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Bibliography of Publications on the Marine Ecology of Juvenile Pacific Salmon in North America, 2006-2014

by

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Abstract:

In this document, we provide a compiliation of primary publications in peer-reviewed journals, as well as applicable NPAFC publications (Bulletin and Documents) that have been published on juvenile Pacific salmon (*Oncorhynchus* spp.) by North American scientists since 2006. This compilation formed the basis of an overview on recent progress in understanding the marine ecology of juvenile salmon in North America that was presented at the "Third International Workshop on Migration and Survival Mechanisms of Juvenile Salmon and Steelhead in Ocean Ecosystems" in Honolulu.

Introduction:

The marine ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) is of the utmost importance to the persistence of salmon stocks. For many Pacific salmon stocks, the mortality rates in the first year of ocean life are a good predictor of year-class strength. Thus, determining the ecological factors that affect mortality during this time is significant for understanding variation in recruitment.

In Trudel and Hertz (2013), we reviewed recent progress in understanding the marine ecology of juvenile salmon in North America since the "Second NPAFC International Workshop on Factors Affecting Production of Juvenile Salmon" held in Sapporo, Japan, in 2006. Here, we provide an updated bibliography of material that has been published up to April 1, 2014. This compilation was requested by many participants at the workshop and includes primary publications in peer-reviewed journals, as well as applicable NPAFC publications (Bulletin and Documents). From primary publications, we did not include review papers, or comments and responses. Similarly, we excluded papers that only considered methodological topics (e.g effects of acoustic tags). For NPAFC publications, we did not include extended abstracts, or papers not reporting new results pertaining to the marine ecology of juvenile salmon. We thank the many authors who provided information for this bibliography.

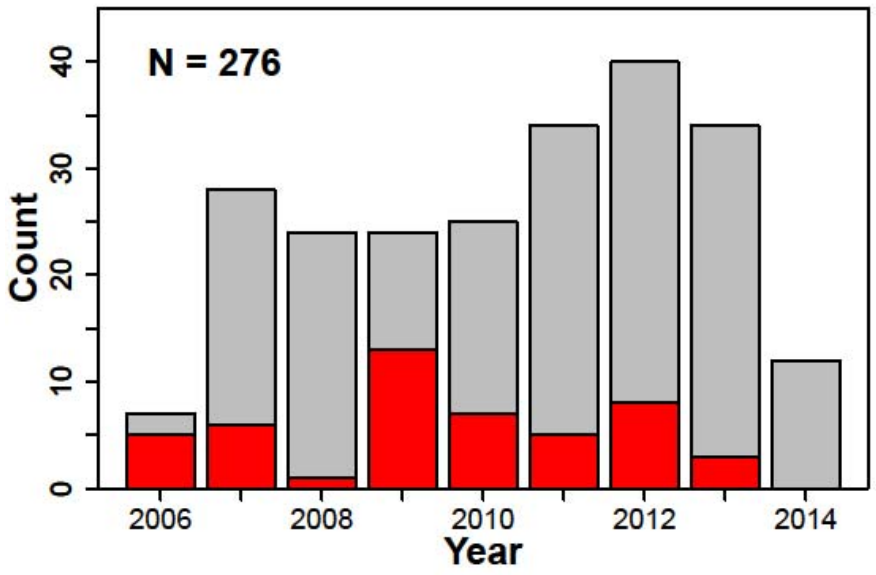

Figure 1: Number of peer-reviewed journal articles (grey bars) and NPAFC publications (red bars) published between 2006 and January 2014 pertaining to the marine ecology of juvenile Pacific salmon in North America.

References:

Trudel, M. & Hertz, E. (2013). Recent Advances in Marine Juvenile Pacific Salmon Research in North America. *North Pacific Anadromous Fish Commission Technical Report, 9*, 11-20.

Agler, B. A., Ruggerone, G. T., Wilson, L. I., & Mueter, F. J. (2013). Historical growth of Bristol Bay and Yukon River, Alaska chum salmon (*Oncorhynchus keta*) in relation to climate and inter- and intraspecific competition. *Deep Sea Research Part II: Topical Studies in Oceanography*, *94*, 165–177. doi:10.1016/j.dsr2.2013.03.028

We examined Bristol Bay and Yukon River adult chum salmon scales to determine whether climate variability, such as changes in sea surface temperature and climate indices, and high pink and Asian chum salmon abundance reduced chum salmon growth. Annual marine growth increments for 1965–2006 were estimated from scale growth measurements and were modeled as a function of potential explanatory variables using a generalized least squares regression approach. First-year growth of salmon originating from Bristol Bay and the Yukon River showed increased growth in association with higher regional ocean temperatures and was negatively affected by wind mixing and ice cover. Third-year growth was lower when Asian chum salmon were more abundant. Contrary to our hypothesis, warmer large-scale sea surface temperatures in the Gulf of Alaska were also associated with reduced third-year growth. Negative effects of high abundances of Russian pink salmon on third-year growth provided some evidence for interspecific interactions, but the effects were smaller than the effects of Asian chum salmon abundance and Gulf of Alaska sea surface temperature. Although the relative effects of Asian chum salmon and sea surface temperature on the growth of Yukon and Bristol Bay chum salmon were difficult to untangle, we found consistent evidence that high abundances of Asian chum salmon contributed to a reduction in the growth of western Alaska chum salmon.

Andrews, A. G., Farley Jr, E. V., Moss, J. H., Murphy, J. M., & Husoe, E. F. (2009). Energy density and length of juvenile pink salmon *Oncorhynchus gorbuscha* in the eastern Bering Sea from 2004 to 2007: a period of relatively warm and cool sea surface temperatures. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 183–189.

Juvenile pink salmon (*Oncorhynchus gorbuscha*) were examined in the eastern Bering Sea from 2004 to 2007 to assess the influence of ocean temperature on whole body energy content (WBEC), length, and diet. Fish were collected during the United States Bering-Aleutian Salmon International Study (U.S. BASIS) surveys in the eastern Bering Sea. Warmer spring and summer sea surface temperatures prevailed from 2004 to 2005 on the eastern Bering Sea shelf, whereas cooler spring and summer sea surface temperatures occurred from 2006 to 2007.Juvenile pink salmon changed diet between the warm and cool years. Walleye pollock *Theragra chalcogramma* dominated the diet (> 50% wet mass) in warm years, while walleye pollock were nearly absent from the diet in cool years. Juvenile pink salmon lengths were significantly longer in warm years but WBEC was significantly lower. We interpret our results to indicate that length is not always a reliable measure of energy status

Araujo, A.H., Holt, C., Curtis, J. M. R., Perry, R. I., Irvine, J. R., & Michielsens, C. G. J. (2013). Building an ecosystem model using mismatched and fragmented data: A probabilistic network of early marine survival for coho salmon *Oncorhynchus kisutch* in the Strait of Georgia. *Progress in Oceanography*, *115*, 41–52. doi:10.1016/j.pocean.2013.05.022

We evaluated the effects of biophysical conditions and hatchery production on the early

marine survival of coho salmon *Oncorhynchus kisutch* in the Strait of Georgia, British Columbia, Canada. Due to a paucity of balanced multivariate ecosystem data, we developed a probabilistic network that integrated physical and ecological data and information from literature, expert opinion, oceanographic models, and in situ observations. This approach allowed us to evaluate alternate hypotheses about drivers of early marine survival while accounting for uncertainties in relationships among variables. Probabilistic networks allow users to explore multiple environmental settings and evaluate the consequences of management decisions under current and projected future states. We found that the zooplankton biomass anomaly, calanoid copepod biomass, and herring biomass were the best indicators of early marine survival. It also appears that concentrating hatchery supplementation during periods of negative PDO and ENSO (Pacific Decadal and El Niño Southern Oscillation respectively), indicative of generally favorable ocean conditions for salmon, tends to increase survival of hatchery coho salmon while minimizing negative impacts on the survival of wild juveniles. Scientists and managers can benefit from the approach presented here by exploring multiple scenarios, providing a basis for open and repeatable ecosystem-based risk assessments when data are limited.

Armstrong, J. L., Myers, K. W., Beauchamp, D. A., Davis, N. D., Walker, R. V., Boldt, J. L., Piccolo, J. J., Haldorson, L. J., & Moss, J. H. (2008). Interannual and spatial feeding patterns of hatchery and wild juvenile pink salmon in the Gulf of Alaska in years of low and high survival. *Transactions of the American Fisheries Society*, *137*(5), 1299–1316. doi:10.1577/T07-196.1

To improve understanding of the mechanisms affecting growth and survival, we evaluated the summer diets and feeding patterns (prey composition, energy density, and stomach fullness) of hatchery and wild juvenile pink salmon *Oncorhynchus gorbuscha* in Prince William Sound (PWS) and the northern coastal Gulf of Alaska (CGOA). Our

study (1999-2004) included 2 years of low (~3%), mid (~5%), and high (~8-9%)

survival of PWS hatchery pink salmon. Because variations in diet should affect growth and ultimately survival, we expected that the variations in diet, growth, and survival would be correlated. During August in the CGOA, pteropod-dominated diets and higher gut fullness corresponded to high survival (5-9%), and copepod-dominated diets and lower gut fullness corresponded to low survival (3%). Within years, no significant differences were found in diet composition or gut fullness between hatchery and wild fish or among the four PWS hatchery stocks. Diets varied by water mass (habitat) as juveniles moved from PWS to more saline habitats in the CGOA. In July, when juveniles were most abundant in PWS, their diets were dominated by pteropods and hyperiid amphipods. The diets of fish that moved to inner-shelf (i.e., the least-saline) habitat in the CGOA in July were dominated by larvaceans in low-survival years and pteropods in high-survival years. Diet quality was higher in CGOA habitats than in PWS in July. In August, fish moved to the more productive, more saline water masses in the CGOA, where large copepods and pteropods were dominant prey and diet quality was better than in PWS. Our results indicate that spatial variation in the diets of juvenile pink salmon in July and

the timing of migration to the CGOA play a critical role in marine growth and survival.

Ashander, J., Krkosek, M., & Lewis, M. (2012). Aquaculture-induced changes to dynamics of a migratory host and specialist parasite: a case study of pink salmon and sea lice. *Theoretical Ecology*, *5*, 231–252.

Exchange of diseases between domesticated and wild animals is a rising concern for conservation. In the ocean, many species display life histories that separate juveniles from adults. For pink salmon (*Oncorhynchus gorbuscha*) and parasitic sea lice (*Lepeophtheirus salmonis*), infection of juvenile salmon in early marine life occurs near salmon sea-cage aquaculture sites and is associated with declining abundance of wild salmon. Here, we develop a theoretical model for the pink salmon/sea lice host–parasite system and use it to explore the effects of aquaculture hosts, acting as reservoirs, on dynamics. Because pink salmon have a 2-year lifespan, even- and odd-year lineages breed in alternate years in a given river. These lineages can have consistently different relative abundances, a phenomenon termed "line dominance". These dominance relationships between host lineages serve as a useful probe for the dynamical effects of introducing aquaculture hosts into this host–parasite system. We demonstrate how parasite spillover (farm-to-wild transfer) and spill-back (wild-to-farm transfer) with aquaculture hosts can either increase or decrease the line dominance in an affected wild population. The direction of the effect depends on the response of farms to wild-origin infection. If aquaculture parasites are managed to a constant abundance, independent of the intensity of infections from wild to farm, then line dominance increases. On the other hand, if wild-origin parasites on aquaculture hosts are proportionally controlled to their abundance then line dominance decreases.

Atcheson, M. E., Myers, K. W., Beauchamp, D. A., & Mantua, N. J. (2012). Bioenergetic response by steelhead to variation in diet, thermal habitat, and climate in the North Pacific Ocean. *Transactions of the American Fisheries Society*, *141*(4), 1081–1096. doi:10.1080/00028487.2012.675914

Energetic responses of steelhead *Oncorhynchus mykiss* to climate-driven changes in marine conditions are expected to affect the species' ocean distribution, feeding, growth, and survival. With a unique 18-year data series (1991–2008) for steelhead sampled in the open ocean, we simulated interannual variation in prey consumption and growth efficiency of steelhead using a bioenergetics model to evaluate the temperature-dependent growth response of steelhead to past climate events and to estimate growth potential of steelhead under future climate scenarios. Our results showed that annual ocean growth of steelhead is highly variable depending on prey quality, consumption rates, total consumption, and thermal experience. At optimal growing temperatures, steelhead can compensate for a low-energy diet by increasing consumption rates and consuming more prey, if available. Our findings suggest that steelhead have a narrow temperature window in which to achieve optimal growth, which is strongly influenced by climate-driven changes in ocean temperature.

Atcheson, M. E., Myers, K. W., Davis, N. D., & Mantua, N. J. (2012). Potential trophodynamic and environmental drivers of steelhead (*Oncorhynchus mykiss*) productivity in the North Pacific Ocean. *Fisheries Oceanography*, *21*(5), 321–335.

doi:10.1111/j.1365-2419.2012.00627.x
Information on prey availability, diets, and trophic levels of fish predators and their prey provides a link between physical and biological changes in the ecosystem and subsequent productivity (growth and survival) of fish populations. In this study two long-term data sets on summer diets of steelhead (*Oncorhynchus mykiss*) in international waters of the central North Pacific Ocean (CNP; 1991–2009) and Gulf of Alaska (GOA; 1993–2002) were evaluated to identify potential drivers of steelhead productivity in the North Pacific. Stable isotopes of steelhead muscle tissue were assessed to corroborate the results of stomach content analysis. We found the composition of steelhead diets varied by ocean age group, region, and year. In both the GOA and CNP, gonatid squid (*Berryteuthis anonychus*) were the most influential component of steelhead diets, leading to higher prey energy densities and stomach fullness. Stomach contents during an exceptionally warm year in the GOA and CNP (1997) were characterized by high diversity of prey with low energy density, few squid, and a large amount of potentially toxic debris (e.g., plastic). Indicators of good diets (high proportions of squid and high prey energy density) were negatively correlated with abundance of wild populations of eastern Kamchatka pink salmon (*O. gorbuscha*) in the CNP. In conclusion, interannual variations in climate, abundance of squid, and density-dependent interactions with highly-abundant stocks of pink salmon were identified as potential key drivers of steelhead productivity in these ecosystems. Additional research in genetic stock identification is needed to link these potential drivers of productivity to individual populations.

Baldwin, R. E., Miller, T. W., Brodeur, R. D., & Jacobson, K. C. (2008). Expanding the foraging history of juvenile Pacific salmon: combining stomach-content and macroparasite- community analyses for studying marine diets. *Journal of Fish Biology*, *72*(6), 1268–1294. doi:10.1111/j.1095-8649.2007.01792.x
Stomach contents and macroparasites were examined from the same fishes collected off Oregon and California in June and August of 2000 and 2002 to provide a more comprehensive description of the diet of juvenile Chinook salmon *Oncorhynchus tshawytscha* and coho salmon *Oncorhynchus kisutch* during their first few months at sea. Temporal and spatial similarities of the two data sets were assessed using multivariate analyses. Both stomach contents and macroparasite communities indicated that fishes, euphausiids and hyperiid amphipods were consumed by both salmonid species, although their relative contribution to each species diet was highly variable. In June, the greater abundances of parasite species in Chinook salmon compared to coho salmon suggested that Chinook salmon consumed more infected intermediate hosts (crustaceans or larval fishes) shortly after ocean entry (April and May). Although the macroparasite analysis lacked the specificity of stomach analysis in identifying prey, macroparasites can provide a longer term history of feeding and diet information for fishes with empty stomachs.

Balfry, S., Welch, D. W., Atkinson, J., Lill, A., & Vincent, S. (2011). The effect of hatchery release strategy on marine migratory behaviour and apparent survival of Seymour River steelhead smolts (*Oncorhynchus mykiss*). *PLoS ONE*, *6*(3), e14779. doi:10.1371/journal.pone.0014779
Early marine migratory behaviour and apparent survival of hatchery-reared Seymour River steelhead (*Oncorhynchus mykiss*) smolts was examined over a four year period

(2006–2009) to assess the impact of various management strategies on improving early marine survival. Acoustically tagged smolts were released to measure their survival using estuary and coastal marine receivers forming components of the Pacific Ocean Shelf Tracking (POST) array. Early marine survival was statistically indistinguishable between releases of summer run and winter run steelhead races, night and day releases, and groups released 10 days apart. In 2009, the survival of summer run steelhead released into the river was again trialed against groups released directly into the ocean at a distance from the river mouth. Apparent survival was improved significantly for the ocean released groups. The health and physiological status of the various release groups were monitored in years 2007–2009, and results indicate that the fish were in good health, with no clinical signs of disease at the time of release. The possibility of a disease event contributing to early marine mortality was further examined in 2009 by vaccinating half of the released fish against common fish diseases (vibriosis, furunculosis). The results suggest that marine survival may be enhanced using this approach, although not to the extent observed when the smolts were transported away from the river mouth before release. In summary, direct experimental testing of different release strategies using the POST array to measure ocean survival accelerated the scientific process by allowing rapid collection of data which enabled the rejection of several existing theories and allowed tentative identification of several new alternative approaches that might improve early marine survival of Seymour River steelhead.

Beacham, T. D., Candy, J. R., Sato, S., Urawa, S., Le, K. D., & Wetklo, M. (2009). Stock origins of chum salmon (*Oncorhynchus keta*) in the Gulf of Alaska during winter as estimated with microsatellites. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 15–23.

A microsatellite baseline incorporating over 53,000 chum salmon (*Oncorhynchus keta*) sampled from over 380 locations in Asia and North America was applied to estimate stock composition in mixed-stock fishery samples from the Gulf of Alaska. High resolution of these mixed-stock samples was possible, with 1 reporting group developed for Korean populations, 7 groups for Japanese populations, 8 groups for Russian populations,15 groups for Alaskan populations, 5 groups for Canadian Yukon River populations, 16 groups for British Columbia populations, and 5 groups for Washington populations. In February 2006 samples from the Gulf of Alaska (145°W), chum salmon in more northern areas (54°N) were primarily of North American origin (55% British Columbia, 30% Alaska), but in more southern areas (48°N), nearly 40% of chum salmon sampled were of Japanese origin (Sea of Okhotsk and Pacific coasts of Hokkaido), and 30% were of Russian origin (Kamchatka and northeast Russia). Ocean age-1 chum salmon spending their first winter in the Gulf of Alaska were almost entirely from southeast Alaska (39%), Prince William Sound (31%), or southern British Columbia (26%). However, by the second winter, 30% of ocean age-2 chum salmon were identified as of Asian origin (18% Japanese, 12% Russian).

Beacham, T. D., Candy, J. R., Tucker, S., Sato, S., Urawa, S., Moss, J. H., & Trudel, M. (2012). Nonrandom distribution of Canadian sockeye salmon rearing in the Bering Sea and coastal Gulf of Alaska. *North Pacific Anadromous Fish Commission Document*, *1403*, 10 pp.

Individual identification of sockeye salmon (*Oncorhynchus nerka*) caught in coastal Gulf of Alaska and central Bering Sea sampling sites was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for 2,255 juvenile sockeye salmon obtained from coastal surveys in the Gulf of Alaska, and 627 immature individuals from surveys in the Bering Sea. A 387-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the individual identification of the fish sampled, with emphasis on Canadian-origin salmon. Not all Fraser River stocks displayed the same trends in relative abundance with respect to coastal Gulf of Alaska sampling groups, perhaps indicative of differential initial rearing environments. Immature sockeye salmon from some Canadian stocks rear in the Bering Sea at levels that are not commensurate with subsequent abundance as measured by escapement, indicative of a nonrandom distribution of rearing areas by stock. Immature Harrison River sockeye salmon from the lower Fraser River have only been identified in samples originating from waters in British Columbia. The marine rearing areas subsequent to the first year of marine residence are unknown for this population.

Beamish, R. J., Gordon, E., Neville, C.-E., & Sweeting, R. (2006). Evidence of a linkage between fall-winter ocean conditions and the critical size hypothesis for a study of pink salmon in the central coast area of British Columbia. ***North Pacific Anadromous Fish Commission Document*****,** ***982*****, 14 pp.**

Intercirculi spacing of scales from the even year line of pink salmon from stocks in areas of the central coast of British Columbia was measured for the 2003/2004 and 2005/2006 brood years. All juvenile pink salmon in the 2003 sample had five circuli by the end of June. The average spacing of the first five circuli of juveniles in 2003 was larger than the spacing of the first five circuli on the scales of the adults from the same brood year that returned to spawn in 2004. In 2006, the spacing observed on the scales of returning adult pink salmon from the same line (even year) was significantly larger than the spacing observed on scales of juveniles in 2005. The marine survival was exceptionally high in 2003/2004 and lower in 2005/2006. We propose that there was not a critical size effect in 2003/2004 because the feeding and ocean conditions were favourable for juvenile pink salmon after they left the coastal area in 2003. The ocean conditions probably were less favourable for growth and survival in 2005/2006, resulting in large mortalities of the smaller pink salmon consistent with the critical size-critical period hypothesis. The timing of the size-based mortality is not known except that significant mortality of the smaller pink salmon occurred after June, 2005.

Beamish, R. J., Lange, K. L., Neville, C.-E., Sweeting, R. M., & Beacham, T. D. (2011). Structural patterns in the distribution of ocean- and stream-type juvenile chinook salmon populations in the Strait of Georgia in 2010 during the critical early marine period. ***North Pacific Anadromous Fish Commission Document*****,** ***1354*****, 27 pp.**

There is increasing evidence that brood year strength of chinook salmon is mostly determined in the first few months in the ocean, particularly in a stressful environment. During this period in the Strait of Georgia, some chinook salmon populations have a distinct and persistent behaviour that relates to ocean entry times or concentrates their distributions in areas or at particular depths. Populations with both ocean- and stream-type life histories remain within the Strait of Georgia for three to four months, depending

on their ocean entry times. These distinct and persistent behaviours during the critical early marine period indicate that conditions in the Strait of Georgia have a major impact on the productivity of the various populations. Populations of both stream- and ocean-type fish remained in the Strait of Georgia through to mid September, indicating that conditions within the Strait of Georgia would have a major impact on growth and survival. The major structural change in the population composition between July and September and the observation that the late ocean entry populations have a higher productivity than populations with an earlier ocean entry is evidence that recent changes in the environment of the Strait of Georgia are affecting the combined productivity of all populations. Other studies have shown that the environment within the Strait of Georgia has been changing and the changes appear to be long-term trends. Thus, it is advisable that the management of chinook salmon recognize the differences among populations within the early marine period as these differences may explain the reason for poor or good survival. Populations with good survival have the resilience needed to adapt to future environmental changes in the Strait of Georgia.

Beamish, R. J., Lange, K. L., Neville, C.-E., Sweeting, R., Beacham, T. D., & Preikshot, D. (2010). Late ocean entry of sea-type sockeye salmon from the Harrison River in the Fraser River drainage results in improved productivity. ***North Pacific Anadromous Fish Commission Document*****,** ***1283*****, 30 pp.**

The productivity of sockeye salmon from the Fraser River declined from the early 1990s to 2009. However, the productivity of sea-type sockeye salmon from the Harrison River increased. Sockeye salmon with a sea-type life history enter the ocean after emerging from the gravel without rearing for a year in a lake. Sea-type sockeye salmon are rare in the Fraser River, representing only about one percent of the average production. However, in the most recent five years they represented an average of 9%. They enter the Strait of Georgia about six weeks later than the lake-type sockeye salmon and remain in the Strait of Georgia for three to four months during which they more than double their size. There is evidence that competition from juvenile pink salmon affects their age at return which may indicate that growth rates in the early marine period are associated with age at return. The condition of the juvenile sea-type Harrison River fish in September, compared to the condition of all other juvenile sockeye salmon in July, indicates that the improved survival is a result of better feeding conditions later in the summer in the Strait of Georgia. Harrison River sockeye salmon probably leave the Strait of Georgia through Juan de Fuca Strait in the south, compared to the lake-type that migrate north out of the Strait of Georgia through Johnstone Strait. The increased production of the sea-type life history is evidence of the importance of managing the diversity of life history strategies within sockeye salmon populations to maximize their survival in a changing climate.

Beamish, R. J., Jones, S., Neville, C.-E., Sweeting, R., Karreman, G., Saksida, S., & Gordon, E. (2006). Exceptional marine survival of pink salmon that entered the marine environment in 2003 suggests that farmed Atlantic salmon and Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast of Canada. ***ICES Journal of Marine Science: Journal du Conseil*****,** ***63*****(7), 1326–1337. doi:10.1016/j.icesjms.2006.04.011**

Juvenile pink salmon that entered a marine ecosystem along the eastern margin of Queen

Charlotte Strait in 2003 and returned as adults in 2004 had very high marine survival. The early seaward migration and midsummer rearing in 2003 were in an area containing 16 active Atlantic salmon farms. Two species of sea louse, *Lepeophtheirus salmonis* and *Caligus clemensi*, were commonly found on farmed salmon and juvenile Pacific salmon during the early rearing period of the pink salmon. Mobile *L. salmonis* and *C. clemensi* were most abundant on farmed Atlantic salmon from February to May and on pink salmon in June. Chalimus stages were the dominant stages on pink salmon to the end of May. Mobile stages of *C. clemensi* were the dominant stages and species of sea louse on farmed Atlantic salmon and pink salmon at about the same time in June. DNA studies showed that local juvenile pink salmon were in the area until August. The exceptional returns of the brood year suggest that pink salmon populations and farmed Atlantic salmon coexisted successfully during 2003 within an environment that included sea lice and farmed Atlantic salmon. The processes responsible for the high marine survival cannot be identified with certainty, but they could include increased freshwater discharge in 2003, which may have resulted in lower salinity less favourable to sea louse production, increased inflow of nutrient-rich water to the study area, and the introduction of a Provincial Action Plan that required mandatory louse monitoring and established a fallowed migration corridor for pink salmon.

