salmonid abundance along 8 transects in coastal waters off Washington and Oregon, in June and September, for the past 13 years, and hydrography, zooplankton and krill along a transect off Newport for 15 years. Qualitative forecasts of returns of coho and Chinook salmon to the rivers of the Pacific Northwest are based on 15 physical indicators (PDO, MEI, SST, upwelling, date of spring transition) and biological indicators (biomass anomalies of northern lipid-rich copepods, copepod species richness, copepod community structure, date of biological spring transition and catches of juvenile Chinook during June and juvenile coho in September). Values are assigned a color code (red = indicator suggests poor returns of salmon; green = indicator suggests good returns of salmon; yellow = neutral. More quantitative forecasts are now being made based on the rank of each indicator across years (rows), then summing of the ranks by year (colums). The annual "sum of ranks", from 1998 to present is regressed against annual counts of salmon at Bonneville Dam to produce forecasts of returns of coho salmon (one year in advance) and Chinook salmon

(two years in advance). Forecasts for 2010 returns will contribute to a summary table that Pete Lawson will populate as part of the competition for who came up with the most accurate forecast for various salmon stock groups in 2010.

Temporal trends of *Renibacterium salmoninarum* infection in stocks groups of juvenile coho and Chinook salmon.

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One of the most important pathogens of Pacific salmonids is the bacterium Renibacterium salmoninarum. We have been measuring the prevalence of R. salmoninarum in juvenile coho and Chinook salmon during early marine residence since 1999 and have recently included analysis of intensity of infection using a quantitative measure of bacterial DNA, a quantitative polymerase chain reaction (qPCR). Prevalence of R. salmoninarum in both coho salmon and yearling Chinook salmon was variable in years 1999-2003 ranging from approximately 25% to 60% and in 2004-2010 ranged from 10 to 20%. Analysis by stock groups shows that among Chinook stocks, that prevalence of R. salmoninarum is higher on average in upper Columbia River summer/fall Chinook salmon compared to mid and upper Columbia River or Snake River spring Chinook salmon, due primarily to higher prevalence in 2006, 2008, and 2009. In contrast, stocks of coho salmon (Washington coast, Columbia River, and Oregon coast) have had similar temporal trends in infection from 1999-2009, which suggests that they are responding similarly to factors affecting infections. Additional results presented and discussed will be our recently acquired data on intensity of infection in stock groups of both coho and Chinook salmon.

Do pink salmon affect the productivity and life history characteristics of Fraser River sockeye salmon?

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Recent studies indicate that Bristol Bay sockeye salmon compete for food at sea with Russian pink salmon, leading to 1) significant reduction in survival of sockeye smolts at sea, 2) reduced adult abundance, and 3) smaller adult length-at-age. Productivity of Fraser River sockeye salmon has declined since the early 1990s (except for the 2006 brood return in 2010), therefore the potential effects of pink salmon on Fraser River sockeye salmon were examined in a preliminary analysis using stock-specific sockeye data provided by the Pacific Salmon Commission. Pink salmon abundance in the North Pacific Ocean has been exceptionally high since the mid-1970s and abundance maturing

pink salmon is greater during odd-numbered years. Mean productivity (residual from Ricker recruitment curve) of Fraser sockeye salmon was significantly less from odd-year versus even-year broods, 1979-2005, leading to a 28% reduction in abundance during odd-year broods when standardizing values to mean parent escapement. This pattern was not directly associated with juvenile pink salmon produced in the Fraser River. Instead, mean annual productivity of 16 sockeye stocks was inversely correlated with abundance of maturing pink salmon in the North Pacific Ocean since the early 1960s, corresponding to the year of sockeye return. During 1953-2009, mean length of age-1.2 sockeye salmon (mean of 4 stocks, accounted for gender) was significantly smaller during odd versus even years of return. Age-at-maturation of Fraser sockeye stocks was delayed in response to greater pink salmon abundance since the early 1960s. These findings indicate that high abundances of pink salmon affect productivity, growth, and age-at-maturation of Fraser sockeye salmon. The uniquely low sockeye return in 2009 and the high return in 2010 are consistent with the pink salmon hypotheses, but the data indicate significant interaction with other factors.