Beamish, R. J., Neville, C.-E., & Sweeting, R. M. (2012). An early marine life history strategy for Fraser River sockeye salmon. *North Pacific Anadromous Fish Commission Document*, *1423*, 23 pp.

The Fraser River is one of the major producers of sockeye salmon. Most of the populations have fry that spend one year in a lake before migra ting to the ocean. A small percentage spends two years in a lake, and a small percentage are sea type and migrate directly into the ocean in the year that they emerge from the gravel. Most smolts from the lake-type populations migrate into the Strait of Georgia in early May and by the end of June they are spread out from the Gulf Islands area in the Strait of Georgia to at least Hecate Strait, a linear distance of about 1,000 km. Most sea-type juveniles enter the Strait of Georgia in July and remain until about November. Although the sea-type population was only about 1.2 % of the production in the since 1952, it has been 5.0% in the last six years. We propose that sockeye salmon smolts from the Fraser River migrate and disperse over a vast area of the ocean in the critical early marine period, as well as using the Strait of Georgia over an extended period, to ensure that some juveniles always find favourable ocean conditions and abundant prey. This means that juvenile sockeye salmon from the Fraser River are spread out in time and space in the early marine period. It is important to recognize that there is an early marine life history strategy for Fraser River sockeye salmon and that the strategy is an adaptation to optimize the survival of the aggregate of populations over a period of hundreds to thousands of years of changing climate and ocean conditions.

Beamish, R. J., Neville, C. M., Sweeting, R. M., Jones, S. R. M., Ambers, N., Gordon, E. K., Hunter, K. L., & McDonald, T. E. (2007). A proposed life history strategy for the salmon louse, *Lepeophtheirus salmonis* in the subarctic Pacific. *Aquaculture*, *264*(1–4), 428–440. doi:10.1016/j.aquaculture.2006.12.039

The sea louse, *Lepeophtheirus salmonis*, is commonly found on Pacific salmon that are

rearing in the central North Pacific Ocean and adjacent seas (subarctic Pacific). Large numbers of sea lice have also been observed on all species of adult Pacific salmon when they return to coastal marine areas in the summer during their spawning migration. We propose that the transport of sea lice into coastal areas is a strategy employed by *L. salmonis* to improve their productivity by improving the transmission potential of the infectious stage when host densities are decreased in the open ocean and increased in the coastal areas. Juveniles of the species of Pacific salmon inhabit the same areas at the same time as the returning adult salmon and, according to the proposed strategy, will become infected from sea lice on the adult Pacific salmon. Juvenile pink, chum and sockeye salmon will carry these sea lice into the open ocean when they migrate away from the coastal areas later in the year. The offspring of these sea lice on pink, chum and sockeye would infect Pacific salmon on the high seas and thus maintain high abundances of sea lice. Juvenile coho and Chinook salmon that remain in the coastal areas would serve as hosts for the sea lice over the winter. The sea lice on these resident coho and Chinook salmon would infect juvenile Pacific salmon that enter the ocean in the early spring. The strategy would result in the infection of juvenile Pacific salmon throughout their range in all coastal areas.

Beamish, R. J., Neville, C., Sweeting, R., & Lange, K. (2012). The synchronous failure of juvenile Pacific salmon and herring production in the Strait of Georgia in 2007 and the poor return of sockeye salmon to the Fraser River in 2009. *Marine and Coastal Fisheries*, *4*(1), 403–414. doi:10.1080/19425120.2012.676607

Trawl studies from 1998 to 2009 indicated that juvenile Pacific salmon *Oncorhynchus* spp. and Pacific herring *Clupea pallasii* represented 98% of the fish in the surface waters of the Strait of Georgia during the day in the spring and early summer. Standardized catches of all juvenile Pacific salmon in the trawl surveys were lowest in 2007. Catches of young-of-the-year Pacific herring were also extremely low in 2007. Three years later, the 2007 year-class had the lowest recruitment to the fishery in recorded history. In 2007, juvenile coho salmon *O. kisutch* and Chinook salmon *O. tshawytscha* were small and had the lowest condition of the fish in all surveys as well as a high percentage of empty stomachs. The early marine survival of coho salmon in 2007 and the total survival in 2008 were exceptionally poor. Trawl catches of juvenile chum salmon *O. keta* in 2007 were the lowest of all surveys. Adult chum salmon from these juveniles that returned in 2010 had extremely poor survival. Juvenile sockeye salmon *O. nerka* that entered the Strait of Georgia in the spring of 2007 and returned to the Fraser River as adults in 2009 also had such exceptionally poor marine survival that a judicial inquiry was conducted to determine the causes. The synchronous poor growth, survival, or both of all of the major species in the surface waters of the Strait of Georgia in the spring of 2007 indicated that there was a common cause which we propose as poor food production. The causes of the high mortality likely represented a unique extreme in the variability of the factors that normally affect the survival of juvenile Pacific salmon and Pacific herring in the early marine period in the Strait of Georgia.

Beamish, R. J., & Sweeting, R. (2012). Exceptionally poor survival of Chinook salmon

entering the Strait of Georgia in 2007 is consistent with the synchronous poor survival of other Pacific salmon and Pacific herring. ***North Pacific Anadromous Fish Commission Document*****,** ***1424*****, 15 pp.**
Indices of marine survival of eight populations of Chinook salmon entering the Strait of Georgia identified the ocean entry year 2007 as a year of generally poor survival. Marine survival was exceptionally low for the Harrison River population which is the largest Chinook salmon population in British Columbia. The low survival is consistent with the poor survival and poor growth of the other species of Pacific salmon and juvenile Pacific herring that reared in the Strait of Georgia in the spring of 2007.

Beamish, R. J., Sweeting, R., Beacham, T. D., Lange, K. L., & Neville, C. M. (2010). A late ocean entry life history strategy improves the marine survival of chinook salmon in the Strait of Georgia. ***North Pacific Anadromous Fish Commission Document*****,** ***1282*****, 14 pp.**
The productivity of juvenile chinook salmon that enter the Strait of Georgia has generally declined over the past two decades. One aggregate of 15 populations from the South Thompson drainage of the Fraser River drainage, however, has increased. The increased productivity appears to be related to a life history strategy that results in juveniles entering the ocean in July, much later than most other chinook salmon populations. Juveniles from the South Thompson drainage are generally not common in the Strait of Georgia early in July, but they are abundant in September. They appear to leave the Strait of Georgia by November, probably through Juan de Fuca Strait. Late ocean entry, sea-type, Harrison River sockeye salmon are also surviving better in recent years than the majority of sockeye salmon that are entering the ocean earlier. Because pink and chum salmon that enter the ocean early are at high levels of abundance, it is possible that very early and very late ocean entry times are life history strategies that match the current state of the Strait of Georgia ecosystem.

Beamish, R. J., Sweeting, R. M., Lange, K. L., & Neville, C. M. (2008). Changes in the population ecology of hatchery and wild coho calmon in the Strait of Georgia. ***Transactions of the American Fisheries Society*****,** ***137*****(2), 503–520. doi:10.1577/T07-080.1**
An analysis of the results of a 10-year study of the population ecology of juvenile hatchery and wild coho salmon *Oncorhynchus kisutch* in the Strait of Georgia produced new information about the interannual and interseasonal fluctuations in abundance and marine survival. A decline in the percentage of hatchery coho salmon was related to declines in hatchery fish abundance and marine survival; wild coho salmon abundance was more stable. The declining marine survival of hatchery coho salmon appeared to be related to a fixed average date of release from hatcheries and a possibility of earlier prey production. The relatively stable abundance of wild coho salmon may relate to a natural trend toward earlier ocean entry dates. Oscillations in hatchery coho salmon percentage and abundance were related to oscillations in abundance of juvenile pink salmon *O. gorbuscha*. The impact of oscillating density affected marine survival of hatchery coho salmon more than that of wild coho salmon. Marine survival and abundance of hatchery and wild coho salmon in July were positively related to average fork length, indicating that growth within the first few months after ocean entry affected marine survival.

However, absolute size was not important, as wild coho salmon were consistently smaller than hatchery coho salmon. Wild coho salmon responded to conditions in the marine ecosystem differently than hatchery coho salmon, as relationships among growth, survival, and abundance were apparent for wild coho salmon earlier in the year than for hatchery fish. The length increase between July and September was inversely related to marine survival, suggesting that fish that were larger in July grew less and survived better because they were storing more lipids than smaller coho salmon. The study indicated that a more experimental management strategy is needed for both hatchery and wild coho salmon.

Beamish, R. J., Sweeting, R. M., Lange, K. L., Noakes, D. J., Preikshot, D., & Neville, C. M. (2010). Early marine survival of coho salmon in the Strait of Georgia declines to very low levels. *Marine and Coastal Fisheries*, *2*(1), 424–439. doi:10.1577/C09-040.1
The marine survival of juvenile coho salmon *Oncorhynchus kisutch* from the time they enter the Strait of Georgia in mid-May to the time of our trawl survey in mid-September declined from an average of about 15% in 1998 to approximately 1% in 2007. Early marine survival rates for juvenile coho salmon have been consistently low (<5%) since 2002, and the rate of decline in early marine survival was greater for hatchery fish than for wild fish. This suggests that hatchery coho salmon are perhaps less able to survive than wild fish in the current marine ecosystem. The steady decline in total marine survival for coho salmon over the past four decades coincided with a warming of the Strait of Georgia, where both sea surface and sea bottom temperatures have increased by approximately 1°C since 1970. Another factor that appears to have contributed to the decline in early marine survival since the late 1990s is an increase in the number of days with an average sustained wind strength greater than 25 km/h. The linkage between wind strength and marine survival requires further study, but wind strength is known to affect the timing and level of primary productivity. The processes that caused the declining marine survival remain to be identified and may include factors associated with disease originating in both freshwater and salt water, metabolic stress, competition, and predation. The data suggest that coho salmon brood year strength is now mostly determined during the first 4 months spent in the Strait of Georgia. If the current low levels of marine survival continue, management initiatives to protect wild coho salmon will be urgently required, and it will be timely to critically evaluate the hatchery programs and policies.

Beamish, R. J., Sweeting, R., Neville, C. M., & Lange, K. L. (2006). Hatchery and wild percentages of coho salmon in the Strait of Georgia are related to shifts in species dominance. *North Pacific Anadromous Fish Commission Document*, *981*, 21 pp.
The Strait of Georgia is the major rearing area for juvenile Pacific salmon on the west coast of Canada. Historically, there have been major commercial and recreational fisheries for all five species of Pacific salmon in the strait. In recent years, fisheries for coho have collapsed. At the same time abundances of other species increased. Presently there may be three and a half times more juvenile Pacific salmon in the strait than in the past. Our studies of the hatchery percentages of wild and hatchery coho indicate that early food production for juvenile salmon may be shifting the Strait of Georgia to an

ecosystem that is more favourable for pink, chum and sockeye salmon and less favourable for coho and chinook salmon.

Beamish, R., Sweeting, R., Neville, C. M., & Lange, K. L. (2010). Competitive interactions between pink salmon and other juvenile Pacific salmon in the Strait of Georgia. *North Pacific Anadromous Fish Commission Document*, *1284*, 26 pp.
Hundreds of millions of juvenile pink salmon enter the Strait of Georgia from the Fraser River in even-numbered years. In odd-numbered years, there are very few juvenile pink salmon. This alternating pattern of very large and very small abundance provides an excellent opportunity to study the competitive interactions between juvenile pink salmon and other juvenile Pacific salmon in the Stra it of Georgia. In July, juvenile sockeye salmon were consistently smaller and had a higher percentage of empty stomachs in years of large pink salmon abundance. Other species of Pacific salmon also had higher percentages of empty stomachs in some years when pink salmon were abundant. The early marine survival of juvenile coho salmon was lower in years of pink salmon abundance, but this occurred mostly for hatchery coho salmon and not wild coho salmon. An interpretation is that wild coho salmon survive better than hatc hery coho salmon in a stressful environment. There was a consistent response between juvenile pink salmon and the dominant line of juvenile sockeye salmon that was present in the Strait of Georgia every four years. Catches of pink salmon were more abundant in July in this four-year cycle, but less abundant in September. However, the daily rate of growth of juvenile pink salmon between July and September was greater in the years when the dominant line of sockeye salmon was abundant earlier in the year. An explanation may relate to juvenile migration patterns, but the explanation remains to be discovered. The catches in 2010 were seven times higher than the average of all other surveys and the abundance estimate of 24 million juvenile pink salmon was five times the average abundance in all other surveys. This abundance may indicate that an exceptional return will occur in 2011. The large abundances of juvenile pink salmon and their interactions with other juvenile Pacific salmon in the Strait of Georgia indicates that the management of Pacific salmon returning to the Fraser River needs to extend beyond the stewardship of escapements and into the consequences of interactions among juveniles within the Strait of Georgia ecosystem.

Beamish, R. J., Sweeting, R. M., Neville, C. M., Lange, K. L., Beacham, T. D., & Preikshot, D. (2012). Wild chinook salmon survive better than hatchery salmon in a period of poor production. *Environmental Biology of Fishes*, *94*(1), 135–148. doi:10.1007/s10641-011-9783-5
The population dynamics of chinook salmon (*Oncorhynchus tshawytscha*) from the Cowichan River on Vancouver Island, British Columbia, Canada are used by the Pacific Salmon Commission as an index of the general state of chinook salmon coast wide. In recent years the production declined to very low levels despite the use of a hatchery that was intended to increase production by improving the number of smolts entering the ocean. In 2008, we carried out an extensive study of the early marine survival of the hatchery and wild juvenile chinook salmon. We found that both rearing types mostly remained within the Gulf Islands study area during the period when most of the marine mortality occurred for the hatchery fish. By mid September, approximately 1.3% of all

hatchery fish survived, compared to 7.8%–31.5% for wild fish. This six to 24 times difference in survival could negate an estimated increased egg-to-smolt survival of about 13% that is theorized to result through the use of a hatchery. Estimates of the early marine survival are approximate, but sufficient to show a dramatic difference in the response of the two rearing types to the marine nursery area. If the declining trend in production continues for both rearing types, modifications to the hatchery program are needed to improve survival or an emphasis on improving the abundances of wild stocks is necessary, or both. The discovery that the juvenile Cowichan River chinook salmon remain within a relatively confined area of the Gulf Islands within the Strait of Georgia offers an excellent opportunity to research the mechanisms that cause the early marine mortalities and hopefully contribute to a management that improves the production.

Beamish, R., Wade, J., Pennell, W., Gordon, E., Jones, S., Neville, C., Lang, K., & Sweeting, R. (2009). A large, natural infection of sea lice on juvenile Pacific salmon in the Gulf Islands area of British Columbia, Canada. *Aquaculture*, *297*(1–4), 31–37. doi:10.1016/j.aquaculture.2009.09.001

High levels of sea lice generally exceeding a prevalence of 60% were found on all species of juvenile Pacific salmon and on juvenile Pacific herring in the Gulf Islands area within the Strait of Georgia, British Columbia. Virtually all sea lice were *Caligus clemensi* and most stages were maturing or mature. There are no active fish farms in this area, indicating that this is a naturally occurring epizootic of sea lice. It is possible that the infection was associated with Pacific herring that spawned in the area in the spring, although the linkage between the spawning Pacific herring and the infection on Pacific salmon was not determined.

Beauchamp, D. A. (2009). Bioenergetic ontogeny: linking climate and mass-specific feeding to life-cycle growth and survival of salmon. *American Fisheries Society Symposium*, *70*, 1–19.

Size-selective mortality is a dominant factor regulating the dynamics of salmon populations. Body size, growth rate, and energy state during one life stage influence survival during that and subsequent life stages. Therefore, simultaneously examining allometric processes, foraging, and thermal constraints on growth within and among life stages can provide a powerful analytical framework for identifying critical periods and sizes during the life cycle of salmon, and for understanding the processes that contribute to the specific ecological bottlenecks confronting different species or stocks of salmon. A bioenergetics model was used to simulate generalized growth responses to a factorial combination of body size, daily feeding rate, and prey energy density over a continuous range of temperatures (0–24 C). The results of these simulations indicated that: 1) smaller salmon benefit from higher potential scope for growth or activity than larger salmon, based on the different allometric relationships for maximum consumption, metabolism, and waste; 2) optimal temperatures for growth decline with increasing body size; 3) optimal temperatures for growth also decline as daily rations decline; 4) thermal tolerances (temperature thresholds beyond which weight loss will occur) also shift to cooler temperatures for larger salmon and when ration sizes decline; 5) increasing the composite energy density of the diet can increase both optimal growth temperature and

thermal tolerance, especially at larger body sizes; 6) after spawners enter freshwater, the amount of energy and days available to migrate and successfully spawn at a given upstream location was very sensitive to ambient river temperature and the swimming speed required to reach the spawning grounds. When placed in the context of climate variability and seasonal shifts in temperature and food availability, these simulations suggest that growth will be more frequently limited by feeding rate (prey availability) and prey quality than by temperature, especially for smaller, younger life stages. Larger salmon should be more sensitive to temperature change, but reductions in optimal growth temperature and thermal tolerance would be magnified for all life stages if either feeding rate or prey quality were reduced. Given intense size-selective mortality during one or more early life stages, this simulation framework could be adopted to identify the key factors limiting growth to critical sizes during critical periods in the life cycle of specific salmon stocks.

Beauchamp, D. A., Cross, A. D., Armstrong, J. L., Myers, K. W., Moss, J. H., Boldt, J. L., & Haldorson, L. J. (2007). Bioenergetic responses by Pacific salmon to climate and ecosystem variation. ***North Pacific Anadromous Fish Commission Bulletin*****, *4*, 257–269.**

Salmon growth can respond to changes in temperature, food availability, food quality, and activity. Climatic variability can affect one or more of these factors, because different climate regimes are associated with different temporal-spatial patterns of temperature, salinity, and other oceanographic features that can alter ocean distribution patterns of salmon and cause shifts in assemblages of other organisms. Consequently, climate variability can simultaneously change the availability or productivity of exploitable prey, and the intensity of competition or predation experienced by salmon at various stages of ocean life. Variability across multiple factors canpotentially confound the understanding and prediction of salmon growth or survival. Bioenergetics models can account for changing thermal and food conditions explicitly, and are valuable analytical tools for isolating andevaluating the relative contribution of different factors (e.g., temperature, feeding rate, food availability, food quality) to the consumption and growth of salmon during different life stages. Model simulations, coupled with data on growth trajectories, diet composition, and thermal experience, provide estimates of: 1) consumption rates on eachprey (measures of both the importance of various prey to the energy budget of salmon, and the predation impact of salmon on prey species); 2) feeding rate as a proportion of the theoretical maximum consumption rate, a measure of relative food availability; and 3) growth efficiency, a measure of how much food was required to achieve the observed growth rate. We applied bioenergetics models to juvenile pink salmon in the Gulf of Alaska during years of low (2001) versus high (2002) ocean survival to examine feeding and growth performance between years while explicitly accounting for significant variability in stage-specific distribution, diet, growth, and consumption. From these simulations, we determined that higher feeding rates on pteropods, primarily during July–August 2002, explained the higher growth rates and larger body mass of juveniles that were associated with higher stage-specific marine survival for juveniles in 2002. Current bioenergetics models for salmonids provide valuable diagnostic and analytical tools. However, as modeling applications become more predictive and demanding, modifications and improvements will be required to

address important topics like behavior, variable activity costs, seasonal and ontogenetic energy allocation, and foraging models.

Benkwitt, C. E., Brodeur, R. D., Hurst, T. P., & Daly, E. A. (2009). Diel feeding chronology, gastric evacuation, and daily food consumption of juvenile Chinook salmon in Oregon coastal waters. *Transactions of the American Fisheries Society*, *138*(1), 111–120. doi:10.1577/T08-060.1

The diel feeding periodicity of juvenile Chinook salmon *Oncorhynchus tshawytscha* was determined from stomachs collected in coastal waters off Oregon in 2000 and 2003. Juvenile Chinook salmon exhibited a diurnal feeding pattern with morning and evening feeding periods. There were differences in the duration and magnitude of the dawn and dusk peaks between the 2 years. Gastric evacuation rates of euphausiid meals were estimated from laboratory experiments at 9.3, 10.7, and 13.9°C. Based on an exponential model, the instantaneous evacuation rates at these three temperatures were 0.0407, 0.0589, and 0.0807 per hour, respectively. The daily ration of juvenile Chinook salmon in Oregon coastal waters in 2000 and 2003 was estimated using three models. Using laboratory-derived evacuation rates, the Elliott and Persson and Eggers models produced daily ration estimates of 2.04% and 2.57% of body weight (BW), respectively, in 2000 and 2.93% and 2.46%BW in 2003. The MAXIMS model, which does not rely on laboratory-derived evacuation rates, produced higher estimates of daily ration (3.84% and 4.28%BW). Our diel feeding chronology, gastric evacuation rate, and daily ration estimates for juvenile Chinook salmon were comparable to those of other juvenile salmonids.

Bi, H., Peterson, W. T., Lamb, J., & Casillas, E. (2011). Copepods and salmon: characterizing the spatial distribution of juvenile salmon along the Washington and Oregon coast, USA. *Fisheries Oceanography*, *20*(2), 125–138. doi:10.1111/j.1365-2419.2011.00573.x

Yearling Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) were sampled concurrently with physical variables (temperature, salinity, depth) and biological variables (chlorophyll *a* concentration and copepod abundance) along the Washington and Oregon coast in June 1998–2008. Copepod species were divided into four different groups based on their water-type affinities: cold neritic, subarctic oceanic, warm neritic, and warm oceanic. Generalized linear mixed models were used to quantify the relationship between the abundance of these four different copepod groups and the abundance of juvenile salmon. The relationships between juvenile salmon and different copepod groups were further validated using regression analysis of annual mean juvenile salmon abundance versus the mean abundance of the copepod groups. Yearling Chinook salmon abundance was negatively correlated with warm oceanic copepods, warm neritic copepods, and bottom depth, and positively correlated with cold neritic copepods, subarctic copepods, and chlorophyll *a* concentration. The selected habitat variables explained 67% of the variation in yearling Chinook abundance. Yearling coho salmon abundance was negatively correlated with warm oceanic copepods, warm neritic copepods, and bottom depth, and positively correlated with temperature. The selected habitat variables explained 40% of the variation in yearling coho abundance. Results suggest that copepod communities can be used to characterize spatio-temporal patterns of

abundance of juvenile salmon, i.e., large-scale interannual variations in ocean conditions (warm versus cold years) and inshore-offshore (cross-shelf) gradients in the abundance of juvenile salmon can be characterized by differences in the abundance of copepod species with various water mass affinities.

Bi, H., Peterson, W. T., & Strub, P. T. (2011). Transport and coastal zooplankton communities in the northern California Current system. *Geophysical Research Letters, 38(12).* L12607 *doi:10.1029/2011GL047927*

Alongshore transport was estimated from the gridded AVISO altimeter data and water level data from NOAA tide gauges (1993–2010) for the northern California Current (NCC) system. The biomass of the cold neritic copepods including *Calanus marshallae, Pseudocalanus mimus* and *Acartia longiremis* (dominants in the eastern Bering Sea, coastal Gulf of Alaska, and NCC) was estimated from a 15 year time series of zooplankton samples (1996–2010) collected biweekly at a coastal station 9 km off Newport Oregon U.S.A. The alongshore currents and the biomass of the cold neritic copepods exhibit a strong seasonal pattern and fluctuate in opposite phase: positive alongshore current (from south) leads to low biomass in winter and negative alongshore current (from north) leads to high biomass in summer. When the Pacific Decadal Oscillation (PDO) is positive, i.e., warm conditions around the northeast Pacific, there is more movement of water from the south in the NCC during winter. When the PDO is negative, there is more movement of water from the north during summer. The mean biomass of cold neritic copepods was positively correlated with the survival rate of juvenile coho salmon and cumulative transport was negatively correlated with coho salmon survival, i.e., in years when a greater portion of the source waters feeding the NCC enters from the north, the greater the salmon survival. We conclude that alongshore transport manifests PDO signals and serves as a linkage between large scale forcing to local ecosystem dynamics.

Bi, H., Ruppel, R. E., & Peterson, W. T. (2007). Modeling the pelagic habitat of salmon off the Pacific Northwest (USA) coast using logistic regression. *Marine Ecology Progress Series*, *336*, 249–265. doi:10.3354/meps336249

Defining marine habitat use for Pacific salmon *Oncorhynchus* spp. is important for effective resource management because salmon production has been linked to ocean conditions in the Northeast Pacific. Towards that goal, Chinook *O. tshawytscha* and coho salmon *O. kisutch* populations were sampled off Washington and Oregon, USA, in June 1998 to 2005 along with habitat variables including temperature, salinity, water depth, and chlorophyll *a* concentration. Correlation analysis and stepwise logistic regressions were run to identify the physical and biological factors that predict the presence of Chinook and coho salmon. Low zero-catch probability was used to indicate used habitat. For all life history stages, zero-catch probability decreased with increased chlorophyll concentration and decreased depth. Temperature was a significant predictor variable for subyearling Chinook and yearling coho presence based on stepwise logistic regression. The size of used habitat showed large spatial and temporal variations, where more used habitat occurred off Washington and the Columbia River mouth than off Oregon. This pattern may relate to a wider shelf and greater primary production to the north. The largest amount of used habitat occurred in 2000 and 2003 for all 5 life history stages

examined. Sea-viewing Wide Field-of-Sensor (SeaWiFS) satellite images indicated high chlorophyll concentration in that period.