Hedging our bets: Multi-model forecasts of Oregon coast natural coho salmon (*Oncorhynchus kisutch*) adult recruitment

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Generalized additive models (GAMs) relating physical ocean environment indices to adult recruitment of Oregon coast natural river (OCNR) coho salmon (Oncorhynchus kisutch) have been developed with the express purpose of forecasting the next pre-harvest returns of OCNR coho to support management objectives. From thousands of possible models built from combinations of predictor variables, an ensemble of six models was chosen to make forecasts. All six models in the ensemble use the four-year average, late-spring/early-summer Pacific Decadal Oscillation index to represent the multi-year trend in ocean conditions, while using other indices to represent inter-annual variation. The indices include the multivariate ENSO index, the PFEL upwelling index, coastal sea surface temperature, sea surface height, the date of the upwelling spring transition, and parent spawner abundance. The models were chosen to provide a range of forecasts, with each model representing different influences that particular indices may have on recruitment. Attempts to link each index to mechanistic processes are made, in order to have consistency between modeled relationships and the current understanding of how ocean circulation affects productivity. In addition to making six individual forecasts, a single forecast is made from the ensemble mean forecast. The ensemble mean is found to perform better in terms of variance explained and ordinary cross-validation than any of the six individual models. From a practical perspective, the multi-model approach serves to reduce forecast error caused by any single predictor variable coming out of phase with

recruitment, either for mechanistic reasons or because the modeled relationship is simply spurious.

An ecosystem modeling approach to study trophic dynamics within the Northern California Current: inter-annual variability in bottom-up energy supply and top-down predation pressure upon juvenile salmon

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Many studies have shown correspondence between lower trophic level production within the Northern California Current (NCC) and the ocean survival of juvenile salmon. Others have argued for the potential of predation pressure to moderate survival. While an ecosystem-modeling approach cannot demonstrate the action of either top-down or bottom-up pressures in the real system, a model can be used to infer the relative importance and temporal variability of these processes if built upon an adequate time-series data set.

Plankton, fish, and seabird surveys conducted off Oregon and Washington provide time-series data about the pelagic community composition within the NCC. From these observations were developed a series of independent, mass-balanced food web models for years 2003 through 2007 from which were inferred both direct and indirect pressures acting upon juvenile coho salmon. Inter-annual changes in bottom-up energy transfer efficiency through the system were quantified, and an inter-annual metric of predation pressure upon juvenile coho was estimated. An index of confidence in each model structure and model-derived metric was obtained through Monte Carlo sampling of functional group abundance from the variability observed within each survey.

The sensitivity of juvenile coho to variability in individual trophic linkages was investigated via sensitivity analyses of a generalized NCC end-to-end model. Targeted scenario investigations were used to analyze the potential response of the system (and juvenile coho in particular) to specific ecosystem events, including recent invasions by Humboldt squid and changes in the caloric value of herbivorous zooplankton at the base of the food chain.

Climate processes affecting productivity of the Northeast Pacific on decadal to centennial timescales during the 20th and 21st centuries

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A leading hypothesis relating productivity with climate variability in the California Current Ecosystem (CCE) describes an alternation between warmer, well-stratified periods of low productivity and cooler periods of high productivity. This empirical relationship suggests that productivity will decline with global warming. Here, we explore the response of productivity to future climate change in the CCE using an earth system model. This model projects increases in nitrate supply and productivity in the CCE during the 21st century despite increases in stratification and limited change in wind-driven upwelling. We attribute the increased nitrate supply to enrichment of deep source waters entering the CCE resulting from decreased ventilation of the North Pacific. Decreases in dissolved-oxygen concentration and increasing acidification accompany projected increases in nitrate. This analysis illustrates that anthropogenic climate change may be unlike past variability; empirical relationships based on historical observations may be inappropriate for projecting ecosystem responses to future climate change.

Investigation of estuarine and ocean survival components for Columbia/Snake River transported salmonids using relative indices

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Anadromous salmonids have a complex life-cycle generally requiring temporal and spatial passage through riverine, estuarine, and ocean habitats. For Columbia/Snake River yearling spring/summer Chinook salmon and steelhead, much is known about riverine survival, less about estuarine survival, and little about ocean survival. Appropriate comparison of overall migratory life-cycle survival to an index of estuarine survival can provide insight to ocean survival. From 2006 to 2008, we attempted this by PIT-tagging large numbers of these salmon, transporting them by barge through the river thus "removing" mortality for that component, and releasing them either at the upstream end of the estuary (below Bonneville Dam) or near the end of the estuary (below the Astoria bridge). These tags were recovered on the estuarine-located East Sand Island providing an index of avian predation for the two groups. The ratio of these indices was then a relative index of estuarine survival and was compared to the ratio of each groups' subsequent smolt-to-adult return rate (SAR) to Bonneville Dam one to three years later.

This study is nearly complete. Results-to-date are variable between species and across years. For Chinook salmon, the two survival components were not well-correlated and relative SAR was more variable than the predation index. Steelhead SARs were also more variable but more positively-correlated. We continue to examine these data using additional information such as juvenile size at tagging, ocean condition indices, and adult age of return.

Does turbidity affect early marine foraging by Chinook salmon? Foraging experiments and application to western Alaskan stocks

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The environmental conditions affecting salmon growth during their first months at sea are considered critical to ocean survival. Turbidity can be highly variable in many coastal habitats used by Chinook salmon Oncorhynchus tshawytscha during this period due to phytoplankton blooms and sediments transported by river plumes, tides, and waves. Since turbidity can both reduce foraging rates and provide cover from predators, this variability may have important consequences for Chinook salmon feeding, growth, and survival. We will present plans for feeding experiments to test three hypotheses about the effects of turbidity on Chinook salmon foraging dynamics, and to develop parameters for modeling foraging opportunities. Experiments will be conducted in saltwater tanks with juvenile stream-type Chinook salmon as predators and chum salmon O. gorbuscha and other taxa as prey. First, predators will be presented a low density of prey at a range of turbidity treatments to determine the effect of turbidity on foraging. Second, predators will be presented a range of prey densities, at low and high turbidity levels to test whether turbidity and prey density have interactive effects. An interaction (e.g. turbidity becomes less limiting with increasing prey density) would have implications for the value of feeding in turbid habitats with high prey densities. We will discuss opportunities to apply experimental results with data from large-scale field studies to test whether including turbidity information can improve model estimates of juvenile Chinook salmon growth, distribution, or ocean survival.

Size-dependent mortality of juvenile Chinook salmon across years of varying ocean productivity as revealed by otolith increment analysis

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Changes in the distribution of body size can provide insight into selective mortality processes (e.g. starvation or predation) during early life history stages that can have significant population level consequences. However, empirical data quantifying when this selection occurs, and under what environmental conditions, are difficult to obtain. An increase in juvenile mortality due to poor ocean conditions in 2005 is believed to be the driver behind the collapse of several salmonid stocks in the California Current ecosystem in 2007. Using otoliths from central California fall-run Chinook, we compared otolith

growth in years of higher ocean productivity (2000 and 2001) to a year of low productivity (2005). Fish were collected as they exited the estuary, after their first couple months at sea, and five months after ocean entry. By comparing average otolith increment width, otolith radius at a given increment, and body condition (K-factor) among these groups, we were able to detect patterns of size and growth rate-selective mortality associated with poor ocean conditions. These data come from a regional survey conducted by the SWFSC Fisheries Ecology Division that ran from 1995 until 2005. Recently, the SWFSC joined with the NWFSC to initiate a coast-wide study focusing on the marine distribution and ecology of juvenile salmon. The new program will extend from central California to the Canadian border, and therefore encompass all of the coastal waters that offer habitat to newly emigrating Chinook and coho salmon populations, providing many additional opportunities to better understand how environmental conditions affect salmon populations.

Salmon as predators and prey in marine waters of Alaska

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Predation during the early critical period of rapid fish growth is thought to determine year class strength for juvenile salmon and many other species, yet surprisingly little has been published on the impact of specific marine predation. Predation impact is hard to document because it requires consistent sampling over extended periods to capture infrequent or episodic events. We examined diets of adult salmon in migratory corridors from a 14-year time series (1997-2010) of surface trawl catches in Southeast Alaska and from two years (2009-2010) of purse seine test fisheries in southwestern Prince William Sound. Our objectives were to investigate four aspects of predation: a) the incidence of predation on juvenile salmon by adult/immature Chinook, coho, sockeye, chum, and pink salmon, b) piscivory on forage fish by adult salmon, c) the potential for cannibalism by odd-even year broodlines of pink salmon to depress adult returns the following year, and d) predation impact on juvenile salmon by an episodic strong year class of sablefish. We present highlights of research on these trophic interactions that could affect salmon recruitment.

Genetic identification of Columbia River Basin juvenile fall Chinook salmon off the Oregon and Washington coast

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From 1998 to present we have sampled juvenile salmon in the Northern California Current. We use genetic methods to estimate the stock origins of juvenile salmon sampled each May, June, and September in coastal areas off Oregon and Washington. Using microsatellite DNA loci and baseline datasets that characterize spawning populations, we have analyzed nearly 10,000 Chinook salmon. In this presentation, we focus on the distributions of fish from Columbia River Basin fall-run (season of adult return) stocks. In June, juveniles from all of the stock groups were primarily sampled at transects off of the Columbia River and the Washington coast. This "northern" distribution was also apparent in September for fish from one Lower Columbia River ESU genetic group (Spring Creek Group "tule" fall stock originating in tributaries to the Columbia River Gorge above Bonneville Dam). However, other fall run stocks, including fish from both lower and upper Columbia River ESUs and from the Snake River fall run ESU, were caught from Washington to central Oregon in September. We hypothesize that these stock-specific distributions are related to timing of ocean entry. We present supporting genetic stock estimates of migrating fall Chinook salmon sampled in both shallow and main channel habitats of the Columbia River estuary. And finally, we combine our genetic estimates with data on fish size and age (from scales) to explore evidence that Columbia River fall Chinook salmon juveniles remain in (or return to) our study area during their second summer at sea.