Bi, H., Ruppel, R. E., Peterson, W. T., & Casillas, E. (2008). Spatial distribution of ocean habitat of yearling Chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon off Washington and Oregon, USA. *Fisheries Oceanography*, *17*(6), 463–476. doi:10.1111/j.1365-2419.2008.00493.x

We determined the habitat usage and habitat connectivity of juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon in continental shelf waters off Washington and Oregon, based on samples collected every June for 9 yr (1998–2006). Habitat usage and connectivity were evaluated using SeaWiFS satellite-derived chlorophyll *a* data and water depth. Logistic regression models were developed for both species, and habitats were first classified using a threshold value estimated from a receiver operating characteristic curve. A Bernoulli random process using catch probabilities from observed data, i.e. the frequency of occurrence of a fish divided by the number of times a station was surveyed, was applied to reclassify stations. Zero-catch probabilities of yearling Chinook and yearling coho salmon decreased with increases in chlorophyll *a* concentration, and with decreases in water depth. From 1998 to 2006, ~ 47% of stations surveyed were classified as unfavorable habitat for yearling Chinook salmon and ~ 53% for yearling coho salmon. Potentially favorable habitat varied among years and ranged from 9 856 to 15 120 km^2 (Chinook) and from 14 800 to 16 736 km^2 (coho). For both species, the smallest habitat area occurred in 1998, an El Niño year. Favorable habitats for yearling Chinook salmon were more isolated in 1998 and 2005 than in other years. Both species had larger and more continuous favorable habitat areas along the Washington coast than along the Oregon coast. The favorable habitats were also larger and more continuous nearshore than offshore for both species. Further investigations on large-scale transport, mesoscale physical features, and prey and predator availability in the study area are necessary to explain the spatial arrangement of juvenile salmon habitats in continental shelf waters.

Bollens, S. M., vanden Hooff, R., Butler, M., Cordell, J. R., & Frost, B. W. (2010). Feeding ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in a northeast Pacific fjord: diet, availability of zooplankton, selectivity for prey, and potential competition for prey resources. *Fishery Bulletin*, *108*(4), 393–407.

We investigated the feeding ecology of juvenile salmon during the critical early life-history stage of transition from shallow to deep marine waters by sampling two stations (190 m and 60 m deep) in a northeast Pacific fjord (Dabob Bay, WA) between May 1985 and October 1987. Four species of Pacific salmon—*Oncorhynchus keta* (chum), *O. tshawytscha* (Chinook), *O. gorbuscha* (pink), and *O. kisutch* (coho)—were examined for

stomach contents. Diets of these fishes varied temporally, spatially, and between species, but were dominated by insects, euphausiids, and decapod larvae. Zooplankton assemblages and dry weights differed between stations, and less so between years. Salmon often demonstrated strongly positive or negative selection for specific prey types: copepods were far more abundant in the zooplankton than in the diet, whereas Insecta, Araneae, Cephalapoda, Teleostei, and Ctenophora were more abundant in the diet than in the plankton. Overall diet overlap was highest for Chinook and coho salmon (mean=77.9%)—species that seldom were found together. Chum and Chinook salmon were found together the most frequently, but diet overlap was lower (38.8%) and zooplankton biomass was not correlated with their gut fullness (% body weight). Thus, despite occasional occurrences of significant diet overlap between salmon species, our results indicate that interspecific competition among juvenile salmon does not occur in Dabob Bay.

Bond, M. H., Hayes, S. A., Hanson, C. V., & MacFarlane, R. B. (2008). Marine survival of steelhead (*Oncorhynchus mykiss*) enhanced by a seasonally closed estuary. *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(10), 2242–2252. doi:10.1139/F08-131

To investigate the role that estuaries play in the survival of steelhead, *Oncorhynchus mykiss*, we compared juvenile size at ocean entry with back-calculated measures of size at ocean entry for returning adults in Scott Creek, a representative California coastal stream. During the annual spring emigration, the largest smolts (>150 mm fork length (FL)) move directly to sea, while some smaller smolts remain in the estuary until sandbar formation creates a closed freshwater lagoon. High growth rates in the estuary throughout the summer result in a near doubling of fork length from the time of estuary entry (mean FL of spring migrants = 102.2 mm; mean FL of fall lagoon resident = 195.9 mm). Analysis of the scale morphology of returning adult steelhead indicates that there is strong size-dependent mortality at sea, with estuary-reared steelhead showing a large survival advantage, comprising between 87% and 95.5% (based on tag returns and scale analysis, respectively) of the returning adult population despite being between 8% and 48% of the annual downstream migrating population. Although the estuary forms less than 5% of the watershed area, it is critical nursery habitat, and steelhead population persistence in southern margin ecosystems may well depend upon healthy estuaries.

Borstad, G., Crawford, W., Hipfner, J. M., Thomson, R., & Hyatt, K. (2011). Environmental control of the breeding success of rhinoceros auklets at Triangle Island, British Columbia. *Marine Ecology Progress Series*, *424*, 285–302. doi:10.3354/meps08950

There are few studies of the mechanistic links between physical environmental processes and biotic responses in marine ecosystems that have strong predictive power. At Triangle Island, the largest seabird colony along Canada's Pacific coast, annual breeding success of rhinoceros auklets *Cerorhinca monocerata* varies dramatically. Previous studies have correlated this variability with ocean temperature, but this relationship occasionally fails, suggesting that it is not causal. We used historical satellite data time series of sea surface temperature, chlorophyll, and winds to study the oceanography of this remote colony. We found that rhinoceros auklets bred more successfully when the spring transition in regional winds and the resulting spring phytoplankton bloom occurred early in April.

These factors appear to control the annual recruitment of Pacific sand lance *Ammodytes hexapterus*, as measured by the percent by biomass of young-of-the-year sandlance in the nestling diet. These linkages imply bottom-up control in this system. Suggesting broader implications of our work, we also found that marine survival of economically and culturally important sockeye salmon *Oncorhynchus nerka* from nearby Smith Inlet was strongly correlated with the fledgling mass of the rhinoceros auklets, sandlance in the chicks' diets, and regional chlorophyll in April. The timing of the spring wind transition and phytoplankton bloom appear to be important for other predators in this system. We think that these relationships with wind and chlorophyll derived from satellite data are potentially valuable explanatory tools that will be widely applicable to studies of early marine survival of many marine species.

Braden, L. M., Barker, D. E., Koop, B. F., & Jones, S. R. M. (2012). Comparative defense-associated responses in salmon skin elicited by the ectoparasite *Lepeophtheirus salmonis*. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, *7*(2), 100–109. doi:10.1016/j.cbd.2011.12.002

Susceptibility among salmonids to the ectoparasite *Lepeophtheirus salmonis* is related to inflammatory reactions at the site of parasite attachment. Salmon from two susceptible (*Salmo salar, Oncorhynchus keta*) and one resistant (*Oncorhynchus gorbuscha*) species were exposed to adult *L. salmonis*. After 24 and 48 h, skin samples directly below the attachment site and at non-attachment sites were assessed for transcriptomic profiles of select innate defense genes. Abrasion of the skin permitted comparisons between abrasion-associated injury and louse-associated injury. Infection responses were consistently higher than those caused by abrasion. Temporal patterns of expression were evident in all species for the transcription factor CCAAT/enhancer-binding protein β (C/EBP-β), the cytokine interleukin-6 (IL-6) and the enzyme prostaglandin D synthase (PGDS) at attachment sites. *O. gorbuscha* was the highest responder in a number of genes while there was an absence of C-reactive protein (CRP) gene expression in *S. salar* and *O. keta*, indicating an altered acute-phase response. Moreover, *O. keta* displayed distinct interleukin-8 (IL-8) and serum amyloid P (SAP) responses. Impaired genetic expression or over-expression in these pathways may be evidence for species-specific pathways of susceptibility to the parasite. At *L. salmonis* attachment sites, reduced expression compared to non-attachment sites was observed for C/EBP-β (*S. salar*), CRP (*S. salar*), SAP (*S. salar, O. gorbuscha, O. keta*), PGDS (*S. salar, O. gorbuscha, O. keta*), and major histocompatibility class II (MH class II, *S. salar*), suggesting local immunodepression.

Brauner, C. J., Sackville, M., Gallagher, Z., Tang, S., Nendick, L., & Farrell, A. P. (2012). Physiological consequences of the salmon louse (*Lepeophtheirus salmonis*) on juvenile pink salmon (*Oncorhynchus gorbuscha*): implications for wild salmon ecology and management, and for salmon aquaculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1596), 1770–1779. doi:10.1098/rstb.2011.0423

Pink salmon, *Oncorhynchus gorbuscha*, are the most abundant wild salmon species and are thought of as an indicator of ecosystem health. The salmon louse, *Lepeophtheirus salmonis*, is endemic to pink salmon habitat but these ectoparasites have been implicated

in reducing local pink salmon populations in the Broughton Archipelago, British Columbia. This allegation arose largely because juvenile pink salmon migrate past commercial open net salmon farms, which are known to incubate the salmon louse. Juvenile pink salmon are thought to be especially sensitive to this ectoparasite because they enter the sea at such a small size (approx. 0.2 g). Here, we describe how "no effect" thresholds for salmon louse sublethal impacts on juvenile pink salmon were determined using physiological principles. These data were accepted by environmental managers and are being used to minimize the impact of salmon aquaculture on wild pink salmon populations.

Brodeur, R. D., Daly, E. A., Schabetsberger, R. A., & Mier, K. L. (2007). Interannual and interdecadal variability in juvenile coho salmon (*Oncorhynchus kisutch*) diets in relation to environmental changes in the northern California Current. *Fisheries Oceanography*, *16*(5), 395–408. doi:10.1111/j.1365-2419.2007.00438.x

The feeding habits of juvenile coho salmon, *Oncorhynchus kisutch*, in the northern California Current were examined using samples from two different time periods (1980–85 and 1998–2003) of highly contrasting oceanographic conditions. The goal was to test the influence of interannual and interdecadal changes in taxonomic composition of prey, feeding intensity, and size spectra of teleost prey. Analyses were done for samples taken both early in the summer (June) shortly after the salmon enter the ocean, and also in late summer (September) following some ocean residency. Fish prey dominated coho salmon diets by weight during most years, but this trend was more pronounced during the 1980–85 sampling period. In terms of numerical composition, the diets were more variable on an interannual basis, but decapod larvae and euphausiids were important prey in most years. Pteropods and copepods were important prey during weak upwelling or El Niño years, whereas euphausiids were important during strong upwelling or otherwise highly productive years. Hyperiid amphipods comprised a substantial proportion of the diets only in 2000. Coho salmon showed highly significant differences in prey composition among years or between decades both in weight and numerical composition. The percentage of empty stomachs was highly variable by year in both June and September, but was significantly different only for September between decades. In contrast, an index of feeding intensity did not show many significant changes in either comparison. However, the relative size ratios for fish prey consumed were highly variable by year, and larger than average fish prey were consumed during 1998, leading to the highest feeding intensity observed.

Brodeur, R. D., Daly, E. A., Sturdevant, M. V., Miller, T. W., Moss, J. H., Thiess, M. E., Trudel, M., Weitkamp, L. A., Armstrong, J.,& Norton, E. C. (2007). Regional comparisons of juvenile salmon feeding in coastal marine waters off the west coast of North America. *American Fisheries Society Symposium*, *57*, 283–203.

Upon entering marine waters, juvenile Pacific salmon *Oncorhynchus* spp. depend on feeding at high and sustained levels to achieve growth necessary for survival. In the last decade, several concurrent studies have been examining the food habits and feeding intensity of juvenile Pacific salmon in the shelf regions from California to the northern Gulf of Alaska. In this paper, we compared results from feeding studies for all five species of juvenile salmon (Chinook salmon *O. tshawytscha*, coho salmon *O. kisutch*,

chum salmon *O. keta*, sockeye salmon *O. nerka*, and pink salmon *O. gorbuscha*) between 2000 and 2002, years when these regions were sampled extensively. Within these years, we temporally stratified our samples to include early (May–July) and late (August–October) periods of ocean migration. Coho and Chinook salmon diets were most similar due to a high consumption of fish prey, whereas pink, chum, and sockeye salmon diets were more variable with no consistently dominant prey taxa. Salmon diets varied more spatially (by oceanographic and regional factors) than temporally (by season or year) in terms of percentage weight or volume of major prey categories. We also examined regional variations in feeding intensity based on stomach fullness (expressed as percent body weight) and percent of empty or overly full stomachs. Stomach fullness tended to be greater off Alaska than off the west coast of the United States, but the data were highly variable. Results from these comparisons provide a large-scale picture of juvenile salmon feeding in coastal waters throughout much of their range, allowing for comparison with available prey resources, growth, and survival patterns associated with the different regions.

Brodeur, R. D., Suchman, C. L., Reese, D. C., Miller, T. W., & Daly, E. A. (2008). Spatial overlap and trophic interactions between pelagic fish and large jellyfish in the northern California Current. *Marine Biology*, *154*(4), 649–659. doi:10.1007/s00227-008-0958-3

Recent studies have indicated that populations of gelatinous zooplankton may be increasing and expanding in geographic coverage, and these increases may in turn affect coastal fish populations. We conducted trawl surveys in the northern California Current and documented a substantial biomass of scyphomedusae consisting primarily of two species (*Chrysaora fuscescens* and *Aurelia labiata*). Spatial overlap of these jellyfish with most pelagic fishes, including salmon, was generally low, but there were regions of relatively high overlap where trophic interactions may have been occurring. We compared feeding ecology of jellyfish and pelagic fishes based on diet composition and found that trophic overlap was high with planktivorous species that consume copepods and euphausiid eggs such as Pacific sardines (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), Pacific saury (*Cololabis saira*), and Pacific herring (*Clupea pallasi*). Moreover, isotope and diet analyses suggest that jellyfish occupy a trophic level similar to that of small pelagic fishes such as herring, sardines and northern anchovy. Thus jellyfish have the potential, given their substantial biomass, of competing with these species, especially in years with low ecosystem productivity where prey resources will be limited.

Brosnan, I. G., Welch, D. W., Rechisky, E. L., & Porter, A. D. (2014). Evaluating the influence of environmental factors on yearling Chinook salmon survival in the Columbia River plume (USA). *Marine Ecology Progress Series*, *496*, 181–196. doi:10.3354/meps10550

The impact of oceanographic processes on early marine survival of Pacific salmon is typically estimated upon adult return, 1 to 5 yr after ocean entry, and many 1000s of kilometers after initial exposure. Here, we use direct estimates of early marine survival obtained from acoustic-tagged yearling Chinook salmon *Oncorhynchus tshawytscha* that entered the Columbia River plume (USA) after migrating down the river and then north

to the coastal waters off Willapa Bay, Washington. Plume residence time averaged 7 d, and was of such short duration that predation, rather than feeding and growth conditions, was the likely primary cause of mortality. Plume survival ranged from 0.13 to 0.86, but was stable when scaled by plume residence time, and we find that a simple exponential decay model adequately describes plume survival. Plume survival, and perhaps adult returns, could be improved by reducing plume residence time if the drivers controlling residence time were amenable to management control. However, we show that a statistical model of plume residence time that includes only sea-surface temperature far outperforms models that include river discharge and coastal upwelling. Timing hatchery releases using marine environmental forecasts could potentially improve smolt survival by minimizing their residence time in regions of poor survival. Acoustic telemetry may be used to evaluate the value and effectiveness of such approaches.

Buhle, E. R., Holsman, K. K., Scheuerell, M. D., & Albaugh, A. (2009). Using an unplanned experiment to evaluate the effects of hatcheries and environmental variation on threatened populations of wild salmon. *Biological Conservation*, *142*(11), 2449–2455. doi:10.1016/j.biocon.2009.05.013

Efforts to conserve depleted populations of Pacific salmon (*Oncorhynchus* spp.) often rely on hatchery programs to offset losses of fish from natural and anthropogenic causes, but their use has been contentious. We examined the impact of a large-scale reduction in hatchery stocking on 15 populations of wild coho salmon along the coast of Oregon (USA). Our analyses highlight four critical factors influencing the productivity of these

populations: (1) negative density-dependent effects of hatchery-origin spawners were ~5

times greater than those of wild spawners; (2) the productivity of wild salmon decreased as releases of hatchery juveniles increased; (3) salmon production was positively related to an index of freshwater habitat quality; and (4) ocean conditions strongly affect productivity at large spatial scales, potentially masking more localized drivers. These results suggest that hatchery programs' unintended negative effects on wild salmon populations, and their role in salmon recovery, should be considered in the context of other ecological drivers.

Burke, B. J., Anderson, J. J., & Baptista, A. M. (2014). Evidence for multiple navigational sensory capabilities of Chinook salmon. *Aquatic Biology*, *20*(1), 77–90. doi:10.3354/ab00541

To study the complex coastal migrations patterns exhibited by juvenile Columbia River Chinook salmon as they enter and move through the marine environment, we created an individual-based model in a coupled Eulerian-Lagrangian framework. We modeled 5 distinct migration strategies and compared the resulting spatial distributions to catch data collected during May and June in 3 years. Two strategies produced fish distributions similar to those observed in May but only one also produced the observed June distributions. In both strategies, salmon distinguish north from south (i.e. they have a compass sense), and they control their position relative to particular landmarks, such as the river mouth. With these 2 abilities, we posit that salmon follow spatially explicit

behavior rules that prevent entrapment in strong southward currents and advection offshore. Additionally, the consistent spatio-temporal distributions observed among years suggest that salmon use a clock sense to adjust their swim speed, within and among years, in response to progress along their migration.

Burke, B. J., Liermann, M. C., Teel, D. J., & Anderson, J. J. (2013). Environmental and geospatial factors drive juvenile Chinook salmon distribution during early ocean migration. *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(8), 1167–1177. doi:10.1139/cjfas-2012-0505

Migrating animals rely on a variety of cues to guide them, but the relative importance of those signals may vary with size, life stage, or location. During their initial ocean migration, yearling Chinook salmon (*Oncorhynchus tshawytcha*) from the Columbia River have stock-specific spatial distributions that shift through time. We used a two-process mixture model to examine how the distribution of yearling migrants from three Chinook salmon stocks varies as a function of geospatial (e.g., latitude and distance from shore) and environmental (e.g., chlorophyll *a* and temperature) covariates. In this framework, one process described the probability of being inside the spatial, temporal, and environmental boundaries of the migration route, and one process described the patchy distribution of salmon abundance within that route. We found that both environmental and geospatial covariates explained substantial portions of observed spatial patterns in abundance, suggesting that these stocks responded to multiple cues during migration. However, model selection criteria indicated that fish distributions were moreaffected by geospatial than by environmental covariates. We conclude that during migration, behavioral responses to environ-mental variation are secondary to responses to geospatial variation, sometimes resulting in suboptimal environmental conditions. This may have sublethal effects on growth and could ultimately influence stock-specific responses to broad-scale climate changes.

Burke, B. J., Peterson, W. T., Beckman, B. R., Morgan, C., Daly, E. A., & Litz, M. (2013). Multivariate models of adult Pacific salmon returns. *PLoS ONE*, *8*(1), e54134. doi:10.1371/journal.pone.0054134

Most modeling and statistical approaches encourage simplicity, yet ecological processes are often complex, as they are influenced by numerous dynamic environmental and biological factors. Pacific salmon abundance has been highly variable over the last few decades and most forecasting models have proven inadequate, primarily because of a lack of understanding of the processes affecting variability in survival. Better methods and data for predicting the abundance of returning adults are therefore required to effectively manage the species. We combined 31 distinct indicators of the marine environment collected over an 11-year period into a multivariate analysis to summarize and predict adult spring Chinook salmon returns to the Columbia River in 2012. In addition to forecasts, this tool quantifies the strength of the relationship between various ecological indicators and salmon returns, allowing interpretation of ecosystem processes. The relative importance of indicators varied, but a few trends emerged. Adult returns of spring Chinook salmon were best described using indicators of bottom-up ecological processes such as composition and abundance of zooplankton and fish prey as well as measures of individual fish, such as growth and condition. Local indicators of

temperature or coastal upwelling did not contribute as much as large-scale indicators of temperature variability, matching the spatial scale over which salmon spend the majority of their ocean residence. Results suggest that effective management of Pacific salmon requires multiple types of data and that no single indicator can represent the complex early-ocean ecology of salmon.

Buser, T., Davis, N. D., Jiménez-Hidalgo, I., & Hauser, L. (2009). Genetic techniques provide evidence of Chinook salmon feeding on walleye pollock offal. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 225–229.

Declining runs of Chinook salmon in western Alaska have focused interest on the ocean condition and food habits of Chinook salmon in the Bering Sea, including potential mortality from bycatch in the pollock fishery. Examination of Chinook salmon stomach contents collected in the eastern Bering Sea by the U.S. North Pacific Groundfish Observer Program (NOAA Fisheries) revealed isolated pieces of skin, bones, and fins (offal) belonging to large-bodied fish which were physically identified as either walleye pollock (*Theragra chalcogramma*) or Pacific cod (*Gadus macrocephalus*). To confirm the species identification of the offal, we matched DNA sequences of these offal samples to known sequences of walleye pollock and Pacific cod. Novel mitochondrial DNA (mtDNA) primers were designed to amplify a 174-base pair (bp)-long section of the cytochromec oxidase subunit I (COI) gene, which was sequenced and compared with sequences downloaded from the GenBank database. Typically, much longer sections (~700 bp) of DNA are used for species identification but due to the state of digestion of the samples, long sequences of DNA were no longer present. The specific design of our primers, however, allowed us to make positive identification and differentiation of walleye pollock and Pacific cod. Of the 15 offal samples, nine yielded usable sequences, all of which were positively identified as walleye pollock. Our results clearly demonstrate the utility of a short COI sequence for species identification of Chinook salmon stomach contents that might otherwise be unidentifiable due to either the state of digestion, or because the salmon consumed isolated body parts (offal) rather than whole fish. These results suggest that walleye pollock offal supplements the diet of Chinook salmon during winter.

Celewycz, A. G., Berger, J. D., Cusick, J., Davis, N. D., Fukuwaku, M., & Malecha, P. W. (2009). High seas salmonid coded-wire tag recovery data, 2009. *North Pacific Anadromous Fish Commission Document*, *1179*, 22 pp.

Information on high seas recoveries of salmonids (*Oncorhynchus* spp.) tagged with coded-wire tags (CWTs) has been reported annually to the International North Pacific Fisheries Commission (1981-1992) and to the North Pacific Anadromous Fish Commission (NPAFC, 1993-present). Data from these CWT recoveries are also reported into the coastwide on-line CWT recovery database (http://www.rmpc.org) maintained by the Regional Mark Processing Center (RMPC) of the Pacific States Marine Fisheries Commission (PSMFC). This document lists recovery data for 34 CWT salmonids that will be reported to SMFC/RMPC for the first time. These 34 CWTs were recovered from the 2008 U.S. groundfish trawl fishery in the Gulf of Alaska (13 Chinook salmon, *Oncorhynchus tshawytscha*) , the 2003, 2006, 2007, and 2009 U.S. groundfish trawl fishery in the eastern Bering Sea-Aleutian Islands (7 Chinook salmon), the 2008 Pacific

hake (*Merluccius productus*) trawl fishery in the Northern Pacific Ocean off Washington/Oregon/California (WA/OR/CA, 10 Chinook salmon), the 2008 limited-entry non-hake groundfish trawl off WA/OR/CA (2 Chinook salmon), and 2008 U.S. trawl research in the northern Gulf of Alaska (2 coho salmon, *Oncorhynchus kisutch*).

Celewycz, A. G., & Moss, J. H. (2011). High seas salmonid coded-wire tag recovery data, 2011. *North Pacific Anadromous Fish Commission Document*, *1341*, 24 pp.
Information on high seas recoveries of salmonids (*Oncorhynchus* spp.) tagged with coded-wire tags (CWTs) has been reported annually to the International North Pacific Fisheries Commission (1981-1992) and to the North Pacific Anadromous Fish Commission (NPAFC, 1993-present). Data from these CWT recoveries are also reported into the Regional Mark Information System Database maintained by the Regional Mark Processing Center (RMPC, http://www.rmpc.org) of the Pacific States Marine Fisheries Commission (PSMFC). This document lists recovery data for 61 CWT salmonids that will be reported to PSMFC/RMPC for the first time. These 61 CWTs were recovered from the 2008, 2009, and 2010 U.S. groundfish trawl fishery in the Gulf of Alaska (41 Chinook salmon, *Oncorhynchus tshawytscha*), the 2009 and 2010 U.S. groundfish trawl fishery in the eastern Bering Sea-Aleutian Islands (13 Chinook salmon and 1 coho salmon *Oncorhynchus kisutch*), and from 2010 US research vessel operations in the Gulf of Alaska (3 Chinook salmon and 3 coho salmon,). Recovery information is also presented for 9 new recoveries of Chinook salmon tagged with agency-only wire tags (not CWTs)

Chamberlin, J. W., Essington, T. E., Ferguson, J. W., & Quinn, T. P. (2011). The influence of hatchery rearing practices on salmon migratory behavior: Is the tendency of Chinook salmon to remain within Puget Sound affected by size and date of release? *Transactions of the American Fisheries Society*, *140*(5), 1398–1408. doi:10.1080/00028487.2011.623993
The marine migrations of Pacific salmon *Oncorhynchus* spp., and especially Chinook salmon *O. tshawytscha*, vary greatly in duration and spatial extent. In Puget Sound, Washington, most Chinook salmon migrate from freshwater to the coastal waters of the Pacific Ocean before returning to spawn in their natal streams. However, some leave freshwater but remain in the semi-estuarine waters of Puget Sound until they mature and then return to freshwater to spawn. The objective of our study was to determine the effect of rearing conditions and hatchery location on the prevalence of this alternative pattern of marine distribution by hatchery-produced Chinook salmon in Puget Sound. We used coded wire tag recovery data to analyze the effect of release region, age, size, and date of release on the proportion of fish showing resident-type behavior, defined as recovery in Puget Sound fisheries outside the period when maturing salmon return from the coast. Based on 226 different release groups from 26 hatcheries throughout Puget Sound from 1972 to 1993, 24% of the fish recovered were classified as residents, though this is not an actual estimate of the percentage of fish displaying this distribution pattern. The best single predictor of residency was release region, suggesting that where fish enter the marine environment had the largest influence on whether they adopted resident behavior or migrated directly to the ocean. The overall best model included an interactive effect between release region and size at release, revealing that the propensity of large fish to

remain resident varied significantly among regions. The actual mechanisms that create the diversity of distribution patterns are still unknown, but the effects of rearing conditions and release location provide useful information for the management of these salmon populations.