Ocean distribution and migration of threatened stocks of sockeye salmon

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Large scale declines in the returns of Pacific salmon (*Oncorhynchus* spp.) ranging from California to south central British Columbia brought some stocks to the verge of extirpation in less than a decade, even in nearly 'pristine' watersheds. Adult returns have been so low for some southern stocks that severe fishing restrictions and closures have been put in place to protect and rebuild these stocks. Although a number of factors may be responsible for the decline of southern stocks, a simultaneous decline of salmon

originating from geographically-distant watersheds suggests a common cause is affecting these stocks in the marine environment. Hence, an understanding of stock-specific migration behavior is required to determine how climate and ocean conditions regulate Pacific salmon production. Here, we use coded-wire tag recoveries and DNA analyses performed on juvenile salmon caught at sea to describe the early marine life of two depressed stocks of sockeye salmon (*O. nerka*): Redfish Lake (Columbia River, USA) and Cultus Lake (Fraser River, Canada).

Yet Another Method for Ecosystem-based Predictions

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In recent years, there have been a number of talks at this meeting about ways of predicting salmon success (marine survival, returns, growth, etc.) based on multiple indicators of the state of the ocean ecosystem. A few years ago, I presented a method based on a fuzzy logic tree which, while interesting and colorful, did not provide an entirely satisfactory forecast. The goals of that effort were to improve on the Peterson red-light green-light method by (1) focusing on the causal pathways between indicators and salmon response, and (2) avoiding the redundancy problem resulting from including multiple indicator series for closely-related (and thus highly correlated) pathways. Here, I present a new tree-based probability method that addresses these goals but is less arbitrary than the previous fuzzy-logic method. Like the Peterson method, this method classifies years into good, neutral, and poor ocean conditions for salmon production/survival, rather than producing a point estimate of predicted salmon returns. This choice of a qualitative rather than quantitative assessment reflects the lack of precision in our understanding of the links between environmental variation and salmon production.

Where is the mortality determining adult salmon returns expressed?--Current evidence from the POST pilot-phase array

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Large-scale declines in marine survival of many Pacific salmon populations occurred in the last three decades. We examined when in the life history this mortality can be expressed using the POST prototype array.

We first compared the size at tagging of released smolts and of the survivors at distant

marine array locations, hundreds of kilometers away from the release site and requiring ≥1 month travel time. The mean, variance, and higher order moments of the size-frequency distribution was equivalent for each species examined (sockeye, steelhead, Chinook, & coho). This indicates that mortality processes did not substantially distort the size distribution of survivors and that, above minimum size thresholds specified for surgical implantation, larger smolts did not survive better than smaller smolts, as often assumed. We also found that survival to adult return of acoustically tagged Fraser R sockeye and Snake River spring Chinook smolts matched that of the overall (untagged) run in at least some years. As surgical implantation of acoustic tags does not therefore substantially reduce smolt survival after release, it is possible to calculate how much of the overall mortality is expressed in the first 1~2 months after release and how much afterwards; the results indicate that total mortality still to occur after the first 1 month of life in the sea equals or exceeds that occurring to that time. Thus events later in the life history still have the potential to determine the declining marine survival of the salmon stocks we have examined.

Inter-annual Variation in Lower River and Early Marine Survival of Chilko & Cultus Lake Sockeye: 2004-2010

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Major declines in survival of Fraser sockeye have occurred over the past two decades, with smolt-to-adult survival dropping in recent years to 1/10th of the 1980s level. For Chilko sockeye, a weir at the lake outlet allowed a complete census of the outmigrating smolts since 1949, and provides an excellent survival baseline. In this stock, the roughly 10% smolt-to-adult survival rate occurring before the 1990s began a long decline, and has in recent years been only on the order of 1%. This survival decline is mirrored in the worsening adult returns of almost all other Fraser River sockeye stocks. Where and why the poor survival develops is unclear. In 2010 we tagged outmigrating 2 yr old wild Chilko Lake sockeye smolts and measured their survival and tracked their movements with the POST array. We contrasted their survival with that of the Cultus Lake sockeye smolts tagged in 2004-07. Two potential survival bottlenecks were identified for wild Chilko smolts: (a) immediately after leaving the lake in the Chilko River and (b) in the Discovery Passage-Queen Charlotte Strait region. When compared with the survival data for hatchery-reared Cultus Lake sockeye (a lower river stock), survival was similar and high in the lower Fraser River (Mission to river mouth) and in the Strait of Georgia (river mouth to NSOG). However, wild Chilko smolts in 2010 had clearly lower survival in the final segment of their monitored migration pathway than hatchery-reared Cultus Lake sockeye smolts in the prior 2004-2007 study period.