Chamberlin, J. W., Kagley, A. N., Fresh, K. L., & Quinn, T. P. (2011). Movements of yearling Chinook salmon during the first summer in marine waters of Hood Canal, Washington. *Transactions of the American Fisheries Society*, *140*(2), 429–439. doi:10.1080/00028487.2011.572006

Migration is a fundamental component of the life history and ecology of many species, but the extent and duration of specific migrations can vary depending on species and environment. Chinook salmon *Oncorhynchus tshawytscha* are characterized by a spectrum of life history types with different migration patterns and spatial distributions. The objective of this study was to quantify the movements of yearling Chinook salmon smolts during their initial summer in Hood Canal, a long, narrow fjord in western Puget Sound, Washington. Fifty-eight yearling hatchery-reared smolts were tagged with acoustic transmitters and tracked during May–August 2008 with a network of 50 receivers placed throughout Hood Canal. A total of 41 fish were detected during the study period; of these, 18 fish were still being detected in Hood Canal after 100 d. Fish initially congregated near the release site and gradually dispersed during summer; individual movement rates ranged between 0.44 and 1.52 body lengths/s. Fish movement occurred both with and against tidal currents, and nearly all fish showed some period of inactivity, especially as recorded on receivers near estuaries and tidal deltas. Eight fish (20%) were detected as leaving Hood Canal during the study, but seven of them later returned to Hood Canal. The extended use of Hood Canal as rearing habitat indicated the importance of such environments beyond their role as migratory corridors to the Pacific Ocean.

Chittenden, C. M., Beamish, R. J., Neville, C. M., Sweeting, R. M., & McKinley, R. S. (2009). The use of acoustic tags to determine the timing and location of the juvenile coho salmon migration out of the Strait of Georgia, Canada. *Transactions of the American Fisheries Society*, *138*(6), 1220–1225. doi:10.1577/T09-037.1

The migration of juvenile coho salmon *Oncorhynchus kisutch* out of the Strait of Georgia in 2006 was investigated by means of acoustic telemetry. During July and September, 173 juvenile coho salmon were caught in the strait with a purse seine, surgically implanted with acoustic tags, and released the same day. In 2006, approximately 19% of the fish tagged in July and 52% of those tagged in September left the Strait of Georgia. Most of these fish did so in October and November through Juan de Fuca Strait and not by a northward migration through Queen Charlotte Strait. This movement was several months later than that observed for coho salmon migrating out of Puget Sound. A small number of coho salmon that moved out of the Strait of Georgia migrated south to areas off the coast of Washington and Oregon. The documentation of a movement out of the Strait of Georgia late in the year was important, as it shows that population changes of the juvenile coho salmon that enter the strait during spring and summer are a consequence of ecosystem-related effects within the strait.

Chittenden, C. M., Jensen, J. L. A., Ewart, D., Anderson, S., Balfry, S., Downey, E., Eaves, A., Saksida, S., Smith, B., & McKinley, R. S. (2010). Recent salmon declines: A result of lost feeding opportunities due to bad timing? *PLoS ONE*, *5*(8), e12423. doi:10.1371/journal.pone.0012423

As the timing of spring productivity blooms in near-shore areas advances due to warming trends in global climate, the selection pressures on out-migrating salmon smolts are shifting. Species and stocks that leave natal streams earlier may be favoured over later-migrating fish. The low post-release survival of hatchery fish during recent years may be in part due to static release times that do not take the timing of plankton blooms into account. This study examined the effects of release time on the migratory behaviour and survival of wild and hatchery-reared coho salmon (*Oncorhynchus kisutch*) using acoustic and coded-wire telemetry. Plankton monitoring and near-shore seining were also conducted to determine which habitat and food sources were favoured. Acoustic tags (n=140) and coded-wire tags (n=266,692) were implanted into coho salmon smolts at the Seymour and Quinsam Rivers, in British Columbia, Canada. Differences between wild and hatchery fish, and early and late releases were examined during the entire lifecycle. Physiological sampling was also carried out on 30 fish from each release group. The smolt-to-adult survival of coho salmon released during periods of high marine productivity was 1.5- to 3-fold greater than those released both before and after, and the fish's degree of smoltification affected their downstream migration time and duration of stay in the estuary. Therefore, hatchery managers should consider having smolts fully developed and ready for release during the peak of the near-shore plankton blooms. Monitoring chlorophyll *a* levels and water temperature early in the spring could provide a forecast of the timing of these blooms, giving hatcheries time to adjust their release schedule.

Chittenden, C. M., Melnychuk, M. C., Welch, D. W., & McKinley, R. S. (2010). An investigation into the poor survival of an endangered coho salmon population. *PLoS ONE*, *5*(5), e10869. doi:10.1371/journal.pone.0010869

To investigate reasons for the decline of an endangered population of coho salmon (*O. kisutch*), 190 smolts were acoustically tagged during three consecutive years and their movements and survival were estimated using the Pacific Ocean Shelf Tracking project (POST) array. Median travel times of the Thompson River coho salmon smolts to the lower Fraser River sub-array were 16, 12 and 10 days during 2004, 2005 and 2006, respectively. Few smolts were recorded on marine arrays. Freshwater survival rates of the tagged smolts during their downstream migration were 0.0–5.6% (0.0–9.0% s.e.) in 2004, 7.0% (6.2% s.e.) in 2005, and 50.9% (18.6% s.e.) in 2006. Overall smolt-to-adult return rates exhibited a similar pattern, which suggests that low freshwater survival rates of out-migrating smolts may be a primary reason for the poor conservation status of this endangered coho salmon population.

Chittenden, C. M., Sura, S., Butterworth, K. G., Cubitt, K. F., Plantalech Manel-la, N., Balfry, S., Okland, F., & McKinley, R. S. (2008). Riverine, estuarine and marine migratory behaviour and physiology of wild and hatchery-reared coho salmon *Oncorhynchus kisutch* (Walbaum) smolts descending the Campbell River, BC, Canada. *Journal of Fish Biology*, *72*(3), 614–628. doi:10.1111/j.1095-

8649.2007.01729.x

Eighty coho salmon *Oncorhynchus kisutch* smolts (40 wild and 40 hatchery-reared) were surgically implanted with acoustic transmitters and released into the Quinsam River over 2 days. Differences in physiology, travel time and migratory behaviour were examined between wild and hatchery-reared fish. In addition, tagged and control fish of both wild and hatchery-reared stock were raised for 3 months following surgery to compare survival and tag retention. Detection ranges of the acoustic receivers were tested in the river, estuary and ocean in a variety of flow conditions and tide levels. Receivers were placed in the river, estuary and up to 50 km north and south from the river mouth in the marine environment. Wild smolts were significantly smaller by mass, fork length and condition factor than hatchery-reared smolts and exhibited significantly higher levels of sodium, potassium and chloride in their blood plasma than hatchery-reared smolts. The gill Na^+K^+-ATPase activity was also significantly higher in the wild coho smolts at the time of release. Ninety-eight per cent of wild and 80% of hatchery-reared fish survived to the estuary, 8 km downstream of the release site. No difference was found in migration speed, timing or survival between smolts released during daylight and those released after dark. Wild smolts, however, spent less time in the river and estuary, and as a result entered the ocean earlier than hatchery-reared smolts. Average marine swimming speeds for wild smolts were double those of their hatchery-reared counterparts. While hatchery smolts dispersed in both a northward and southward direction upon entering the marine environment, the majority of wild smolts travelled north from the Campbell River estuary. The wild coho salmon smolts were more physiologically fit and ready to enter sea water than the hatchery-reared smolts, and as a result had higher early survival rates and swimming speeds.

Cieciel, K., Farley Jr, E. V., & Eisner, L. B. (2009). Jellyfish and juvenile salmon associations with oceanographic characteristics during warm and cool years in the eastern Bering Sea. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 209–224.

We explored possible associations between jellyfish biomass (*Aequorea* spp., *Aurelia labiata, Chrysaoramelanaster,* and *Cyanea capillata*), juvenile salmon (*Oncorhynchus keta, O. nerka, O. gorbuscha, O. kisutch*, and *O. tshawytscha*) abundance, and oceanographic characteristics (temperature, salinity, chlorophyll-*a*, and bottom depth) during two warm years (2004, 2005) and two cool years (2006, 2007) in the eastern Bering Sea from the annual Bering-Aleutian Salmon International Surveys (US BASIS). A significant difference was observed in the mean relative biomass of the four jellyfish species in response to the various conditions in warm versus cool years. Our results indicated that juvenile *O. tshawytscha* were significantly associated with cooler temperatures in only cool years and shallower bottom depths in all years. Juvenile *O. kisutch* were associated with shallower than average bottom depths for all years and juvenile *O. keta* had only cool-year associations with lower salinities and shallower bottom depths. Similar spatial distributions were seen between jellyfish and juvenile salmon, suggesting the possibility of competition. Immature *O. keta* were significantly associated with the same physical ocean factors as *Aequorea* spp. during fall warm years, indicating a potential for interaction.

Claiborne, A. M., Fisher, J. P., Hayes, S. A., & Emmett, R. L. (2011). Size at release, size-selective mortality, and age of maturity of Willamette River hatchery yearling Chinook salmon. *Transactions of the American Fisheries Society*, *140*(4), 1135–1144. doi:10.1080/00028487.2011.607050

We analyzed scales from returning Willamette River yearling Chinook salmon *Oncorhynchus tshawytscha* to explore the effects of size at release on subsequent adult returns. We tested the hypothesis that survival to adulthood is independent of size at ocean entry for yearling Chinook salmon. Significant size-selective mortality, indicated by a larger size at ocean entry among surviving adults than among all released juveniles, was observed for Chinook salmon released in 2002–2004 but not for those released in 2005. Juvenile Chinook salmon released in 2002–2004 that entered the ocean at less than 150 mm in fork length were underrepresented in the returning adult populations. We also investigated the relationships between age at maturity and size at ocean entry, timing of release, circulus spacing, and size at the end of the first ocean year. We observed significant differences in fork length at the end of the first ocean winter among returning age-4, -5, and -6 Chinook salmon; the younger returning fish were larger after their first year of ocean growth. Fork length at ocean entry and average first-ocean-year circulus spacing were significantly greater for age-4 than for age-5 and age-6 Chinook salmon but were similar for age-5 and age-6 fish. Our analyses indicate that yearling Chinook salmon may experience size-selective mortality, although the relationship between the intensity of size-selective mortality and smolt-to-adult survival remains unclear.

Claxton, A., Jacobson, K. C., Bhuthimethee, M., Teel, D., & Bottom, D. (2013). Parasites in subyearling Chinook salmon (*Oncorhynchus tshawytscha*) suggest increased habitat use in wetlands compared to sandy beach habitats in the Columbia River estuary. *Hydrobiologia*, *717*(1), 27–39. doi:10.1007/s10750-013-1564-z

Many estuaries in the Pacific Northwest have been severely altered reducing wetlands habitat and resulting in an interest in their importance as rearing areas for juvenile salmon. To examine differences in habitat use during residency in the Columbia River estuary, we examined parasite communities acquired through food web interactions in subyearling Chinook salmon (*Oncorhynchus tshawytscha*) collected from four different habitat types in May and July of 2004 and 2005. Collections were made from two sandy bottom habitat types in the tidal freshwater and marine mixing areas of the estuary. These were compared to two wetlands types: one composed of scrub and shrub vegetation and another with emergent vegetation. Parasite assemblages differed among habitats suggesting differences in salmon feeding opportunities and rearing behaviors. In both years, the nematode, *Hysterothylacium aduncum* and the acanthocephalan, *Echinorhynchus lageniformis*, which use intermediate hosts found in the estuary, were more prevalent in lower wetlands suggesting increased feeding by salmon in these habitats. The differences in parasite assemblages among habitats suggests a variety of rearing and migration patterns through the Columbia River estuary and the increased prevalences of some parasites in the wetlands show that these habitats can be important feeding grounds for salmon.

Connors, B. M., Braun, D. C., Peterman, R. m., Cooper, A. B., Reynolds, J. D., Dill, L. M., Ruggerone, G. T., & Krkošek, M. (2012). Migration links ocean-scale competition

and local ocean conditions with exposure to farmed salmon to shape wild salmon dynamics. *Conservation Letters*, *5*(4), 304–312. doi:10.1111/j.1755-263X.2012.00244.x
Climate, competition, and disease are well-recognized drivers of population dynamics. These stressors can be intertwined by animal migrations, leading to uncertainty about the roles of natural and anthropogenic factors in conservation and resource management. We quantitatively assessed the four leading hypotheses for an enigmatic long-term decline in productivity of Canada's iconic Fraser River sockeye salmon: (1) delayed density-dependence, (2) local oceanographic conditions, (3) pathogen transmission from farmed salmon, and (4) ocean-basin scale competition with pink salmon. Our findings suggest that the long-term decline is primarily explained by competition with pink salmon, which can be amplified by exposure to farmed salmon early in sockeye marine life, and by a compensatory interaction between coastal ocean temperature and farmed-salmon exposure. These correlative relationships suggest oceanic-scale processes, which are beyond the reach of current regulatory agencies, may exacerbate local ecological processes that challenge the coexistence of fisheries and aquaculture-based economies in coastal seas.

Connors, B. M., Hargreaves, N. B., Jones, S. R. M., & Dill, L. M. (2010). Predation intensifies parasite exposure in a salmonid food chain. *Journal of Applied Ecology*, *47*(6), 1365–1371. doi:10.1111/j.1365-2664.2010.01887.x
1. Parasites can influence ecosystem structure, function and dynamics by mediating predator–prey interactions. Recurrent infestations of the salmon louse *Lepeophtheirus salmonis* associated with salmon aquaculture may mediate interactions between juvenile salmonids. Louse infection increases pink salmon *Oncorhynchus gorbuscha* susceptibility to predation, resulting in the trophic transmission of lice (with an adult male bias) to coho salmon *O. kisutch* predators. While experimental evidence is accumulating, the extent to which trophic transmission structures the distribution of lice among juvenile salmon in the wild is unknown. 2. We used a hierarchical modelling approach to examine the abundance and sex ratio of salmon lice on juvenile pink and coho salmon, collected from a region of salmon aquaculture during sea louse infestations, to test the hypothesis that trophic transmission of salmon lice increases infection on coho that feed upon infected pink salmon prey. 3. As predicted, coho had higher adult and pre-adult louse abundance than their pink salmon prey, and louse abundance was more adult male biased on predators than sympatric prey. We estimate that trophic transmission accounts for 53–67% of pre-adult and adult louse infection on coho. 4. Synthesis and applications. These results suggest that, by evading predation, salmon lice can accumulate up juvenile salmon food webs. Predators, such as coho, can experience a two- to threefold increase in parasite exposure through predation on infected prey than would otherwise occur through passive exposure to infective larvae. Thus, predation may intensify parasite exposure and undermine the protection to ectoparasites conferred by the larger body size of predators. For larger predatory wild juvenile salmon, the risk of louse transmission from farmed salmon may therefore be greater than previously appreciated. These findings argue for an ecosystem perspective in monitoring and managing the marine environment in areas of intensive salmon aquaculture that includes the productivity and ecological interactions of all salmonid species.

Connors, B. M., Krkošek, M., & Dill, L. M. (2008). Sea lice escape predation on their host. *Biology Letters*, *4*(5), 455–457. doi:10.1098/rsbl.2008.0276
Parasites seldom have predators but often fall victim to those of their hosts. How parasites respond to host predation can have important consequences for both hosts and parasites, though empirical investigations are rare. The exposure of wild juvenile salmon to sea lice (*Lepeophtheirus salmonis*) from salmon farms allowed us to study a novel ecological interaction: the response of sea lice to predation on their juvenile pink and chum salmon hosts by two salmonid predators—coho smolts and cut-throat trout. In approximately 70% of trials in which a predator consumed a parasitized prey, lice escaped predation by swimming or moving directly onto the predator. This trophic transmission is strongly male biased, probably because behaviour and morphology constrain female movement and transmission. These findings highlight the potential for sea lice to be transmitted up marine food webs in areas of intensive salmon aquaculture, with implications for louse population dynamics and predatory salmonid health.

Connors, B. M., Krkošek, M., Ford, J., & Dill, L. M. (2010). Coho salmon productivity in relation to salmon lice from infected prey and salmon farms. *Journal of Applied Ecology*, *47*(6), 1372–1377. doi:10.1111/j.1365-2664.2010.01889.x
1. Pathogen transmission from open net-pen aquaculture facilities can depress sympatric wild fish populations. However, little is known about the effects of pathogen transmission from farmed fish on species interactions or other ecosystem components. Coho salmon *Oncorhynchus kisutch* smolts are susceptible hosts to the parasitic salmon louse *Lepeophtheirus salmonis* as well as a primary predator of juvenile pink *Oncorhynchus gorbuscha* salmon, a major host species for lice. 2. We used a hierarchical model of stock-recruit dynamics to compare coho salmon population dynamics across a region that varies in salmon louse infestation of juvenile coho and their pink salmon prey. 3. During a period of recurring salmon louse infestations in a region of open net-pen salmon farms, coho salmon productivity (recruits per spawner at low spawner abundance) was depressed approximately sevenfold relative to unexposed populations. Alternate hypotheses for the observed difference in productivity, such as declines in coho prey, perturbations to freshwater habitat or stochasticity, are unlikely to explain this pattern. 4. Lice parasitizing juvenile coho salmon were likely to be trophically transmitted during predation on parasitized juvenile pink salmon as well as directly transmitted from salmon farms. 5. Synthesis and applications. The finding that species interactions may cause the effects of pathogen transmission from farmed to wild fish to propagate up a marine food web has important conservation implications: (i) the management of salmon aquaculture should consider and account for species interactions and the potential for these interactions to intensify pathogen transmission from farmed to wild fish, (ii) the ecosystem impact of louse transmission from farmed to wild salmon has likely to have been previously underestimated and (iii) comprehensive monitoring of wild salmon and their population dynamics in areas of intensive salmon aquaculture should be a priority to determine if open net-pen salmon aquaculture is ecologically sustainable.

Coyle, K. O., Eisner, L. B., Mueter, F. J., Pinchuk, A. I., Janout, M. A., Cieciel, K. D., Farley, E. V., & Andrews, A. G. (2011). Climate change in the southeastern Bering Sea: impacts on pollock stocks and implications for the oscillating control

hypothesis. *Fisheries Oceanography*, *20*(2), 139–156. doi:10.1111/j.1365-2419.2011.00574.x

Concern about impacts of climate change in the Bering Sea prompted several research programs to elucidate mechanistic links between climate and ecosystem responses. Following a detailed literature review, Hunt et al. (2011) (*Deep-Sea Res. II*, 49, 2002, 5821) developed a conceptual framework, the Oscillating Control Hypothesis (OCH), linking climate-related changes in physical oceanographic conditions to stock recruitment using walleye pollock (*Theragra chalcogramma*) as a model. The OCH conceptual model treats zooplankton as a single box, with reduced zooplankton production during cold conditions, producing bottom-up control of apex predators and elevated zooplankton production during warm periods leading to top-down control by apex predators. A recent warming trend followed by rapid cooling on the Bering Sea shelf permitted testing of the OCH. During warm years (2003–06), euphausiid and *Calanus marshallae* populations declined, post-larval pollock diets shifted from a mixture of large zooplankton and small copepods to almost exclusively small copepods, and juvenile pollock dominated the diets of large predators. With cooling from 2006–09, populations of large zooplankton increased, post-larval pollock consumed greater proportions of *C. marshallae* and other large zooplankton, and juvenile pollock virtually disappeared from the diets of large pollock and salmon. These shifts in energy flow were accompanied by large declines in pollock stocks attributed to poor recruitment between 2001 and 2005. Observations presented here indicate the need for revision of the OCH to account for shifts in energy flow through differing food-web pathways due to warming and cooling on the southeastern Bering Sea shelf.

Cross, A. D., Beauchamp, D. A., Moss, J. H., & Myers, K. W. (2009). Interannual variability in early marine growth, size-selective mortality, and marine survival for Prince William Sound pink salmon. *Marine and Coastal Fisheries*, *1*(1), 57–70. doi:10.1577/C08-005.1

The main objective of this study was to use scale patterns to compare the early marine growth of the average pink salmon *Oncorhynchus gorbuscha* with that of fish from the same year-class that survived to adulthood to gain insight on critical periods for growth and survival. During 2001–2004, pink salmon that survived to adulthood were larger and grew faster than the average juvenile throughout the first growing season, indicating that larger, faster-growing juveniles experienced higher survival. Growth rate declined from mid–late June to early–mid-July for both juveniles at-large and fish that survived to adulthood. The adult survivors then grew at a faster rate than the average juvenile through September. Both the juvenile pink salmon population at-large and all cohorts that survived to adulthood grew at a faster rate during high-survival years than low-survival years from mid–late June to mid–late August. Greater variability in the growth trajectories of surviving adults was observed during high-survival years, potentially a result of diversified feeding or distribution strategies. This study supports findings that significant size-selective mortality of juvenile pink salmon occurs after the first growing season. Investigating the timing and magnitude of size-selective mortality on juvenile pink salmon during their first growing season is an initial step toward understanding the processes regulating growth and survival.

Cross, A. D., Beauchamp, D. A., Myers, K. W., & Moss, J. H. (2008). Early marine growth of pink salmon in Prince William Sound and the coastal Gulf of Alaska during years of low and high survival. *Transactions of the American Fisheries Society*, *137*(3), 927–939. doi:10.1577/T07-015.1

Although early marine growth has repeatedly been correlated with overall survival in Pacific salmon *Oncorhynchus* spp., we currently lack a mechanistic understanding of smolt-to-adult survival. Smolt-to-adult survival of pink salmon *O. gorbuscha* returning to Prince William Sound was lower than average for juveniles that entered marine waters in 2001 and 2003 (3% in both years), and high for those that entered the ocean in 2002 (9%) and 2004 (8%). We used circulus patterns from scales to determine how the early marine growth of juvenile pink salmon differed (1) seasonally during May-October, the period hypothesized to be critical for survival; (2) between years of low and high survival; and (3) between hatchery and wild fish. Juvenile pink salmon exhibited larger average size, migrated onto the continental shelf and out of the sampling area more quickly, and survived better during 2002 and 2004 than during 2001 and 2003. Pink salmon were consistently larger throughout the summer and early fall during 2002 and 2004 than during 2001 and 2003, indicating that larger, faster-growing juveniles experienced higher survival. Wild juvenile pink salmon were larger than hatchery fish during low-survival years, but no difference was observed during high-survival years. Differences in size among years were determined by some combination of growing conditions and early mortality, the strength of which could vary significantly among years.

Daly, E. A., Auth, T. D., Brodeur, R. D., & Peterson, W. T. (2013). Winter ichthyoplankton biomass as a predictor of early summer prey fields and survival of juvenile salmon in the northern California Current. *Marine Ecology Progress Series*, *484*, 203–217. doi:10.3354/meps10320

Diets of juvenile coho *Oncorhynchus kisutch* and Chinook *O. tshawytscha* salmon are made up primarily of winter-spawning fish taxa in the late-larval and early juvenile stages that are undersampled in plankton and larger trawl nets. Although we have no direct measure of the availability of fish prey important to juvenile salmon during early marine residence, we do have data on the larval stage of their prey that may be used as a surrogate for the later stages. Data on these prey items were obtained from ichthyoplankton samples collected along the Newport Oregon Hydrographic line (44.65°N) during January–March in 1998–2010. We explored winter biomass of prey fish larvae as a potential indicator of marine feeding conditions for young salmon the following spring. The proportion of total winter ichthyoplankton biomass considered to be common salmon fish prey fluctuated from 13.9% in 2006 to 95.0% in 2000. The relationship between biomass of fish larvae in winter and subsequent coho salmon survival was highly significant ($r^2 = 50.0$, $p = 0.004$). When the 2 outlier years of 1998 (El Niño) and 1999 (La Niña) were removed, this relationship was also highly significant for spring Chinook ($r^2 = 70.7$, $p = 0.0002$) and significant for fall Chinook salmon ($r^2 = 34.0$, $p = 0.03$) returns. Winter larval fish composition showed a high degree of overlap with juvenile salmon diets during May, but less overlap in June. Larval fishes appeared to be an early and cost-effective indicator of ocean ecosystem conditions and future juvenile salmon survival.