Seasonal Changes in Sub-Yearling Chinook Salmon Diet in the Columbia River Estuary

By: Troy Wilcox Mentor: Laurie Weitkamp

The goal of this study is to examine seasonal changes in sub-yearling Chinook salmon diet in the Columbia River estuary and investigate any behavior changes these might indicate. Analysis of the stomach content was examined using percent prey composition and percent fullness. The sub-yearling Chinook used in this study were primarily from 2007 and 2009 with a small number from spring 2008. The results indicate a significant shift in diet between fall and spring 2007 and fall and spring 2009 largely due to a shift from eating amphipods in the spring to decapods and fish in the fall. This suggests that the salmon switch from an exclusively freshwater/estuarine prey to one more influenced by marine prey. This change is likely a mechanism to increase overall fitness and survival. This behavioral change may be in response to greater food availability in salt water and to escape late season hot water. The first reason is indicated by a calculated percent fullness of 1.3 in the fall and only .8 in the spring. The second reason is due to the large number of dams on the Columbia River which allow the river to warm in late summer to far above historic values. This information is important because understanding salmon behavior is critical in developing successful management plans.

Relative effects of freshwater and ocean indices on marine survival of Columbia River sockeye

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In 2010, more than 386,000 adult sockeye salmon *Oncorhynchus nerka* returned to the Columbia River Basin. Most were fish of wild origin, primarily from the Okanogan River Basin, and to a lesser extent the Wentachee system, and most were products of the 2008 outmigration. The adult return to Bonneville Dam in 2010 was the highest since prior to construction of Bonneville Dam in 1938. Based on the estimated number of wild smolts passing McNary Dam in 2008, 1- and 2-ocean adult returns to date, and expected 3-ocean returns from the 2008 outmigration, we estimate the smolt-to-adult return rate (SAR) from the 2008 outmigration will exceed 25%; far exceeding the estimated 9.4% SAR from 2000 outmigration. To evaluate conditions that may have influenced this high SAR, and the SARs that varied from 0.24-9.4% over the period from 1985-2007, we considered 17 different variables representing different freshwater and ocean. Using model selection procedures, we found that of the top 7 models with the lowest ΔAICc values, 6 were 3-variable models and had $R^2 \sim 0.73$-0.74. The other model was a 2-variable model with $R^2 \sim 0.70$. The top 7 models all included April upwelling and 6 of 7 (including the 2-variable model) included the Pacific Northwest Index (PNI). The third variable was either another ocean index or in 2 cases, a freshwater index (one flow and one precipitation). While the analyses were primarily correlative and limited by the type and amount of data currently available, we conclude that the factors responsible for the high return in 2010 largely acted on fish downstream of Bonneville Dam and during the marine component of their life cycle, and not in the river upstream of Bonneville Dam.

Salmon CSI: Web-based training and digital image reference library for diet analysis of marine predators

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Diet analyses are a fundamental element of ecological science because they define the trophic links forming ecosystem structure. Knowledge of diet composition is used in the study of bioenergetics, predator-prey interactions, food web structure, and ecosystem energy flow. As fisheries management incorporates ocean salmon ecology into forecasts and ecosystem management plans, information on the diets of salmon and salmon predators will be required.

High resolution digital cameras and digital imaging software now make it possible to distinguish a wider array of fish bone types and structures in diet samples. Images can be enhanced, stored digitally, and subsequently used to improve resolution and accuracy of prey identification. Unlike physical specimens, digital images can be made instantly available to an unlimited number of users. We plan to develop and launch a website that would make updated bone analysis protocols, training materials, and digital images available to the research community in the Pacific Northwest. The goal of our project is to improve training, accuracy, and efficiency of diet analyses of fish remains in marine predator diets. Images of diagnostic bones from specimens of known origin would provide updated reference and training material to address ecosystem information needs for Puget Sound, the Northern California Current, and West Coast estuaries. Communicating information through a web site will be much more efficient than filling requests on a case-by-case basis; it will reach a larger, broader user community; and it will allow update and expansion of content as methodological improvements or new reference material became available.