Daly, E. A., Benkwitt, C. E., Brodeur, R. D., Litz, M. N. C., & Copeman, L. A. (2010). Fatty acid profiles of juvenile salmon indicate prey selection strategies in coastal marine waters. *Marine Biology*, *157*(9), 1975–1987. doi:10.1007/s00227-010-1466-9

Juvenile salmon exhibit high growth rates upon their arrival into the marine environment. Dietary changes from freshwater and estuarine habitats to those derived from the marine environment may play an important role in ultimate adult survival. We measured the total lipid and fatty acid (FA) composition of juvenile Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and 18 of their potential prey items sampled from coastal waters during their first few months at sea. Coho salmon had significant reductions in their lipid content (% wet weight) between May and June, likely due to early marine growth. We did not find a significant drop between May and June Chinook salmon lipid content, which may indicate an earlier ontogenetic selection to marine prey that are higher in lipids and essential fatty acids (EFAs). Juvenile salmon ate prey of both high and low lipids. Significant FA compositional changes occurred for both coho and Chinook salmon between May and June. In May, the FA profile of juvenile salmon, especially coho salmon, did not resemble their prey items; however, in June, there was a strong correlation between salmon and their common fish prey as determined by gut content analysis. Significant increases in the level of EFAs, especially docosahexaenoic acid (DHA, 22:6n-3) accounted for the majority of the monthly differences in salmon tissue FA composition. In order for juvenile salmon to adequately meet their physiological requirements, they may have adapted to select advantageous prey with higher levels of EFAs, especially DHA, in order to rapidly increase their growth and ultimate survival.

Daly, E. A., Brodeur, R. D., Fisher, J. P., Weitkamp, L. A., Teel, D. J., & Beckman, B. R. (2012). 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. *Environmental Biology of Fishes*, *94*(1), 117–134. doi:10.1007/s10641-011-9857-4

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.

Daly, E. A., Brodeur, R. D., & Weitkamp, L. A. (2009). Ontogenetic shifts in diets of juvenile and subadult Coho and Chinook Salmon in coastal marine waters: important for marine survival? *Transactions of the American Fisheries Society*, *138*(6), 1420–1438. doi:10.1577/T08-226.1

Successfully shifting to a more piscivorous diet may be an important factor in the growth and survival of juvenile coho salmon *Oncorhynchus kisutch* and Chinook salmon *O. tshawytscha* during their first summer in the northern California Current. Nonmetric multidimensional scaling and cluster analysis of diets by size showed several distinct groupings as the salmon grew during their first marine summer. These size-based diet differences were clearly driven by increased rates of piscivory for both species. Fish prey composition, feeding intensity, and fish prey–predator length ratios all significantly increased for coho salmon at approximately 240 mm fork length when they changed from diets dominated by juvenile rockfishes *Sebastes* spp., the larvae of crabs *Cancer spp.*, and adult euphausiids to one of predominantly juvenile forage fish. As Chinook salmon grew, they gradually increased the proportional contribution (by weight) of fish prey in their diets—from 55% in the smallest length-class examined (80–100 mm) to 95% in the largest one (>375 mm). Chinook salmon fed in the same marine environments as coho salmon and consistently ate more and longer fish prey at a given size than coho salmon but had lower overall feeding intensity, perhaps owing to a higher level of prey selection. Relating subsequent interannual adult salmon returns to juvenile diets showed mixed results. During lower-survival years, coho salmon ate fewer and smaller fish prey, while subyearling Chinook salmon had less total food and more empty stomachs. We did not find consistent trophic patterns for yearling Chinook salmon in relation to their ultimate survival.

Daly, E. A., Scheurer, J. A., Brodeur, R. D., Weitkamp, L. A., Beckman, B. R., & Miller, J. A. (2014). Juvenile Steelhead distribution, migration, feeding, and growth in the Columbia River estuary, plume, and coastal waters. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*.

Relative to extensive research on the freshwater stages of steelhead *Oncorhynchus mykiss* life history, little is known about the species' estuarine and early marine phases despite the decline of numerous populations, including several from the Columbia River. The distribution, diet, and growth of juvenile steelhead collected during surveys of the Columbia River estuary and coastal waters in May, June, and September 1998–2011 were analyzed for comparisons between fish caught in the estuary and ocean and between hatchery (marked) and putative wild (unmarked) fish. Almost all catches of juvenile steelhead in the ocean occurred during the May surveys (96%). Juvenile steelhead were consistently caught at the westernmost stations (> 55 km from shore), indicating an offshore distribution. Based on otolith structure and chemistry, we determined that these juveniles had been in marine waters for an average of only 9.8 d (SD = 10.2). Some of the steelhead that had been in marine waters for 1–33 d were captured at the westernmost edge of survey transects, indicating rapid offshore migration. Estuary-caught fish ate fewer prey types and consumed far less food than did ocean-caught fish, which ate a

variety of prey, including juvenile fishes, euphausiids, and crab megalopae. Estuary- and ocean-caught unmarked fish exhibited higher feeding intensities, fewer empty stomachs, and better condition than hatchery fish. Growth hormone levels (insulin-like growth factor 1 [IGF-1]) in unmarked fish and hatchery fish varied annually, with unmarked fish having slightly higher overall values. In general, the FL, condition, stomach fullness, and IGF-1 of ocean-caught steelhead increased with distance offshore. Unlike juveniles of other salmonid species, steelhead appeared to quickly migrate westward from coastal rivers and showed patterns of increased feeding and growth in offshore waters. An understanding of the estuarine and ocean ecology of steelhead smolts may assist in the management of threatened steelhead populations.

Davis, N. D., Myers, K. W., & Fournier, W. J. (2009). Winter food habits of Chinook salmon in the eastern Bering Sea. ***North Pacific Anadromous Fish Commission Bulletin*****, *5*, 243–253.**

This is the first study of winter diets of Chinook salmon in the eastern Bering Sea. We analyzed Chinook salmon stomach samples collected by U.S. observers on board commercial groundfish trawlers from January to March and July to August, 2007. The proportion of empty stomachs was higher in winter (45%) than summer (8%), suggesting longer time periods between meals in winter. Diversity of squid species in Chinook salmon diets was higher in winter than summer, when more fish, particularly juvenile walleye pollock, were consumed. All age groups of Chinook salmon collected in winter consumed fish offal, likely generated by fishery catch processing activities, however, fish offal was not observed in summer samples. In winter, the ratio of euphausiids and fish offal weight to Chinook salmon body weight was significantly higher in samples collected at shallow depths (< 200 m), and the ratio of squid was significantly higher in salmon collected at deeper depths (201–600 m). The ratio of euphausiids to fish body weight was significantly higher in immature than maturing Chinook salmon.

Duffy, E. J., & Beauchamp, D. A. (2008). Seasonal patterns of predation on juvenile Pacific salmon by anadromous cutthroat trout in Puget Sound. ***Transactions of the American Fisheries Society*****, *137*(1), 165–181. doi:10.1577/T07-049.1**

In the marine environment, Pacific salmon *Oncorhynchus* spp. suffer the greatest natural losses during early marine residence, and predation is hypothesized to be the key source of mortality during this life history stage. In the face of recent declines in Puget Sound salmon populations, our goal was to determine the extent of predation mortality on salmon during early marine life. In spring and summer of 2001-2003, we caught juvenile salmon and potential predators at nearshore areas in northern and southern regions of Puget Sound, Washington. We focused on the potential predation impact of coastal cutthroat trout *O. clarkii clarkii*, which were caught in low but consistent numbers in both regions and were the most abundant large-bodied potential predators of juvenile salmon in our catches. Cutthroat trout consumed a diverse and dynamic array of diet items and became increasingly piscivorous with increasing fork length above 140 mm. Cutthroat trout consumed a greater biomass of Pacific herring *Clupea pallasii* than any other prey fish species, but juvenile salmon were particularly important prey between April and June, making up greater than 50% of the fish prey consumed. Cutthroat trout exhibited size-selective predation, eating salmon that were smaller than the average size of

conspecific prey available in the environment. For a hypothetical size-structured population of 1,000 cutthroat trout, pink salmon *O. gorbuscha* and chum salmon *O. keta* contributed the greatest number of salmon to the diet but Chinook salmon *O. tshawytscha* contributed the greatest salmonid biomass. On an order-of-magnitude basis, these predation estimates represented a relatively minor amount of early marine mortality for Chinook salmon and lower rates for the other salmon species. Conversely, juvenile salmon contributed significantly to the spring energy budget for cutthroat trout in Puget Sound.

Duffy, E. J., & Beauchamp, D. A. (2011). Rapid growth in the early marine period improves the marine survival of Chinook salmon (*Oncorhynchus tshawytscha*) in Puget Sound, Washington. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(2), 232–240. doi:10.1139/F10-144

We examined the effect of early marine entry timing and body size on the marine (smolt-to-adult) survival of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*). We used data from coded wire tag release groups of hatchery Chinook salmon to test whether hatchery release date, release size, and size in offshore waters in July and September influenced marine survival. Marine survival was most strongly related to the average body size in July, with larger sizes associated with higher survivals. This relationship was consistent over multiple years (1997–2002), suggesting that mortality after July is strongly size-dependent. Release size and date only slightly improved this relationship, whereas size in September showed little relationship to marine survival. Specifically, fish that experienced the highest marine survivals were released before 25 May and were larger than 17 g (or 120 mm fork length) by July. Our findings highlight the importance of local conditions in Puget Sound (Washington, USA) during the spring and summer, and suggest that declines in marine survival since the 1980s may have been caused by reductions in the quality of feeding and growing conditions during early marine life.

Duffy, E. J., Beauchamp, D. A., Sweeting, R. M., Beamish, R. J., & Brennan, J. S. (2010). Ontogenetic diet shifts of juvenile Chinook salmon in nearshore and offshore habitats of Puget Sound. *Transactions of the American Fisheries Society*, *139*(3), 803–823. doi:10.1577/T08-244.1

Marine growth and survival of juvenile Chinook salmon *Oncorhynchus tshawytscha* depend in part on the quality and quantity of prey consumed during this potentially critical life stage; however, little is known about the early marine diet of these fish or factors that affect the diet's variability. We examined the recent (2001–2007) dietary habits of Puget Sound, Washington, Chinook salmon (listed as threatened under the U.S. Endangered Species Act) during their first marine growing season (April–September). Juvenile Chinook salmon initially fed in nearshore marine habitats and then shifted to feed primarily offshore during July–September. Diet composition varied significantly among sampling regions (northern, central, and southern), habitats (nearshore, offshore), years, months, and fish size-classes. At nearshore sites, insects (all months) and gammarid amphipods (July) were dominant prey sources, whereas in offshore diets decapods (primarily crab larvae; July) and fish (September) were most important. Chinook salmon became increasingly piscivorous as they grew and ate fish with fork lengths up to 51% (nearshore) and 52% (offshore) of predator fork length. At nearshore

sites, Chinook salmon fed mainly on larval and juvenile Pacific sand lances *Ammodytes hexapterus*; offshore, they primarily ate juvenile and older Pacific herring *Clupea pallasii*. Overall, Chinook salmon had more diverse diets and ate higher-quality prey (insects) in northern nearshore and central offshore waters, whereas Chinook salmon caught in the southern nearshore and northern offshore waters had a lower proportion of empty stomachs but ate lower-quality prey (crustaceans). Annual variation in the composition of offshore prey appeared to be determined early in the growing season, suggesting that environmental factors (e.g., climate) affecting marine productivity might produce strong interannual trends in marine survival of Puget Sound Chinook salmon. In addition, the importance of insects as high-quality prey highlighted the terrestrial link to the marine feeding of Chinook salmon and suggests that shoreline development and land use changes will affect feeding opportunities for these fish in Puget Sound.

Emmett, R. L., & Krutzikowsky, G. K. (2008). Nocturnal feeding of Pacific hake and jack mackerel off the mouth of the Columbia River, 1998-2004: Implications for juvenile salmon predation. *Transactions of the American Fisheries Society*, *137*(3), 657–676. doi:10.1577/T06-058.1

Predation by piscivorous marine fishes has been hypothesized to be a primary source of marine mortality for Pacific Northwest juvenile salmon. During the springs and summers of 1998-2004, we collected predator and prey fishes (forage and juvenile salmonids) at the surface at night off the mouth of the Columbia River. Pacific hake *Merluccius productus* had relatively low percentages of empty stomachs during cool-ocean years (2000 through 2002) and high percentages during 1998, a warm-ocean year. Euphausiids and fishes were the most commonly eaten prey for both species. Pacific hake and jack mackerel *Trachurus symmetricus* appeared to show some diet selectivity, eating some fish, including salmonids, in a higher proportion than found in the environment. Both Pacific hake and jack mackerel ate juvenile salmonids, but at very low amounts. After considering population sizes in the study area, these two predators do not appear to be responsible for the death of large numbers of Columbia River juvenile salmon smolts. However, we may have underestimated the number of salmonids eaten by hake and mackerel due to the limitations of our study. More work needs to be done to identify and quantify predation of juvenile salmon off the Pacific Northwest.

Emmett, R. L., Krutzikowsky, G. K., & Bentley, P. (2006). Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998–2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. *Progress in Oceanography*, *68*(1), 1–26. doi:10.1016/j.pocean.2005.08.001

From 1998 to 2003, we observed large fluctuations in the abundance and distribution of four pelagic predatory (piscivorous) fishes off northern Oregon and southern Washington, USA. Fluctuations in predatory fish species composition and abundance were strongly linked to the date of the spring transition and to ocean temperatures. Predatory fishes, forage fishes, and juvenile salmonids had distinct spatial distributions, with predators distributed primarily offshore and forage fish and salmonids onshore, but this varied depending on ocean conditions. We suggest that predatory and forage fish distributions respond to ocean temperatures, predator/prey interactions, and possibly turbidity. A shift in ocean conditions in 1999 decreased overall predator fish abundance

in the Columbia River plume, particularly for Pacific hake. Marine survival of juvenile salmon started to increase in 1999, and forage fish densities increased in 2000, lagging by one year.

Emmett, R. L., & Sampson, D. B. (2007). The relationships between predatory fish, forage fishes, and juvenile salmonid marine survival off the Columbia River: a simple trophic model analysis. *CalCOFI Rep*, *48,* 92-105.

A trophic model that simulates interactions between a predatory fish (Pacific hake, *Merluccius productus*), forage fish, and juvenile salmon off the Columbia River was constructed to identify if trophic interactions could account for marine mortality of Columbia River juvenile salmon. The model estimates the number of juvenile salmon that are eaten annually by Pacific hake off the Columbia River for a given hake and forage fish population. Model results indicate that the presence of high numbers of Pacific hake could account for high mortality of some juvenile salmonid species/stocks leaving the Columbia River, and that this mortality would be much reduced when forage fish are abundant. Estimates of hake and forage fish abundance, based on field data collected from 1998–2005, were used in the model to derive annual estimates of the number of salmon possibly eaten by hake. A multiple regression analysis using the output from the trophic model and average May/June Columbia River flows accounted for much of the annual variation in Columbia River fall Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon marine survival ($p < 0.05$, $R^2 > 60\%$), but not spring or summer Chinook salmon. For these two stocks, average May/June sea-surface temperature was the best predictor of marine survival. Results support the hypothesis that for some Columbia River salmon species/stocks, marine survival is predation-driven and affected by the interaction between the abundance of Pacific hake, forage fish, Columbia River flows, and possibly ocean turbidity. Future modeling work should include predation estimates of other large fishes, marine mammals, and sea birds.

Farley, E. V., & Moss, J. H. (2009). Growth rate potential of juvenile chum salmon on the eastern Bering Sea shelf: an assessment of salmon carrying capacity. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 265–277.

Spatial and temporal variation in growing conditions for juvenile salmon may determine the survival of salmon after their first year at sea. To assess this aspect of habitat quality, a spatially explicit bioenergetics model was used to predict juvenile chum salmon (*Oncorhynchus keta*) growth rate potential (GRP) on the eastern Bering Sea shelf during years with cold and warm spring sea surface temperatures (SSTs). Annual averages of juvenile chum salmon GRP were generally lower among years and regions with cold spring SSTs. In addition, juvenile chum salmon GRP was generally higher in offshore than in nearshore regions of the eastern Bering Sea shelf during years with warm SSTs; however, the distribution (catch per unit effort) of juvenile chum salmon was not significantly ($P< 0.05$) related to GRP. Shifts from warm to cold SSTs in the northern region do not appear to affect summer abundance of juvenile Yukon River chum salmon, whereas the abundance of juvenile Kuskokwim River chum salmon drops precipitously during years with cold SSTs. From this result, we hypothesize that size-selective predation is highest on juvenile Kuskokwim chum salmon during cold years, but that predation is not as great a factor for juvenile Yukon River chum salmon. Although not

addressed in this study, we also hypothesize that the smaller Yukon River chum salmon captured during years with cold SSTs likely incur higher size-selective mortality during winter.

Farley, E. V., Murphy, J. M., Adkison, M. D., Eisner, L. B., Helle, J. H., Moss, J. H., & Nielsen, J. (2007). Early marine growth in relation to marine-stage survival rates for Alaska sockeye salmon (*Oncorhynchus nerka*). *Fishery Bulletin*, *105*(1), 121–130.
We tested the hypothesis that larger juvenile sockeye salmon (*Oncorhynchus nerka*) in Bristol Bay, Alaska, have higher marine-stage survival rates than smaller juvenile salmon. We used scales from returning adults (33 years of data) and trawl samples of juveniles (n= 3572) collected along the eastern Bering Sea shelf during August through September 2000−02. The size of juvenile sockeye salmon mirrored indices of their marine-stage survival rate (e.g., smaller fish had lower indices of marine-stage survival rate). However, there was no relationship between the size of sockeye salmon after their first year at sea, as estimated from archived scales, and brood-year survival size was relatively uniform over the time series, possibly indicating size-selective mortality on smaller individuals during their marine residence. Variation in size, relative abundance, and marine-stage survival rate of juvenile sockeye salmon is likely related to ocean conditions affecting their early marine migratory pathways along the eastern Bering Sea shelf.

Farley, E. V., Murphy, J. M., Adkison, M., & Eisner, L. (2007). Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea shelf. *Journal of Fish Biology*, *71*(4), 1145–1158. doi:10.1111/j.1095-8649.2007.01587.x
Interannual variations in distribution, size, indices of feeding and condition of juvenile Bristol Bay sockeye salmon *Oncorhynchus nerka* collected in August to September (2000–2003) during Bering–Aleutian Salmon International Surveys were examined to test possible mechanisms influencing their early marine growth and survival. Juvenile sockeye salmon were mainly distributed within the southern region of the eastern Bering Sea, south of 57°0′ N during 2000 and 2001 and farther offshore, south of 58°0′ N during 2002 and 2003. In general, juvenile sockeye salmon were significantly larger ($P < 0{\cdot}05$) and had significantly higher indices of condition ($P < 0{\cdot}05$) during 2002 and 2003 than during 2000 and 2001. The feeding index was generally higher for age 1.0 year sockeye salmon than age 2.0 year during all years. Among-year comparisons suggested that Pacific sand lance *Ammodytes hexapterus* were important components of the juvenile sockeye salmon diet during 2000 and 2001 (20 to 50% of the mean wet mass) and age 0 year walleye pollock *Theragra chalcogramma* were important components during 2002 and 2003 (50 to 60% of the mean wet mass). Warmer sea temperatures during spring and summer of 2002 and 2003 probably increased productivity on the eastern Bering Sea shelf, enhancing juvenile sockeye salmon growth.

Farley Jr, E. V., Murphy, J. M., Middleton, A., Eisner, L., Pohl, J., Ivanov, O., Kuznetsova, N., Cieciel, K., Courtney, M., & George, H. (2006). Eastern Bering Sea (BASIS) coastal research (August - October 2005) on juvenile salmon. *North Pacific Anadromous Fish Commission Document*, *992*, 26 pp.

An eastern Bering Sea research cruise was conducted by National Marine Fisheries Service scientists from the Auke Bay Laboratory, Ocean Carrying Capacity program during August - October 2005 to study early marine distribution, migration, and growth of juvenile salmon (*Oncorhynchus* spp.) salmon on the eastern Bering Sea shelf. A total of 16,615 salmon were captured including juvenile pink (*O. gorbuscha*; 9.2%), chum (*O. keta*; 14.9%), sockeye (*O. nerka*; 69.8%), coho (*O. kisutch*; 0.9%), and chinook (*O. tshawytscha*; 2.5%) salmon; less than 3% of the catch consisted of immature and mature chum, sockeye, and chinook salmon. Juvenile pink and chum salmon were generally distributed north of 58°N with large catches occurring near Nunivak Island. Juvenile sockeye salmon were widely distributed within Bristol Bay (159°W) to as far east as 170°W with the largest catches occurring within Bristol Bay and south of Nunivak Island. Juvenile coho and chinook salmon were distributed within nearshore waters less than 50-m depth from Bristol Bay to Norton Sound with the largest catches occurring within Bristol Bay. Greater than 75% (percent body weight) of the prey items found in juvenile salmon stomachs consisted of larval and juvenile fish with the exception of juvenile pink and chum salmon (approximately 53% and 67% larval and juvenile fish respectively). Analyses of plankton, and of salmon age, size, growth data, and genetic stock identification, will be done to gain additional information on the early marine ecology of salmon along the eastern Bering Sea shelf.

Farley, E. V., Starovoytov, A., Naydenko, S., Heintz, R., Trudel, M., Guthrie, C., Eisner, L., & Guyon, J. R. (2011). Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. *ICES Journal of Marine Science: Journal du Conseil*, *68*(6), 1138–1146. doi:10.1093/icesjms/fsr021

Overwinter survival of Pacific salmon (*Oncorhynchus sp.*) is believed to be a function of size and energetic status they gain during their first summer at sea. We test this notion for Bristol Bay sockeye salmon (*O. nerka*), utilizing data from large-scale fisheries and oceanographic surveys conducted during mid-August to September 2002–2008 and from February to March 2009. The new data presented in this paper demonstrate size-selective mortality for Bristol Bay sockeye salmon between autumn and their first winter at sea. Differences in the seasonal energetic signatures for lipid and protein suggest that these fish are not starving, but instead the larger fish caught during winter apparently are utilizing energy stores to minimize predation. Energetic status of juvenile sockeye salmon was also strongly related to marine survival indices and years with lower energetic status apparently are a function of density-dependent processes associated with high abundance of juvenile sockeye salmon. Based on new information regarding eastern Bering Sea ecosystem productivity under a climate-warming scenario, we hypothesize that sustained increases in spring and summer sea temperatures may negatively affect energetic status of juvenile sockeye salmon, potentially resulting in increased overwinter mortality.

Farley, E. V., & Trudel, M. (2009). Growth rate potential of juvenile sockeye salmon in warmer and cooler years on the Eastern Bering Sea Shelf. *Journal of Marine Biology*, *2009*. doi:10.1155/2009/640215

A spatially explicit bioenergetics model was used to predict juvenile sockeye salmon *Oncorhynchus nerka* growth rate potential (GRP) on the eastern Bering Sea shelf during years with cooler and warmer spring sea surface temperatures (SSTs). Annual averages

of juvenile sockeye salmon GRP were generally lower among years with cooler SSTs and generally higher in offshore than nearshore regions of the eastern Bering Sea shelf during years with warmer SSTs. Juvenile sockeye salmon distribution was significantly ($P <$ .05) related to GRP and their prey densities were positively related to spring SST ($P <$ .05). Juvenile sockeye salmon GRP was more sensitive to changes in prey density and observed SSTs during years when spring SSTs were warmer (2002, 2003, and 2005). Our results suggest that the pelagic productivity on the eastern Bering Sea shelf was higher during years with warmer spring SSTs and highlight the importance of bottom-up control on the eastern Bering Sea ecosystem.

Fast, M. D., Johnson, S. C., & Jones, S. R. M. (2007). Differential expression of the pro-inflammatory cytokines IL-1β-1, TNFα-1 and IL-8 in vaccinated pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon juveniles. *Fish & Shellfish Immunology*, *22*(4), 403–407. doi:10.1016/j.fsi.2006.06.012

Laboratory-reared pink and chum salmon juveniles (~2 g) received an intraperitoneal

injection with a commercial, unadjuvanted *Aeromonas salmonicida* bacterin or sterile saline. Relative to elongation factor-1A, expression levels of genes encoding the proinflammatory cytokines interleukin-1β-1 (IL-1β), tumour necrosis factor-α-1 (TNFα) and interleukin-8 (IL-8) in pools of kidney and liver were examined 6- and 24-h after injection. Expression of IL-1β was significantly elevated in pink and chum salmon by 6-h, and declined in pink salmon but not in chum salmon by 24-h. Similarly, expression of TNFα was significantly elevated in both species at 6 h and only in chum salmon after 24-h. Expression of IL-8 was significantly elevated in both species at 6- and 24-h after injection. Expression of the three proinflammatory cytokine genes differed between salmon species both in the timing and magnitude of their expression. The significance of these differences with respect to immune function in these fish requires further research.

Fisher, J. P., Trudel, M., Amman, A., Orsi, J. A., Piccolo, J. J., Bucher, C., Casillas, E., Harding, J. A., MacFarlane, R. B., Brodeur, R. D., Morris, J. F. T., & Welch, D. W. (2007). Comparisons of the coastal distributions and abundances of juvenile Pacific salmon from Central California to the northern Gulf of Alaska. *American Fisheries Society Symposium*, *57*, 31–80.

In this chapter, we describe the distributions and abundances of juvenile Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, chum salmon *O. keta*, pink salmon *O. gorbuscha*, and sockeye salmon *O. nerka* in six regions along the west coast of North America from central California to the northern Gulf of Alaska during the early summer (June and July) and late summer–fall (August–November) of 2000, 2002, and 2004. We also describe fish abundance in relation to bottom depth and to the average temperature and salinity of the upper water column. Salmon were collected in rope trawls from the upper 15–20 m over the open coastal shelf. Catch per unit effort was standardized across the different regions. Subyearling Chinook salmon were found only from central California to British Columbia. Yearling Chinook salmon were widespread, but were most abundant between Oregon and Vancouver Island. Juvenile coho salmon were

widespread from northern California to the northern Gulf of Alaska, whereas chum, sockeye, and pink salmon were only abundant from Vancouver Island north into the Gulf of Alaska. Generally, the juveniles of the different salmon species were most abundant at, or north of, the latitudes at which the adults spawn. Abundances were particularly high near major exit corridors for fish migrating from freshwater or protected marine waters onto the open shelf. Seasonal latitudinal shifts in abundance of the juvenile salmon were generally consistent with the counterclockwise migration model of Hartt and Dell (1986). Subyearling Chinook salmon were associated with the high salinity environment found off California and Oregon, whereas chum, sockeye, and pink salmon were associated with the lower salinity environment in the Gulf of Alaska. However, within regions, evidence for strong temperature or salinity preferences among the different species was lacking. Subyearling Chinook salmon were most abundant in shallow, nearshore water.

Fisher, J. P., Weitkamp, L. A., Teel, D. J., Hinton, S. A., Orsi, J. A., Farley, E. V., Morriss, J.

F. T., Thiess, M. E., Sweeting, R. M., & Trudel, M. (2014). Early ocean dispersal patterns of Columbia River Chinook and coho salmon. *Transactions of the American Fisheries Society*, *143*(1), 252–272. doi:10.1080/00028487.2013.847862

Several evolutionarily significant units (ESUs) of Columbia River asin Chinook Salmon *Oncorhynchus tshawytscha* and Coho Salmon *O. kisutch* are listed as threatened or endangered under the U.S. Endangered Species Act. Yet little is known about the spatial and temporal distributions of these ESUs immediately following ocean entry, when year-class success may be determined. We documented differences in dispersal patterns during the early ocean period among groups defined by ESU, adult run timing, and smolt age. Between 1995 and 2006, 1,896 coded-wire-tagged juvenile fish from the Columbia River basin were recovered during 6,142 research trawl events along the West Coast of North America. Three distinct ocean dispersal patterns were observed: (1) age-1 (yearling) mid and upper Columbia River spring-run and Snake River spring–summer-run Chinook Salmon migrated rapidly northward and by late summer were not found south of Vancouver Island; (2) age-0 (subyearling) lower Columbia River fall, upper Columbia River summer, upper Columbia River fall, and Snake River fall Chinook Salmon dispersed slowly, remaining mainly south of Vancouver Island through autumn; and (3) age-1 lower Columbia River spring, upper Columbia River summer, and upper Willamette River spring Chinook Salmon and Coho Salmon were widespread along the coast from summer through fall, indicating a diversity of dispersal rates. Generally, the ocean dispersal of age-1 fish was faster and more extensive than that of age-0 fish, with some age-1 fish migrating as fast as 10–40 km/d (0.5–3.0 body lengths/s). Within groups, interannual variation in dispersal was moderate. Identification of the distinct temporal and spatial ocean distribution patterns of juvenile salmon from Columbia River basin ESUs is important in order to evaluate the potential influence of changing ocean conditions on the survival and long term sustainability of these fish populations.

Ford, J. S., & Myers, R. A. (2008). A global assessment of salmon aquaculture impacts on wild salmonids. *PLoS Biol*, *6*(2), e33. doi:10.1371/journal.pbio.0060033

Since the late 1980s, wild salmon catch and abundance have declined dramatically in the North Atlantic and in much of the northeastern Pacific south of Alaska. In these areas,

there has been a concomitant increase in the production offarmed salmon. Previous studies have shown negative impacts on wild salmonids, but these results have been difficult to translate into predictions of change in wild population survival and abundance. We compared marine survival of salmonids in areas with salmon farming to adjacent areas without farms in Scotland, Ireland, Atlantic Canada, and Pacific Canada to estimate changes in marine survival concurrent with the growth of salmon aquaculture. Through a meta-analysis of existing data, we show a reduction in survival or abundance of Atlantic salmon; sea trout; and pink, chum, and coho salmon in association with increased production of farmed salmon. In many cases, these reductions in survival or abundance are greater than 50%. Meta-analytic estimates of the mean effect are significant and negative, suggesting that salmon farming has reduced survival of wild salmon and trout in many populations and countries.

Frechette, D., Osterback, A.-M. K., Hayes, S. A., Bond, M. H., Moore, J. W., Shaffer, S. A., & Harvey, J. T. (2012). Assessing avian predation on juvenile salmonids using passive integrated transponder tag recoveries and mark–recapture methods. ***North American Journal of Fisheries Management*****, *32*(6), 1237–1250. doi:10.1080/02755947.2012.728171**

Many populations of coho salmon *Oncorhynchus kisutch* and steelhead *O. mykiss* are listed under the U.S. Endangered Species Act. Until recently, the role of avian predation in limiting recovery of coho salmon and steelhead in central California coastal watersheds has been overlooked. We used recoveries of passive integrated transponder (PIT) tags from Año Nuevo Island (ANI), a breeding site for several species of piscivorous seabirds, to estimate predation rates on juvenile salmonids and identify susceptible life stages and species responsible for predation. A total of 34,485 PIT tags were deployed in coho salmon and steelhead in six watersheds in San Mateo and Santa Cruz counties. Tags were deposited on ANI by predators after ingestion of tagged fish. Because tags were not removed from the island and were detected on multiple sampling occasions, we were able to use mark–recapture models to generate a corrected minimum predation estimate. We used POPAN, a variation of the Jolly–Seber model, to generate an estimate of gross population abundance, which accounted for tags deposited on the island but not detected during surveys. Detections of 196 tags from surveys conducted between autumn 2006 and spring 2009 were incorporated into the model, producing a gross population estimate of 242 tags (SE = 9.8). Addition of tags detected between autumn 2009 and 2010 to the abundance estimate from POPAN produced a new minimum estimate of 362 tags on ANI. Western gulls Larus occidentalis probably were the primary predator depositing tags on ANI. Minimum predation estimates ranged from 0.1% (Soquel Creek) to 4.6% (Waddell Creek) of outmigrating coho salmon and steelhead smolts. Predation was potentially greater given still unquantified deposition of tags off-colony and destruction of tags during digestive processes of predators. Finally, avian predators targeted estuary-reared fish, which contributed disproportionately to adult populations, further impacting imperiled salmon populations.

Friedland, K. D., Ward, B. R., Welch, D. W., & Hayes, S. A. (2014). Postsmolt growth and

thermal regime define the marine survival of Steelhead from the Keogh River, British Columbia. ***Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*****, *6*, 1–11.**
The population of anadromous steelhead *Oncorhynchus mykiss* in the Keogh River has been studied intensively, in part because of its pattern of declining recruitment, which is largely attributed to poor marine survival. Climate variability has changed the productivity of salmonid species in all regions of the North Pacific, with areas alternately shifting between periods of enhanced and depressed productivity. The mechanisms governing marine survival and adult recruitment are central to contemporary resource management concerns but are also of concern with regard to the long-term prospects of managing biodiversity. We provide evidence that postsmolt growth contributes to the pattern of marine survival of Keogh River steelhead over the period corresponding to smolt years 1977–1999. Size at ocean entry did not appear to have sufficient contrast to significantly affect survival. However, assessment of scale growth suggested that the fish's initial growth at sea is not as important as the sustained growth conditions during summer and fall of the postsmolt year. The return rate of steelhead was negatively correlated with sea surface temperature in the ocean domains that were assumed to provide postsmolt nursery habitat, suggesting that growth is directly affected by warming conditions or that ocean warming affects the food web upon which steelhead depend. Steelhead appear to respond to changing climate and growth regimes in a manner similar to that of their North Atlantic analog, the Atlantic Salmon *Salmo salar*. Comparative data show that eastern basin Atlantic Salmon populations are negatively affected by a thermal regime of increasing temperature during the postsmolt year, suggesting a relationship between postsmolt growth and survival.

Gladics, A. J., Suryan, R. M., Brodeur, R. D., Segui, L. M., & Filliger, L. Z. (2014). Constancy and change in marine predator diets across a shift in oceanographic conditions in the Northern California Current. ***Marine Biology*****, 1–15. doi:10.1007/s00227-013-2384-4**
Variable ocean conditions can greatly impact prey assemblages and predator foraging in marine ecosystems. Our goal was to better understand how a change in ocean conditions influenced dietary niche overlap among a suite of midtrophic-level predators. We examined the diets of three fishes and one seabird off central Oregon during two boreal summer upwelling periods with contrasting El Niño (2010) and La Niña (2011) conditions. We found greater niche specialization during El Niño and increased niche overlap during La Niña in both the nekton and micronekton diet components, especially in the larger, more offshore predators. However, only the two smaller, more nearshore predators exhibited interannual variation in diet composition. Concurrent trawl surveys confirmed that changes in components of predator diets reflected changes in the prey community. Using multiple predators across diverse taxa and life histories provided a comprehensive understanding of food-web dynamics during changing ocean conditions.

Gottesfeld, A. S., Proctor, B., Rolston, L. D., & Carr-Harris, C. (2009). Sea lice, ***Lepeophtheirus salmonis*****, transfer between wild sympatric adult and juvenile salmon on the north coast of British Columbia, Canada.** ***Journal of Fish Diseases*****, *32*(1), 45–57. doi:10.1111/j.1365-2761.2008.01003.x**

We examine sea lice, *Lepeophtheirus salmonis*, on juvenile and adult salmon from the north coast of British Columbia between 2004 and 2006 in an area that does not at present contain salmon farms. There is a pronounced zonation in the abundance of *L. salmonis* on juvenile pink salmon, *Oncorhynchus gorbuscha*, in the Skeena and Nass estuaries. Abundances in the proximal and distal zones of these estuaries are 0.01 and 0.05 respectively. The outer zones serve as feeding and staging areas for the pink salmon smolts. Returning Chinook, *Oncorhynchus tshawytscha*, and coho salmon, *Oncorhynchus kisutch*, concentrate in these areas. We collected data in 2006 to examine whether *L. salmonis* on returning adult salmon are an important source of the sea lice that appear on juvenile pink salmon. Nearly all (99%) of the sea lice on returning Chinook and over 80% on coho salmon were *L. salmonis*. Most of the *L. salmonis* were motile stages including many ovigerous females. There was a sharp increase in the abundance of sea lice on juvenile pink salmon smolts between May and July 2006 near the sites of adult captures. As there are no salmon farms on the north coast, few sticklebacks, *Gasterosteus aculeatus*, and very few resident salmonids until later in the summer, it seems that the most important reservoir of *L. salmonis* under natural conditions is returning adult salmon. This natural source of sea lice results in levels of abundance that are one or two orders of magnitude lower than those observed on juvenile pink salmon in areas with salmon farms such as the Broughton Archipelago.

Haeseker, S. L., McCann, J. A., Tuomikoski, J., & Chockley, B. (2012). Assessing freshwater and marine environmental influences on life-stage-specific survival rates of Snake River spring–summer Chinook salmon and steelhead. *Transactions of the American Fisheries Society*, *141*(1), 121–138. doi:10.1080/00028487.2011.652009

Pacific salmon *Oncorhynchus* spp. from the Snake River basin experience a wide range of environmental conditions during their freshwater, estuarine, and marine residence, which in turn influence their survival rates at each life stage. In addition, researchers have found that juvenile out-migration conditions can influence subsequent survival during estuarine and marine residence, a concept known as the hydrosystem-related, delayed-mortality hypothesis. In this analysis, we calculated seasonal, life-stage-specific survival rate estimates for Snake River spring–summer Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* and conducted multiple-regression analyses to identify the freshwater and marine environmental factors associated with survival at each life stage. We also conducted correlation analyses to test the hydrosystem-related, delayed-mortality hypothesis. We found that the freshwater variables we examined (the percentage of river flow spilled over out-migration dams and water transit time) were important for characterizing the variation in survival rates not only during freshwater out-migration but also during estuarine and marine residence. Of the marine factors examined, we found that the Pacific Decadal Oscillation index was the most important variable for characterizing the variation in the marine and cumulative smolt-to-adult survival rates of both species. In support of the hydrosystem-related, delayed-mortality hypothesis, we found that freshwater and marine survival rates were correlated, indicating that a portion of the mortality expressed after leaving the hydrosystem is related to processes affected by downstream migration conditions. Our results indicate that improvements in life-stage-specific and smolt-to-adult survival may be achievable across a range of marine conditions through increasing spill percentages and reducing

water transit times during juvenile salmon out-migration.

Hayes, S. A., Bond, M. H., Hanson, C. V., Freund, E. V., Smith, J. J., Anderson, E. C., Ammann, A. J., & MacFarlane, R. B. (2008). Steelhead growth in a small Central California watershed: upstream and estuarine rearing patterns. *Transactions of the American Fisheries Society*, *137*(1), 114–128. doi:10.1577/T07-043.1

We monitored growth and life history pathways of juvenile steelhead *Oncorhynchus mykiss* and compared growth rates between the upper watershed and estuary in Scott Creek, a typical California coastal stream. Growth in the upper watershed was approximately linear from May to December for age-0 fish. For passive integrated transponder (PIT) tagged, age-1+ fish, growth transitioned to a cyclic pattern, peaking at 0.2% per day during February-April, when maximum flows and temperatures of 7-12°C occurred. Growth of PIT-tagged fish then slowed during August-September (0.01% per day), when temperatures were 14-18°C and flows were low. During each spring, smolts (mean fork length [FL] ± SE = 98.0 ± 1.2 mm) and fry migrated to the estuary; some fish remained there during summer-fall as low flows and waves resulted in seasonal sandbar formation, which created a warm lagoon and restricted access to the ocean. Growth in the estuary-lagoon was much higher (0.2-0.8% per day at 15-24°C). Our data suggest the existence of three juvenile life history pathways: Upper-watershed rearing, estuary-lagoon rearing, and combined upper-watershed and estuary-lagoon rearing. We present a model based upon the above data that reports size at age for each juvenile life history

type. The majority of fish reaching typical steelhead ocean entry sizes (~150-250 mm

FL; age 0.8-3.0) were estuary-lagoon reared, which indicates a disproportionate contribution of this habitat type to survival of Scott Creek steelhead. In contrast, steelhead from higher latitudes rear in tributaries during summer, taking several years to attain ocean entry size.

Hoem Neher, T. D., Rosenberger, A. E., Zimmerman, C. E., Walker, C. M., & Baird, S. J. (2013). Estuarine environments as rearing habitats for juvenile Coho Salmon in contrasting south-central Alaska watersheds. *Transactions of the American Fisheries Society*, *142*(6), 1481–1494. doi:10.1080/00028487.2013.815660

For Pacific salmon, estuaries are typically considered transitional staging areas between freshwater and marine environments, but their potential as rearing habitat has only recently been recognized. The objectives of this study were two-fold: (1) to determine if Coho Salmon *Oncorhynchus kisutch* were rearing in estuarine habitats, and (2) to characterize and compare the body length, age, condition, and duration and timing of estuarine occupancy of juvenile Coho Salmon between the two contrasting estuaries. We examined use of estuary habitats with analysis of microchemistry and microstructure of sagittal otoliths in two watersheds of south-central Alaska. Juvenile Coho Salmon were classified as estuary residents or nonresidents (recent estuary immigrants) based on otolith Sr : Ca ratios and counts of daily growth increments on otoliths. The estuaries differed in water source (glacial versus snowmelt hydrographs) and in relative estuarine and watershed area. Juvenile Coho Salmon with evidence of estuary rearing were greater

in body length and condition than individuals lacking evidence of estuarine rearing. Coho Salmon captured in the glacial estuary had greater variability in body length and condition, and younger age-classes predominated the catch compared with the nearby snowmelt-fed, smaller estuary. Estuary-rearing fish in the glacial estuary arrived later and remained longer (39 versus 24 d of summer growth) during the summer than did fish using the snowmelt estuary. Finally, we observed definitive patterns of overwintering in estuarine and near shore environments in both estuaries. Evidence of estuary rearing and overwintering with differences in fish traits among contrasting estuary types refute the notion that estuaries function as only staging or transitional habitats in the early life history of Coho Salmon.

Holsman, K. K., Scheuerell, M. D., Buhle, E., & Emmett, R. (2012). Interacting effects of translocation, artificial propagation, and environmental conditions on the marine survival of Chinook salmon from the Columbia River, Washington, U.S.A. *Conservation Biology*, *26*(5), 912–922. doi:10.1111/j.1523-1739.2012.01895.x

Captive rearing and translocation are often used concurrently for species conservation, yet the effects of these practices can interact and lead to unintended outcomes that may undermine species' recovery efforts. Controls in translocation or artificial-propagation programs are uncommon; thus, there have been few studies on the interacting effects of these actions and environmental conditions on survival. The Columbia River basin, which drains 668,000 km^2 of the western United States and Canada, has an extensive network of hydroelectric and other dams, which impede and slow migration of anadromous Pacific salmon (*Oncorhynchus* spp.) and can increase mortality rates. To mitigate for hydrosystem-induced mortality during juvenile downriver migration, tens of millions of hatchery fish are released each year and a subset of wild- and hatchery-origin juveniles are translocated downstream beyond the hydropower system. We considered how the results of these practices interact with marine environmental conditions to affect the marine survival of Chinook salmon (*O. tshawytscha*). We analyzed data from more than 1 million individually tagged fish from 1998 through 2006 to evaluate the probability of an individual fish returning as an adult relative to its rearing (hatchery vs. wild) and translocation histories (translocated vs. in-river migrating fish that traveled downriver through the hydropower system) and a suite of environmental variables. Except during select periods of very low river flow, marine survival of wild translocated fish was approximately two-thirds less than survival of wild in-river migrating fish. For hatchery fish, however, survival was roughly two times higher for translocated fish than for in-river migrants. Competition and predator aggregation negatively affected marine survival, and the magnitude of survival depended on rearing and translocation histories and biological and physical conditions encountered during their first few weeks of residence in the ocean. Our results highlight the importance of considering the interacting effects of translocation, artificial propagation, and environmental variables on the long-term viability of species.

Hyun, S.-Y., Myers, K. W., & Talbot, A. (2007). Year-to-year variability in ocean recovery rate of Columbia River Upriver Bright fall Chinook salmon (*Oncorhynchus tshawytscha*). *Fisheries Oceanography*, *16*(4), 350–362. doi:10.1111/j.1365-2419.2007.00436.x

Unusually large returns of several stocks of fall Chinook salmon (*Oncorhynchus tshawytscha*) from the U.S. Northwest commonly occurred during the late 1980s. These synchronous events seem to have been due to ocean rather than freshwater conditions because natal rivers of these stocks were geographically disconnected. We examined year-to-year variability in cohort strength of one of these stocks, Upriver Bright (URB) fall Chinook salmon from the Columbia River Hanford Reach for brood years 1976–99 (recovery years 1979–2002). We used the ocean recovery rate of coded-wire-tag (CWT) fish as an index of cohort strength. To analyse year-to-year variability in the ocean recovery rate, we applied a log-linear model whose candidate explanatory variables were ocean condition variables, fishing effort, age of recovered fish, and fish rearing type (hatchery versus wild). Explanatory variables in the best model included fishing effort, and the quadratic term of winter sea surface temperature (SST) measured from coastal waters of British Columbia, Canada during the fish's first ocean year. The coefficient of the quadratic term of SST was significantly negative, so the model shape was convex. Our findings can be used to infer year-to-year variability in cohort strength of other fall Chinook salmon whose life history and ocean distributions are similar to the URB fish.

Irvine, J. R., & Akenhead, S. A. (2013). Understanding smolt survival trends in sockeye salmon. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, *5*, 303–328. doi:10.1080/19425120.2013.831002

Many populations of Sockeye Salmon *Oncorhynchus nerka* in the eastern North Pacific Ocean experienced significant productivity declines that began about 1990, but there is no consensus on the mechanisms responsible. To better understand Sockeye Salmon survival trends, we examined the 50-year time series for two age-classes of Sockeye Salmon smolts from Chilko Lake in central British Columbia. Arranging survival time series for both age-classes by ocean entry year and combining them, weighted by a proxy model of sampling variance, reduced the sampling variance in the original age-1 smolt survivals sufficiently to indicate a linear trend of increasing survival from 1960 to 1990 that suddenly changed at or near 1991 to a lower and declining trend from 1992 to 2008. Neither density nor mean length influenced smolt survival. Returns in a given year were not good predictors of siblings returning in subsequent years. Time spent at sea increased linearly beginning around 1970. Although smolt survivals differed between ecosystem regimes, there was only the one clear pattern break about 1991. To improve our understanding of mechanisms, survival trends were compared with environmental indices that included catches and hatchery releases of potentially competing salmon from around the North Pacific Ocean. Smolt survivals were more similar to abundance indices of Sockeye Salmon, Chum Salmon *O. keta*, and Pink Salmon *O. gorbuscha* than to indices of global, regional, or local ocean climate. Our results are consistent with the hypothesis that salmon productivity in the North Pacific declined soon after 1990. We present a simple model to illustrate how increased competition at sea, related to the release of large numbers of hatchery salmon, in conjunction with changes in ocean productivity, may have played a significant role in improving Sockeye Salmon survivals while reducing their growth before 1991. After 1991, these factors may have acted to reduce survivals while the growth of survivors showed no effect.

Irvine, J. R., O'Neill, M., Godbout, L., & Schnute, J. (2013). Effects of smolt release timing

and size on the survival of hatchery-origin coho salmon in the Strait of Georgia. *Progress in Oceanography*, *115*, 111–118. doi:10.1016/j.pocean.2013.05.014
Altering release sizes and timings of coho salmon smolts from hatcheries in the Strait of Georgia will not reverse the precipitous survival declines of the past three decades. We modeled the effects on survival of ocean entry year, mean smolt size (weight), and release day. Ocean entry year was by far the most important. During 1979–2006, smolt to adult survivals declined similarly for hatchery and wild coho salmon, although wild salmon consistently survived at higher rates. Best models differed among hatcheries, implying location-specific differences in the optimal size and timing of release. At four of five hatcheries, heavier smolts survived significantly better than lighter smolts. At one hatchery, a significant interaction between ocean entry year and smolt weight reflected an increased positive effect of weight later in the time series. At two Vancouver Island hatcheries, early release groups appeared to survive better than later releases in early years, while later release groups survived best in recent years. We recommend: (1) hatchery managers release coho salmon smolts throughout the outmigration period of higher surviving wild coho salmon smolts and (2) an experimental approach using hatcheries to evaluate density-dependent effects on coho salmon growth and survival.

Jacobson, K. C., Teel, D., Doornik, D. M. V., & Casillas, E. (2008). Parasite-associated mortality of juvenile Pacific salmon caused by the trematode *Nanophyetus salmincola* during early marine residence. *Marine Ecology Progress Series*, *354*, 235–244. doi:10.3354/meps07232
The potential effect of the freshwater trematode *Nanophyetus salmincola* on early marine survival of Pacific salmon was assessed by monitoring the prevalence and intensity of metacercarial infection in yearling coho salmon *Oncorhynchus kisutch*, and yearling and subyearling Chinook salmon *O. tshawytscha* caught off Oregon and Washington during May, June, and September of 1999 to 2002. Annual prevalences of *N. salmincola* infection in yearling coho salmon were 62 to 78% and were significantly greater each year than in both yearling and subyearling Chinook salmon (19.3 to 53.8% and 40.5 to 53.5%, respectively). Yearling coho salmon also had significantly higher intensities of infection (from approximately 2-fold to 12-fold) than yearling and subyearling Chinook salmon. Prevalences and intensities in coho salmon caught in September were significantly lower (by approximately 21%) than in coho salmon caught in May or June in 3 of the 4 years. Variance to mean ratios of parasite abundance in coho salmon were also lowest in September, suggesting parasite-associated host mortality during early ocean residence. There was no evidence for a seasonal decline in infection in yearling or subyearling Chinook salmon. Infection intensities, but not prevalences, were significantly greater in naturally produced (wild) coho salmon than in hatchery produced coho salmon and could be due to differences in exposure to the trematode. Highly infected naturally produced coho salmon were not caught in September. This study suggests that coho salmon with high intensities of *N. salmincola* may not survive early marine residence, and that disease processes need to be considered as a factor affecting marine survival of juvenile salmon.

Jarrin, J. R. M., & Miller, J. A. (2013). Sandy beach surf zones: An alternative nursery

habitat for 0-age Chinook salmon. *Estuarine, Coastal and Shelf Science*, *135*, 220–230. doi:10.1016/j.ecss.2013.10.014

The role of each habitat fish use is of great importance to the dynamics of populations. During their early marine residence, Chinook salmon (*Oncorhynchus tshawytscha*), an anadromous fish species, mostly inhabit estuaries but also use sandy beach surf zones and the coastal ocean. However, the role of surf zones in the early life history of Chinook salmon is unclear. We hypothesized that surf zones serve as an alternative nursery habitat, defined as a habitat that consistently provides a proportion of a population with foraging and growth rates similar to those experienced in the primary nursery. First, we confirmed that juvenile Chinook salmon cohorts are simultaneously using both habitats by combining field collections with otolith chemical and structural analysis to directly compare size and migration patterns of juveniles collected in two Oregon (USA) estuaries and surf zones during three years. We then compared juvenile catch, diet and growth in estuaries and surf zones. Juveniles were consistently caught in both habitats throughout summer. Catches were significantly higher in estuaries (average± SD=34.3±19.7 ind. 100 m^2) than surf zones (1.0±1.5 ind. 100 m^2) and were positively correlated (r=0.92). Size at capture (103±15 mm fork length, FL), size at marine entry (76±13 mm FL), stomach fullness (22% body weight) and growth rates (0.4±0.0 mm day^{-1}) were similar between habitats. Our results suggest that when large numbers of 0-age Chinook salmon inhabit estuaries, juveniles concurrently use surf zones, which serve as an alternative nursery habitat. Therefore, surf zones expand the available rearing habitat for Chinook salmon during early marine residence, a critical period in the life history

Jarrin, J. R. M., Shanks, A. L., & Banks, M. A. (2009). Confirmation of the presence and use

of sandy beach surf-zones by juvenile Chinook salmon. *Environmental Biology of Fishes*, *85*(2), 119–125. doi:10.1007/s10641-009-9470-y

Migration patterns and habitat use of sub-yearling Chinook salmon during initial ocean entrance is poorly understood. Twenty-five years ago, sub-yearling Chinook salmon were hypothesized to stay close to shore (<5 km). To test this hypothesis we sampled the surf-zone of a southern Oregon dissipative sandy beach throughout the summer of 2006 (06/07–09/29) using a beach seine in 1 m of water depth. We caught 48 sub-yearlings over six dates (07/22 to 09/01). Mean standard length of Chinook salmon caught in the surf-zone increased from 9.1 ± 0.6 (07/22/06) to 11.6 ± 0.7 cm (09/01/06), suggesting a mean increase of 0.6 mm in standard length (S.L.) per day. Early in the summer, smaller fish fed mostly on amphipods. Later in the summer, larger juveniles fed primarily on larval and juvenile fish. All prey items were common in the surf-zone. Juveniles appear to migrate from the estuary to the surf-zone where they feed on the local zooplankton for up to two summer months before migrating offshore.

Johnson, L., Anulacion, B., Arkoosh, M., Olson, O. P., Sloan, C., Sol, S. Y., Spromberg, J., Teel, D. T., Yanagida, G. & Ylitalo, G. (2013). Persistent organic pollutants in juvenile Chinook salmon in the Columbia River basin: implications for stock recovery. *Transactions of the American Fisheries Society*, *142*(1), 21–40. doi:10.1080/00028487.2012.720627

Among the populations of Pacific salmon and steelhead *Oncorhynchus mykiss* (anadromous Rainbow Trout) that inhabit the Columbia River basin there are currently 13 Evolutionarily Significant Units listed as threatened or endangered under the U.S. Endangered Species Act. While habitat loss, dams, overharvest, and climate change have been implicated in declining abundance of Chinook Salmon *O. tshawytscha* in the Columbia River, chemical contaminants represent an additional, yet poorly understood, conservation threat. In this study we measured concentrations of persistent organic pollutants in juvenile Chinook Salmon from various Columbia River stocks and life history types to evaluate the potential for adverse effects in these threatened and endangered fish. Polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDTs), recognized contaminants of concern in the Columbia basin, are the primary focus of this paper; other contaminants found in these fish, such as polybrominated diphenyl ethers and polycyclic aromatic hydrocarbons, are described in other publications. We frequently detected PCBs and DDTs in juvenile salmon and salmon diet samples from the lower Columbia River and estuary. In some cases, concentrations in salmon were above estimated thresholds for effects on growth and survival. The tidal freshwater portion of the estuary, between Portland, Oregon, and Longview, Washington, appeared to be an important source of contaminants for juvenile salmon and a region in which salmon were exposed to toxicants associated with urban development and industrial activity. Highest concentrations of PCBs were found in fall Chinook Salmon stocks with subyearling life histories, including populations from the upper Columbia and Snake rivers, which feed and rear in the tidal freshwater and estuarine portions of the river for extended periods. Spring Chinook Salmon stocks with yearling life histories that migrate more rapidly through the estuary generally had low PCB concentrations, but high concentrations of DDTs. Lipid content was low (<1%) in many of the fish examined, contributing to high lipid-adjusted contaminants concentrations in some samples.

Jones, S., Kim, E., & Bennett, W. (2008). Early development of resistance to the salmon louse, *Lepeophtheirus salmonis* (Krøyer), in juvenile pink salmon, *Oncorhynchus gorbuscha* (Walbaum). *Journal of Fish Diseases*, *31*(8), 591–600. doi:10.1111/j.1365-2761.2008.00933.x

This study examined the effect of fish weight on the susceptibility of post-emergent pink salmon to *Lepeophtheirus salmonis* (Krøyer). Three trials were conducted, each with two stocks of pink salmon, *Oncorhynchus gorbuscha* (Walbaum), at starting weights of c. 0.3, 0.7 and 2.4 g, respectively. In each trial, duplicate tanks of fish were exposed to 0, 25 (only in Trial 1), 50 or 100 copepodids per fish. Mortality in Trial 1 was c. 37%, regardless of stock following exposures to 50 or 100 copepodids. Mortalities occurred up to 26 days after exposure, and more than 80% of the lice on the dead fish were chalimus stages. Infections with adult or preadult lice were observed on c. 35% of fish surviving to 37 days after exposure. Mortality was 5% in Trial 2 and there was no mortality in Trial 3. The abundance of *L. salmonis* was lower in Trial 3 compared with Trials 1 or 2. Histological changes in the skin coincident with fish growth included a thickening of the epidermis, infiltration of the dermis with fibroblasts by the end of Trial 1 and the first evidence of scales by the end of Trial 2; scales were evident throughout Trial 3. These results showed that the previously reported innate resistance to *L. salmonis* displayed by pink salmon develops in fish heavier than 0.3 g and appears to be functional by 0.7 g.

This resistance coincided with changes to the epidermis and dermis, including the formation of scales. The present results indicate that elevated risk associated with *L. salmonis* infection among migrating post-emergent pink salmon may occur during a relatively brief period before the fish reaches 0.7 g.

Jones, S., Kim, E., & Dawe, S. (2006). Experimental infections with *Lepeophtheirus salmonis* (Krøyer) on threespine sticklebacks, *Gasterosteus aculeatus* L., and juvenile Pacific salmon, *Oncorhynchus* spp. *Journal of Fish Diseases*, *29*(8), 489–495. doi:10.1111/j.1365-2761.2006.00742.x

Experimental infections with *Lepeophtheirus salmonis* (Krøyer) were established on threespine sticklebacks, *Gasterosteus aculeatus* L., juvenile pink, *Oncorhynchus gorbuscha* (Walbaum), and chum, *Oncorhynchus keta* (Walbaum), salmon. The prevalence and abundance of infections were initially higher on sticklebacks than on either salmon species. The initial prevalence and intensity of infections on chum salmon were higher than those on pink salmon, and declined on both species during louse development. The rate of parasite development to adult stages was similar on all species although development beyond the preadult stage was not observed on sticklebacks. These results confirm previous field observations on the occurrence and development of *L. salmonis* on threespine sticklebacks.

Jones, S. R. M., Fast, M. D., & Johnson, S. C. (2008). Influence of reduced feed ration on *Lepeophtheirus salmonis* infestation and inflammatory gene expression in juvenile pink salmon. *Journal of Aquatic Animal Health*, *20*(2), 103–109. doi:10.1577/H07-014.1

The effect of reduced feed ration on infestation levels with the sea louse *Lepeophtheirus salmonis* and gene expression in juvenile pink salmon *Oncorhynchus gorbuscha* was tested in three laboratory trials. Body weight was significantly lower among fish on the reduced ration for 27, 34, or 65 d than fish on the full ration. Neither the prevalence nor the abundance of *L. salmonis* differed between fish on full and reduced rations at any time in any trial. In trial 2, sea louse rejection was delayed among fish on reduced rations; however, the parasite was ultimately rejected from all fish in this trial regardless of ration. Proinflammatory gene expression in salmon exposed to *L. salmonis* was modulated by reduced rations. There was a reduction in the expression of interleukin-8 in pink salmon on reduced rations 7 d after exposure but not 14 d after exposure. In contrast, the 7-d expression of interleukin-1 beta (IL-1β) was reduced in exposed pink salmon regardless of ration. By day 14, however, expression of IL-1β was increased in association with reduced rations among exposed salmon. Similarly, the expression of tumor necrosis factor alpha (TNFα) was increased 14 d after exposure among salmon on a reduced ration. There was no evidence that short-duration exposure of otherwise healthy juvenile pink salmon to a reduced ration affected susceptibility to *L. salmonis*. The expression data do not suggest an obvious mechanism of louse rejection; rather, they indicate that a more comprehensive suite of inflammatory pathways should be surveyed to better understand the early pink salmon response to *L. salmonis*.

Jones, S. R. M., Fast, M. D., Johnson, S. C., & Groman, D. B. (2007). Differential rejection of salmon lice by pink and chum salmon: disease consequences and expression of

proinflammatory genes. *Diseases of Aquatic Organisms*, *75*(3), 229–238. doi:10.3354/dao075229

The consequences of high (735 copepodids fish^{-1}) and low (243 copepodids fish^{-1}) level exposures of size-matched juvenile pink and chum salmon to *Lepeophtheirus salmonis* copepodids were examined. At both levels of exposure the prevalence and abundance of *L. salmonis* was significantly higher on chum salmon. In addition, the weight of exposed chum salmon following the high exposure was significantly less than that of unexposed chum salmon. At both exposures, the haematocrit of exposed chum salmon was significantly less than that of unexposed chum. Neither weight nor haematocrit of pink salmon was affected by exposures at these levels. Despite the presence of microscopic inflammatory lesions associated with attachment of *L. salmonis* on the epithelium of gill and fin of both salmon species, there were no mortalities following either exposure. A transient cortisol response was observed in chum salmon 21 d after low exposure. An earlier and quantitatively higher expression of the proinflammatory genes interleukin-8 (IL-8), tumour necrosis factor α-1 (TNFα-1) and interleukin-1β (IL-1β) in fin and head kidney of pink salmon suggested a mechanism of more rapid louse rejection in this species. Together, these observations indicate a relatively enhanced innate resistance to *L. salmonis* in the juvenile pink salmon compared with the juvenile chum salmon.

Jones, S. R. M., & Hargreaves, N. B. (2007). The abundance and distribution of *Lepeophtheirus salmonis* (Copepoda: Caligidae) on pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) in coastal British Columbia. *Journal of Parasitology*, *93*(6), 1324–1331. doi:10.1645/GE-1252.1

In total, 23,750 specimens of the salmon louse, *Lepeophtheirus salmonis*, were collected from 3,907 juvenile pink and 3,941 chum salmon caught within the Broughton Archipelago during a 2-yr survey. The prevalence on pink salmon was significantly higher than on chum salmon in 2004 (62.3% and 58.6%, respectively) and in 2005 (26.4% and 23.1%, respectively). The mean abundance on chum salmon was significantly higher than on pink salmon in 2004 (7.0 ± 0.3 and 2.8 ± 0.2, respectively), whereas in 2005 the mean abundance did not differ between species (0.6 ± 0.1 and 0.5 ± 0.0, respectively). The mean intensity on chum salmon was significantly higher than on pink salmon in 2004 (12.0 ± 0.4 and 4.5 ± 0.2, respectively) and in 2005 (2.5 ± 0.2 and 1.7 ± 0.1, respectively). The prevalence, intensity, and abundance of *L. salmonis* were significantly higher on salmon belonging to both host species in 2004 compared with 2005. In both years, a majority of pink and chum salmon had 2 or fewer lice. In general, a decline in abundance of *L. salmonis* over the 3 collection periods in each year coincided with an increased percentage of motile developmental stages. The abundance was lowest on fish collected from zones in which the seawater surface salinity was also lowest. Seawater surface temperature was higher and salinity was lower in 2004 compared with 2005. The spatial and temporal trends in the abundance of *L. salmonis* in relation to host size, infestation rates, and seawater salinity and temperature, evident in both years, must be considered in future studies assessing the role of farmed salmon in the epizootiology of this parasite on juvenile salmon in this area.

Jones, S. R. M., & Hargreaves, N. B. (2009). Infection threshold to estimate *Lepeophtheirus salmonis*-associated mortality among juvenile pink salmon. *Diseases of Aquatic*

***Organisms*, *84*(2), 131–137. doi:10.3354/dao02043**
A threshold of lethal infection was estimated from previous controlled laboratory exposures to be 7.5 *Lepeophtheirus salmonis* g^{-1} for pink salmon *Oncorhynchus gorbuscha* averaging <0.7 g. This threshold was used to assess the risk of mortality caused by *L. salmonis* among pink salmon of the same size class in the Broughton Archipelago, Canada from 2005 to 2008. Virtually all (≥98.9%) pink salmon collected in late March belonged to this size class, and this proportion declined to ≤1% by early July. The proportion of these small pink salmon with infections equal to or exceeding the threshold declined from 4.5 in 2005 to 0% in 2008, coincident with an overall decline in parasite prevalence and intensity during this period. In 2005 and 2006, this proportion was greatest in March (7.8 and 1.1%, respectively) whereas in 2007, the proportion exceeding the threshold was greatest in May (2.9%). In 2008, no infections exceeded the threshold. Parasite development coincided with fish migration through the study area. The declining risk between 2005 and 2008 was possibly related to changes in ocean conditions such as temperature, to changing treatment practices for this parasite on salmon farms, or to changes in the abundance or distribution of non-farmed hosts. The concept of a threshold of *L. salmonis* infection density may be used to assist in the management and conservation of juvenile pink salmon in the Broughton Archipelago region.

Kline Jr., T. C. (2010). Stable carbon and nitrogen isotope variation in the northern lampfish and *Neocalanus*, marine survival rates of pink salmon, and meso-scale eddies in the Gulf of Alaska. *Progress in Oceanography*, *87*(1–4), 49–60. doi:10.1016/j.pocean.2010.09.024
Northern lampfish (NLF), *Stenobrachius leucopsarus* (Myctophidae), the dominant pelagic fish taxon of the subarctic North Pacific Ocean, were sampled opportunistically in MOCNESS tows made on continental slope waters of the Gulf of Alaska (GOA) as well as in deep areas of Prince William Sound (PWS) during 1997–2006. The overall mean whole-body lipid-corrected stable carbon isotope value of NLF from the GOA was −21.4 (SD = 0.7) whereas that from PWS was −19.5 (SD = 0.9). This pattern is similar to that observed for late feeding stage *Neocalanus cristatus* copepods thus confirming a mean cross-shelf carbon stable isotope gradient. As well, there was a statistically significant positive correlation between the considerable temporal variation in the monthly mean carbon stable isotope composition of GOA *Neocalanus* and GOA NLF ($r = 0.69$, $P < 0.001$). In contrast, NLF nitrogen stable isotope values were bi-modal with most data fitting the upper mode value of ~+11.5. NLF nitrogen stable isotope values are a better indicator of trophic level or food chain length whereas carbon stable isotopes reflect organic carbon production. The carbon stable isotope values of NLF, measured in May, were positively correlated to marine survival rate of PWS hatchery salmon cohorts entering the marine environment the same year ($r = 0.84$, $P < 0.001$). The carbon stable isotope values for *Neocalanus* in May were also positively correlated to salmon marine survival ($r = 0.82$, $P < 0.001$). Processes thus manifested through the carbon stable isotope value of biota from the continental slope more closely predicted marine survival

rate than that of the salmon themselves. The incipient relationships suggested by the correlations are consistent with the hypothesis that exchange between coastal and oceanic waters in the study area is driven by meso-scale eddies. These eddies facilitate the occurrence of slope phytoplankton blooms as well as drive oceanic zooplankton subsidies into coastal waters. The strong as well as more significant correlations of salmon marine survival rate to NLF as well as slope *Neocalanus* carbon stable isotope values point to processes taking place at the slope (i.e., interactions driven by meso-scale eddies when at the edge of the shelf) as being the driving force to inter-annual variability in the coastal Gulf of Alaska study area.

Kline Jr., T. C., Boldt, J. L., Farley Jr., E. V., Haldorson, L. J., & Helle, J. H. (2008). Pink salmon (*Oncorhynchus gorbuscha*) marine survival rates reflect early marine carbon source dependency. *Progress in Oceanography*, *77*(2–3), 194–202. doi:10.1016/j.pocean.2008.03.006

Marine survival rate (the number of adult salmon returning divided by the number of salmon fry released) of pink salmon runs propagated by Prince William Sound, Alaska (PWS) salmon hatcheries is highly variable resulting in large year-to-year run size variation, which ranged from ~20 to ~50 million during 1998–2004. Marine survival rate was hypothesized to be determined during their early marine life stage, a time period corresponding to the first growing season after entering the marine environment while they are still in coastal waters. Based on the predictable relationships of $^{13}C/^{12}C$ ratios in food webs and the existence of regional $^{13}C/^{12}C$ gradients in organic carbon, $^{13}C/^{12}C$ ratios of early marine pink salmon were measured to test whether marine survival rate was related to food web processes. Year-to-year variation in marine survival rate was inversely correlated to $^{13}C/^{12}C$ ratios of early marine pink salmon, but with differences among hatcheries. The weakest relationship was for pink salmon from the hatchery without historic co-variation of marine survival rate with other PWS hatcheries or wild stocks. Year-to-year variation in $^{13}C/^{12}C$ ratio of early marine stage pink salmon in combination with regional spatial gradients of $^{13}C/^{12}C$ ratio measured in zooplankton suggested that marine survival was driven by carbon subsidies of oceanic origin (i.e., oceanic zooplankton). The 2001 pink salmon cohort had $^{13}C/^{12}C$ ratios that were very similar to those found for PWS carbon, i.e., when oceanic subsidies were inferred to be nil, and had the lowest marine survival rate (2.6%). Conversely, the 2002 cohort had the highest marine survival (9.7%) and the lowest mean $^{13}C/^{12}C$ ratio. These isotope patterns are consistent with hypotheses that oceanic zooplankton subsidies benefit salmon as food subsidies, or as alternate prey for salmon predators. Oceanic subsidies are manifestations of significant exchange of material between PWS and the Gulf of Alaska. Given that previously observed inter-decadal cycles of oceanic zooplankton abundance were climatically driven, exchange between PWS and the Gulf of Alaska may be an important process for effecting synoptic changes in marine populations of higher trophic levels, and thus an important consideration for climate-change models and scenarios.

Kondzela, C., Garvin, M., Riley, R., Murphy, J., Moss, J., Fuller, S. A., & Gharrett, A.

(2009). Preliminary genetic analysis of juvenile chum salmon from the Chukchi Sea and Bering Strait. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 25–27.
The arctic region has experienced warming in recent years, resulting in decreased summer sea ice cover and increased sea surface temperatures. In September 2007, the U.S. BASIS survey extended surface trawling into the Chukchi Sea. Juvenile (young-of-the-year) chum salmon were collected at most stations. Genetic methods using microsatellite and SNP loci were applied to identify the origin of a subset of juvenile chum salmon collected in the Chukchi Sea and Bering Strait. Most of the juvenile chum salmon caught in the Bering Strait were from populations of the Anadyr-Kanchalan river system of northeastern Russia and the majority of fish collected in the Chukchi Sea site were from populations of northwestern Alaska

Krkošek, M., Ashander, J., Frazer, L. Neil, & Lewis, M. A. (2013). Allee effect from parasite spill-back. *The American Naturalist*, *182*(5), 640–652. doi:10.1086/673238
The exchange of native pathogens between wild and domesticated animals can lead to novel disease threats to wildlife. However, the dynamics of wild host-parasite systems exposed to a reservoir of domesticated hosts are not well understood. A simple mathematical model reveals that the spill-back of native parasites from domestic to wild hosts may cause a demographic Allee effect in the wild host population. A second model is tailored to the particulars of pink salmon (*Oncorhynchus gorbuscha*) and salmon lice (*Lepeophtheirus salmonis*), for which parasite spill-back is a conservation and fishery concern. In both models, parasite spill-back weakens the coupling of parasite and wild host abundance—particularly at low host abundance—causing parasites per host to increase as a wild host population declines. These findings show that parasites shared across host populations have effects analogous to those of generalist predators and can similarly cause an unstable equilibrium in a focal host population that separates persistence and extirpation. Allee effects in wildlife arising from parasite spill-back are likely to be most pronounced in systems where the magnitude of transmission from domestic to wild host populations is high because of high parasite abundance in domestic hosts, prolonged sympatry of domestic and wild hosts, a high transmission coefficient for parasites, long-lived parasite larvae, and proximity of domesticated populations to wildlife migration corridors.

Krkošek, M., Connors, B. M., Ford, H., Peacock, S., Mages, P., Ford, J. S., Morton, A., Volpe, J. P., Hilborn, R., Dill, L. M., & Lewis, M. A. (2011). Fish farms, parasites, and predators: implications for salmon population dynamics. *Ecological Applications*, *21*(3), 897–914. doi:10.1890/09-1861.1
For some salmon populations, the individual and population effects of sea lice (*Lepeophtheirus salmonis*) transmission from sea cage salmon farms is probably mediated by predation, which is a primary natural source of mortality of juvenile salmon. We examined how sea lice infestation affects predation risk and mortality of juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon, and developed a mathematical model to assess the implications for population dynamics and conservation. A risk-taking experiment indicated that infected juvenile pink salmon accept a higher predation risk in order to obtain foraging opportunities. In a schooling experiment with juvenile chum salmon, infected individuals had increased nearest-neighbor distances and

occupied peripheral positions in the school. Prey selection experiments with cutthroat trout (*O. clarkii*) predators indicated that infection reduces the ability of juvenile pink salmon to evade a predatory strike. Group predation experiments with coho salmon (*O. kisutch*) feeding on juvenile pink or chum salmon indicated that predators selectively consume infected prey. The experimental results indicate that lice may increase the rate of prey capture but not the handling time of a predator. Based on this result, we developed a mathematical model of sea lice and salmon population dynamics in which parasitism affects the attack rate in a type II functional response. Analysis of the model indicates that: (1) the estimated mortality of wild juvenile salmon due to sea lice infestation is probably higher than previously thought; (2) predation can cause a simultaneous decline in sea louse abundance on wild fish and salmon productivity that could mislead managers and regulators; and (3) compensatory mortality occurs in the saturation region of the type II functional response where prey are abundant because predators increase mortality of parasites but not overall predation rates. These findings indicate that predation is an important component of salmon–louse dynamics and has implications for estimating mortality, reducing infection, and developing conservation policy.

Krkošek, M., Connors, B. M., Lewis, Mark A., & Poulin, R. (2012). Allee effects may slow the spread of parasites in a coastal marine ecosystem. *The American Naturalist*, *179*(3), 401–412. doi:10.1086/664458

Allee effects are thought to mediate the dynamics of population colonization, particularly for invasive species. However, Allee effects acting on parasites have rarely been considered in the analogous process of infectious disease establishment and spread. We studied the colonization of uninfected wild juvenile Pacific salmon populations by ectoparasitic salmon lice (*Lepeophtheirus salmonis*) over a 4-year period. In a data set of 68,376 fish, we observed 85 occurrences of precopular pair formation among 1,259 preadult female and 613 adult male lice. The probability of pair formation was dependent on the local abundance of lice, but this mate limitation is likely offset somewhat by mate-searching dispersal of males among host fish. A mathematical model of macroparasite population dynamics that incorporates the empirical results suggests a high likelihood of a demographic Allee effect, which can cause the colonizing parasite populations to die out. These results may provide the first empirical evidence for Allee effects in a macroparasite. Furthermore, the data give a rare detailed view of Allee effects in colonization dynamics and suggest that Allee effects may dampen the spread of parasites in a coastal marine ecosystem.

Krkošek, M., Connors, B. M., Morton, A., Lewis, M. A., Dill, L. M., & Hilborn, R. (2011). Effects of parasites from salmon farms on productivity of wild salmon. *Proceedings of the National Academy of Sciences*, *108*(35), 14700–14704. doi:10.1073/pnas.1101845108

The ecological risks of salmon aquaculture have motivated changes to management and policy designed to protect wild salmon populations and habitats in several countries. In Canada, much attention has focused on outbreaks of parasitic copepods, sea lice (*Lepeophtheirus salmonis*), on farmed and wild salmon in the Broughton Archipelago, British Columbia. Several recent studies have reached contradictory conclusions on

whether the spread of lice from salmon farms affects the productivity of sympatric wild salmon populations. We analyzed recently available sea lice data on farms and spawner–recruit data for pink (*Oncorhynchus gorbuscha*) and coho (*Oncorhynchus kisutch*) salmon populations in the Broughton Archipelago and nearby regions where farms are not present. Our results show that sea lice abundance on farms is negatively associated with productivity of both pink and coho salmon in the Broughton Archipelago. These results reconcile the contradictory findings of previous studies and suggest that management and policy measures designed to protect wild salmon from sea lice should yield conservation and fishery benefits.

Krkošek, M., Ford, J. S., Morton, A., Lele, S., Myers, R. A., & Lewis, M. A. (2007). Declining wild salmon populations in relation to parasites from farm salmon. *Science*, *318*(5857), 1772–1775. doi:10.1126/science.1148744

Rather than benefiting wild fish, industrial aquaculture may contribute to declines in ocean fisheries and ecosystems. Farm salmon are commonly infected with salmon lice (*Lepeophtheirus salmonis*), which are native ectoparasitic copepods. We show that recurrent louse infestations of wild juvenile pink salmon (*Oncorhynchus gorbuscha*), all associated with salmon farms, have depressed wild pink salmon populations and placed them on a trajectory toward rapid local extinction. The louse-induced mortality of pink salmon is commonly over 80% and exceeds previous fishing mortality. If outbreaks continue, then local extinction is certain, and a 99% collapse in pink salmon population abundance is expected in four salmon generations. These results suggest that salmon farms can cause parasite outbreaks that erode the capacity of a coastal ecosystem to support wild salmon populations.

Krkošek, M., Gottesfeld, A., Proctor, B., Rolston, D., Carr-Harris, C., & Lewis, M. A. (2007). Effects of host migration, diversity and aquaculture on sea lice threats to Pacific salmon populations. *Proceedings of the Royal Society B: Biological Sciences*, *274*(1629), 3141–3149. doi:10.1098/rspb.2007.1122

Animal migrations can affect disease dynamics. One consequence of migration common to marine fish and invertebrates is migratory allopatry—a period of spatial separation between adult and juvenile hosts, which is caused by host migration and which prevents parasite transmission from adult to juvenile hosts. We studied this characteristic for sea lice (*Lepeophtheirus salmonis* and *Caligus clemensi*) and pink salmon (*Oncorhynchus gorbuscha*) from one of the Canada's largest salmon stocks. Migratory allopatry protects juvenile salmon from *L. salmonis* for two to three months of early marine life (2–3% prevalence). In contrast, host diversity facilitates access for *C. clemensi* to juvenile salmon (8–20% prevalence) but infections appear ephemeral. Aquaculture can augment host abundance and diversity and increase parasite exposure of wild juvenile fish. An empirically parametrized model shows high sensitivity of salmon populations to increased *L. salmonis* exposure, predicting population collapse at one to five motile *L. salmonis* per juvenile pink salmon. These results characterize parasite threats of salmon aquaculture to wild salmon populations and show how host migration and diversity are important factors affecting parasite transmission in the oceans.

Krkošek, M., & Hilborn, R. (2010). Sea lice (*Lepeophtheirus salmonis*) infestations and the

productivity of pink salmon (*Oncorhynchus gorbuscha*) in the Broughton Archipelago, British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(1), 17–29. doi:10.1139/F10-137

The spread of salmon lice (*Lepeophtheirus salmonis*) from salmon farms may threaten some wild salmon populations. Infestations of wild juvenile pink salmon (*Oncorhynchus gorbuscha*) have been associated with high mortality and population decline. Using stock–recruit data for pink salmon from the central coast of British Columbia, we analyzed how fishing mortality and spatial covariation combine with louse infestation to affect pink salmon population dynamics. The results indicate substantial coherence in survival at nested spatial scales — large-scale regional covariation and smaller scale covariation within management areas. Populations exposed to salmon farms (those from the Broughton Archipelago) show a sharp decline in productivity during sea lice infestations relative to pre-infestation years. Unexposed populations (comprising four management areas) did not experience a change in productivity during infestation years and had similar productivity to exposed populations before infestations. Our results suggest that sea lice infestations may result in declines ofpink salmon populations and that management and policy of salmon farms should consider protecting wild juvenile salmon from exposure to sea lice.

Krkošek, M., Hilborn, R., Peterman, R. M., & Quinn, T. P. (2011). Cycles, stochasticity and density dependence in pink salmon population dynamics. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1714), 2060–2068. doi:10.1098/rspb.2010.2335

Complex dynamics of animal populations often involve deterministic and stochastic components. A fascinating example is the variation in magnitude of 2-year cycles in abundances of pink salmon (*Oncorhynchus gorbuscha*) stocks along the North Pacific rim. Pink salmon have a 2-year anadromous and semelparous life cycle, resulting in odd- and even-year lineages that occupy the same habitats but are reproductively isolated in time. One lineage is often much more abundant than the other in a given river, and there are phase switches in dominance between odd- and even-year lines. In some regions, the weak line is absent and in others both lines are abundant. Our analysis of 33 stocks indicates that these patterns probably result from stochastic perturbations of damped oscillations owing to density-dependent mortality caused by interactions between lineages. Possible mechanisms are cannibalism, disease transmission, food depletion and habitat degradation by which one lineage affects the other, although no mechanism has been well-studied. Our results provide comprehensive empirical estimates of lagged density-dependent mortality in salmon populations and suggest that a combination of stochasticity and density dependence drives cyclical dynamics of pink salmon stocks.

Krkošek, M., Lewis, M. A., Morton, A., Frazer, L. N., & Volpe, J. P. (2006). Epizootics of wild fish induced by farm fish. *Proceedings of the National Academy of Sciences*, *103*(42), 15506–15510. doi:10.1073/pnas.0603525103

The continuing decline of ocean fisheries and rise of global fish consumption has driven aquaculture growth by 10% annually over the last decade. The association of fish farms with disease emergence in sympatric wild fish stocks remains one of the most controversial and unresolved threats aquaculture poses to coastal ecosystems and fisheries. We report a comprehensive analysis of the spread and impact of farm-origin

parasites on the survival of wild fish populations. We mathematically coupled extensive data sets of native parasitic sea lice (*Lepeophtheirus salmonis*) transmission and pathogenicity on migratory wild juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon. Farm-origin lice induced 9–95% mortality in several sympatric wild juvenile pink and chum salmon populations. The epizootics arise through a mechanism that is new to our understanding of emerging infectious diseases: fish farms undermine a functional role of host migration in protecting juvenile hosts from parasites associated with adult hosts. Although the migratory life cycles of Pacific salmon naturally separate adults from juveniles, fish farms provide *L. salmonis* novel access to juvenile hosts, in this case raising infection rates for at least the first ≈2.5 months of the salmon's marine life (≈80 km of the migration route). Spatial segregation between juveniles and adults is common among temperate marine fishes, and as aquaculture continues its rapid growth, this disease mechanism may challenge the sustainability of coastal ecosystems and economies.

Krkošek, M., Morton, A., Volpe, J. P., & Lewis, M. A. (2009). Sea lice and salmon population dynamics: effects of exposure time for migratory fish. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1668), 2819–2828. doi:10.1098/rspb.2009.0317

The ecological impact of parasite transmission from fish farms is probably mediated by the migration of wild fishes, which determines the period of exposure to parasites. For Pacific salmon and the parasitic sea louse, *Lepeophtheirus salmonis*, analysis of the exposure period may resolve conflicting observations of epizootic mortality in field studies and parasite rejection in experiments. This is because exposure periods can differ by 2–3 orders of magnitude, ranging from months in the field to hours in experiments. We developed a mathematical model of salmon–louse population dynamics, parametrized by a study that monitored naturally infected juvenile salmon held in ocean enclosures. Analysis of replicated trials indicates that lice suffer high mortality, particularly during pre-adult stages. The model suggests louse populations rapidly decline following brief exposure of juvenile salmon, similar to laboratory study designs and data. However, when the exposure period lasts for several weeks, as occurs when juvenile salmon migrate past salmon farms, the model predicts that lice accumulate to abundances that can elevate salmon mortality and depress salmon populations. The duration of parasite exposure is probably critical to salmon–louse population dynamics, and should therefore be accommodated in coastal planning and management where fish farms are situated on wild fish migration routes.

LaCroix, J. J., Wertheimer, A. C., Orsi, J. A., Sturdevant, M. V., Fergusson, E. A., & Bond, N. A. (2009). A top-down survival mechanism during early marine residency explains coho salmon year-class strength in southeast Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography*, *56*(24), 2560–2569. doi:10.1016/j.dsr2.2009.03.006

Coho salmon (*Oncorhynchus kisutch*) are a vital component in the southeast Alaska marine ecosystem and are an important regional fishery resource; consequently, understanding mechanisms affecting their year-class strength is necessary from both scientific and management perspectives. We examined correlations among juvenile coho

salmon indices, associated biophysical variables, and adult coho salmon harvest data from southeast Alaska over the years 1997–2006. We found no relationship between summer indices of juvenile coho salmon growth, condition, or abundance with subsequent harvest of adult coho salmon in the region. However, using stepwise regression, we found that variation in adult coho salmon harvest was largely explained by indices of juvenile pink salmon (*Oncorhynchus gorbuscha*) abundance (67%) and zooplankton abundance (24%). To determine if high juvenile pink salmon abundance indicates favorable "bottom-up" lower trophic level environmental conditions for juvenile coho salmon, we plotted abundance of juvenile pink salmon against growth and condition of juvenile coho salmon. No change in growth or condition of juvenile coho salmon was observed in relation to the abundance index for juvenile pink salmon. Therefore, we hypothesize that coho salmon year-class strength in southeast Alaska is influenced by a "top-down" predator control mechanism that results from more abundant juvenile pink salmon, which serve as a predator buffer during early marine residency.

MacFarlane, R. B. (2010). Energy dynamics and growth of Chinook salmon (*Oncorhynchus tshawytscha*) from the Central Valley of California during the estuarine phase and first ocean year. *Canadian Journal of Fisheries and Aquatic Sciences*, *67*(10), 1549–1565. doi:10.1139/F10-080

The greatest rates of energy accumulation and growth in subyearling Chinook salmon (*Oncorhynchus tshawytscha*) occurred during the first month following ocean entry, supporting the importance of this critical period. Data from an 11-year study in the coastal ocean off California and the San Francisco Estuary revealed that juvenile salmon gained 3.2 $kJ \cdot day^{-1}$ and 0.8 $g \cdot day^{-1}$, representing 4.3%$\cdot day^{-1}$ and 5.2% day^{-1}, respectively, relative to estuary exit values. Little gain in energy (0.28 $kJ \cdot day^{-1}$) or size (0.07 $g \cdot day^{-1}$) occurred in the estuary, indicating that the nursery function typically ascribed to estuaries can be deferred to initial ocean residence. Calculated northern anchovies (*Engraulis mordax*) equivalents to meet energy gains were one anchovy per day in the estuary (8% body weight$\cdot day^{-1}$) and about three per day immediately following ocean entry (15% body weight$\cdot day^{-1}$). Energy content in the estuary was positively related to higher salinity and lower freshwater outflow, whereas in the ocean, cooler temperatures, lower sea level, and greater upwelling resulted in greater gains. These results suggest that greater freshwater flows, warmer sea temperatures, and reduced or delayed upwelling, all of which are indicated by some (but not all) climate models, will likely decrease growth of juvenile Chinook salmon, leading to reduced survival.

Mackas, D. L., Batten, S., & Trudel, M. (2007). Effects on zooplankton of a warmer ocean: Recent evidence from the Northeast Pacific. *Progress in Oceanography*, *75*(2), 223–252. doi:10.1016/j.pocean.2007.08.010

The consequences for pelagic communities of warming trends in mid and high latitude ocean regions could be substantial, but their magnitude and trajectory are not yet known. Environmental changes predicted by climate models (and beginning to be confirmed by observations) include warming and freshening of the upper ocean and reduction in the extent and duration of ice cover. One way to evaluate response scenarios is by comparing how "similar" zooplankton communities have differed among years and/or locations with

differing temperature. The subarctic Pacific is a strong candidate for such comparisons, because the same mix of zooplankton species dominates over a wide range of temperature climatologies, and observations have spanned substantial temperature variability at interannual-to-decadal time scales. In this paper, we review and extend copepod abundance and phenology time series from net tow and Continuous Plankton Recorder surveys in the subarctic Northeast Pacific. The two strongest responses we have observed are latitudinal shifts in centers of abundance of many species (poleward under warm conditions), and changes in the life cycle timing of Neocalanus plumchrus in both oceanic and coastal regions (earlier by several weeks in warm years and at warmer locations). These zooplankton data, plus indices of higher trophic level responses such as reproduction, growth and survival of pelagic fish and seabirds, are all moderately-to-

strongly intercorrelated ($|r| = 0.25–0.8$) with indices of local and basin-scale temperature

anomalies. A principal components analysis of the normalized anomaly time series from 1979 to 2004 shows that a single "warm-and-low-productivity" vs. "cool-and-high-productivity" component axis accounts for over half of the variance/covariance. Prior to 1990, the scores for this component were negative ("cool" and "productive") or near zero except positive in the El Niño years 1983 and 1987. The scores were strongly and increasingly positive ("warm" and "low productivity") from 1992 to 1998; negative from 1999 to 2002; and again increasingly positive from 2003-present. We suggest that, in strongly seasonal environments, anomalously high temperature may provide misleading environmental cues that contribute to timing mismatch between life history events and the more-nearly-fixed seasonality of insolation, stratification, and food supply.

Mages, P. A., & Dill, L. M. (2010). The effect of sea lice (*Lepeophtheirus salmonis*) on juvenile pink salmon (*Oncorhynchus gorbuscha*) swimming endurance. *Canadian Journal of Fisheries and Aquatic Sciences*, *67*(12), 2045–2051. doi:10.1139/F10-121

The swimming endurance of naturally and experimentally infected juvenile pink salmon (*Oncorhynchus gorbuscha*) was measured to determine the effects of sea lice (*Lepeophtheirus salmonis*). Salmon naturally infected with adult male and preadult stage lice did not appear to have a reduced swim performance, but when experimentally infected with adult female lice, juvenile salmon showed a reduced ability to swim compared with uninfected control fish, and this effect increased with lice load. A reduced swimming endurance is not only likely to influence predation risk for salmon, but may have other ecological implications, such as slower seaward migration.

Maier, G. O., & Simenstad, C. A. (2009). The role of marsh-derived macrodetritus to the food webs of juvenile Chinook salmon in a large altered estuary. *Estuaries and Coasts*, *32*(5), 984–998. doi:10.1007/s12237-009-9197-1

The goal of this study was to determine the food web pathways supporting juvenile Chinook (*Oncorhynchus tshawytscha*) salmon in the Columbia River estuary through multiple stable isotope analysis ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$). Using this method, we distinguished the role of various organic matter sources in Chinook food webs and interpreted the dynamics of their use both spatially and temporally within the estuary. Our results

indicate that subyearling Chinook are associated with fluvial, anthropogenic, estuarine, and marine organic matter sources, with hatchery food and vascular plant detritus being the most dominant sources in juvenile Chinook food webs. Although freshwater phytoplankton is involved in many food web pathways to subyearling Chinook, increased phytoplankton production from the impounded river has not replaced the loss of autochthonous marsh production to fish. Our results indicate that large-scale ecosystem alteration may have decreased the availability and quality of food webs in the estuary and potentially diminished the ability of the Columbia to support Chinook salmon.

Malick, M. J., Adkison, M. D., & Wertheimer, A. C. (2009). Variable effects of biological and environmental processes on coho salmon marine survival in Southeast Alaska. *Transactions of the American Fisheries Society*, *138*(4), 846–860. doi:10.1577/T08-177.1

Correlation analyses, linear regression models, and multistock mixed effects models were used to examine the relationships between coho salmon *Oncorhynchus kisutch* marine survival and six biological and environmental covariates across 14 southeast Alaska (SEAK) stocks. A primary focus of the study was to investigate the influence of pink salmon *O. gorbuscha* and chum salmon *O. keta* fry abundances on coho salmon marine survival. The coho salmon stocks exhibited strong covariation; 88 of the 91 pairwise comparisons among the coho salmon stocks covaried positively and 54 of them were significant ($P < 0.05$). Only one of the covariates, the North Pacific index, which is a measure of the Aleutian low pressure zone, had consistent relationships (positive) across all 14 stocks. The other covariates, including freshwater discharge, the Pacific decadal oscillation, sea-surface temperature, and two indices of pink salmon and chum salmon fry abundances, all had inconsistent relationships with marine survival. The best-fit linear regression models varied greatly among the 14 stocks, as did the R^2 values, which ranged from 0.00 to 0.54. An index representing local hatchery pink salmon and chum salmon fry abundance was the most important variable in explaining the variation in marine survival, having a stronger estimated effect on survival than an index of local wild pink salmon fry abundance. The magnitude and sign of the hatchery pink salmon and chum salmon effect varied greatly among different localities. Our results suggest that (1) SEAK coho salmon stocks are not equally influenced by the same factors and (2) there are factors that appear to affect marine survival of SEAK coho salmon stocks at varying spatial scales. This study also provides evidence that coho salmon stocks throughout SEAK experience some degree of regional concordance in the marine environment but also that local stock-specific conditions are important in fully understanding variation in marine survival.

Malick, M. J., Haldorson, L. J., Piccolo, J. J., & Boldt, J. L. (2011). Growth and survival in relation to body size of juvenile pink salmon in the northern Gulf of Alaska. *Marine and Coastal Fisheries*, *3*(1), 261–270. doi:10.1080/19425120.2011.593467

The abundance of anadromous salmon is partially determined by size-selective mortality during the early marine life phase. Consequently, identifying the growth patterns of juvenile salmon during this life phase is important in understanding the dynamics of salmon populations. We examined patterns of early marine growth in juvenile pink salmon *Oncorhynchus gorbuscha* released by four hatcheries in Prince William Sound

(PWS), Alaska, and explored how these patterns related to marine survival. Since larger individuals are thought to experience reduced mortality, we partitioned the data into weight-based quartiles and compared growth rates (% body weight/d) of all fish, the largest fish (top 25%), and the smallest fish (bottom 25%). Sampling occurred during summer 1997–2004 in PWS, the inshore Gulf of Alaska (GOA), and the offshore GOA. Growth rates varied significantly among years and sampling locations; however, the growth rate patterns were markedly similar among size-groups and hatcheries. Growth rates tended to be high in 1997, 2002, and 2004 and lower in 1998, 2001, and 2003. Fish sampled in the offshore GOA typically had faster growth rates than those sampled elsewhere, although this was less pronounced for the largest fish. For all size-groups, the relationship between survival and growth rate was strongest for fish captured in the offshore GOA and weakest for those captured in PWS, indicating that the likelihood of survival is greater for juveniles that migrate offshore earlier. The strength of the growth rate–survival relationship for pink salmon captured in the offshore GOA was similar among all size-groups, suggesting that once fish migrate offshore they are less vulnerable to size-selective predation.

Mantua, N. J., Taylor, N. G., Ruggerone, G. T., Myers, K. W., Preikshot, D., Augerot, X., Davis, N. D., Dorner, B., Hilborn, R., Peterman, R. M., Rand, P., Schindler, D., Stanford, J., Walker, R. V., & Walters, C. J. (2007). The salmon MALBEC project: a North Pacific-scale study to support salmon conservation planning. ***North Pacific Anadromous Fish Comission Document, 1060,*** **49 pp.**

The Model for Assessing Links Between Ecosystems (MALBEC) is a policy gaming tool with potential to explore the impacts of climate change, harvest policies, hatchery policies, and freshwater habitat capacity changes on salmon at the North Pacific scale. This document provides background information on the MALBEC project, methods, input data, and preliminary results pertaining to (1) hatchery versus wild salmon production in the North Pacific Ocean, (2) rearing, movement, and interactions among Pacific salmon populations in marine environments, (3) marine carrying capacities, density-dependent growth, and survival in Pacific salmon stocks, and (4) climate impacts on productivity in salmon habitat domains across the North Pacific. The basic modeling strategy underlying MALBEC follows the full life-cycle of salmon and allows for density-dependence at multiple life stages, and it includes spatially explicit ecosystem considerations for both freshwater and marine habitat. The model is supported by a data base including annual run-sizes, catches, spawning escapements, and hatchery releases for 146 regional stock groups of hatchery and wild pink, chum, and sockeye salmon around the North Pacific for the period 1952-2000. These data show that hatchery salmon contribute significantly to overall abundance of salmon in some regions and that hatchery chum salmon abundance has exceed that of wild chum salmon since the early 1980s. For this historical period, various hypotheses about density dependent interactions in the marine environment are evaluated based on the goodness of fit between simulated and observed annual run-sizes. While the model does not reproduce the observed data for some specific stock groups, it does predict the same overall production pattern that was observed by reconstructing run sizes with catch and escapement data alone. Our preliminary results indicate that simulations that include density-dependent interactions in the ocean yield better fits to the observed run-size data than those simulations without

density-dependent interactions in the ocean. This suggests that for any level of ocean productivity, the ocean will only support a certain biomass of fish but that this biomass could consist of different combinations of stocks, stock numbers and individual fish size. MALBEC simulations illustrate this point by showing that under scenarios of Pacific-wide reduced hatchery production the total wild number of Alaskan chum salmon increases, and that such increases are large where density-dependent effects on survival are large and small where they are not. Under scenarios with reduced freshwater carrying capacities for wild stocks, the impacts of density-dependent interactions also lead to relative increases in ocean survival and growth rates for stocks using ocean habitats where density-dependence is large. While much progress has been made in the Salmon MALBEC project, this effort is still evolving and aims to tackle several important issues in the near future, including analyses of scenarios for climate change impacts on freshwater and marine carrying capacities, using results from the remote-sensing based Pacific Rim River Typology Project to better estimate habitat-defined freshwater carrying capacity for salmon, and ultimately to use MALBEC to test the outcomes of various policy decisions in the face of climate, habitat, and management uncertainty.

Martinson, E. C., Helle, J. H., Scarnecchia, D. L., & Stokes, H. H. (2008). Density-dependent growth of Alaska sockeye salmon in relation to climate–oceanic regimes, population abundance, and body size, 1925 to 1998. *Marine Ecology Progress Series*, *370*, 1–18. doi:10.3354/meps07665

To better understand how density-dependent growth of ocean-dwelling Pacific salmon varied with climate and population dynamics, we examined the marine growth of sockeye salmon *Oncorhynchus nerka* in relation to an index of sockeye salmon abundances among climate regimes, population abundances, and body sizes under varied life-history stages, from 1925 to 1998, using ordinary least squares and multivariate adaptive regression spline threshold models. The annual marine growth and body size during the juvenile, immature, and maturing life stages were estimated from growth pattern increments on the scales of adult age 2.2 sockeye salmon that returned to spawn at Karluk River and Lake on Kodiak Island, Alaska. Intra-specific density-dependent growth was inferred from inverse relationships between growth and sockeye salmon abundance based on commercial harvest. Density-dependent growth occurred in all marine life stages, during the cool regime, at lower abundance levels, and at smaller body sizes at the start of the juvenile life stage. The finding that density dependence occurred during the cool regime and at low population abundances suggests that a shift to a cool regime or extreme warm regime at higher population abundances could further reduce the marine growth of salmon and increase competition for resources.

Martinson, E. C., Helle, J. H., Scarnecchia, D. L., & Stokes, H. H. (2009). Growth and survival of sockeye salmon (*Oncorhynchus nerka*) from Karluk Lake and River, Alaska, in relation to climatic and oceanic regimes and indices, 1922-2000. *Fishery Bulletin*, *107*(4), 488–500.

We examined whether the relationship between climate and salmon production was linked through the effect of climate on the growth of sockeye salmon (*Oncorhynchus nerka*) at sea. Smolt length and juvenile, immature, and maturing growth rates were estimated from increments on scales of adult sockeye salmon that returned to the Karluk

River and Lake system on Kodiak Island, Alaska, over 77 years, 1924-2000. Survival was higher during the warm climate regimes and lower during the cool regime. Growth was not correlated with survival, as estimated from the residuals of the Ricker stock-recruitment model. Juvenile growth was correlated with an atmospheric forcing index and immature growth was correlated with the amount of coastal precipitation, but the magnitude of winter and spring coastal downwelling in the Gulf of Alaska and the Pacific Northwest atmospheric patterns that influence the directional bifurcation of the Pacific Current were not related to the growth of Karluk sockeye salmon. However, indices of sea surface temperature, coastal precipitation, and atmospheric circulation in the eastern North Pacific were correlated with the survival of Karluk sockeye salmon. Winter and spring precipitation and atmospheric circulation are possible processes linking survival to climate variation in Karluk sockeye salmon.

Martinson, E. C., Stokes, H. H., & Scarnecchia, D. L. (2012). Use of juvenile salmon growth and temperature change indices to predict groundfish post age-0 yr class strengths in the Gulf of Alaska and eastern Bering Sea. *Fisheries Oceanography*, *21*(4), 307–319. doi:10.1111/j.1365-2419.2012.00626.x

Juvenile marine growth (SW1) of salmon and a new temperature change (TC) index were evaluated as ecosystem indicators and predictors for the post age-0 year class strength (YCS) of groundfish in the Gulf of Alaska (GOA) and eastern Bering Sea (EBS). Our hypothesis was that SW1, as measured on the scales of adult Pacific salmon (*Oncorhynchus* spp.), is a proxy for ocean productivity on the continental shelf, a rearing area for young salmon and groundfish. Less negative TC index values are the result of a cool late summer followed by a warm spring, conditions favorable for groundfish YCS. In the GOA, SW1 was a positive predictor of age-1 pollock (*Theragra chalcogramma*), but not age-2 sablefish (*Anoplopoma fimbria*) YCS, indicating that the growth of the Karluk River sockeye salmon that enter Shelikof Strait is a proxy for ocean conditions experienced by age-0 pollock. Contrary to our hypotheses, the TC index was a negative predictor of GOA pollock YCS; and the SW1 a negative predictor of EBS pollock and cod YCS since the 1980s. Recent fisheries oceanography survey results provide insight into possible mechanisms to support the inverse SW1 and YCS relationship. For the EBS, the TC index was a significant positive predictor for pollock and cod YCS, supporting the hypothesis that a cool late summer followed by a warm spring maximizes the over-wintering survival of pollock and cod (Gadus macrocephalus), especially since the 1980s. The TC and SW1 index showed value for the assessment of pollock and cod, but not sablefish.

Marty, G. D., Saksida, S. M., & Quinn, T. J. (2010). Relationship of farm salmon, sea lice, and wild salmon populations. *Proceedings of the National Academy of Sciences*, *107*(52), 22599–22604. doi:10.1073/pnas.1009573108

Increased farm salmon production has heightened concerns about the association between disease on farm and wild fish. The controversy is particularly evident in the Broughton Archipelago of Western Canada, where a high prevalence of sea lice (ectoparasitic copepods) was first reported on juvenile wild pink salmon (*Oncorhynchus gorbuscha*) in 2001. Exposure to sea lice from farmed Atlantic salmon (*Salmo salar*) was thought to be the cause of the 97% population decline before these fish returned to spawn in 2002,

although no diagnostic investigation was done to rule out other causes of mortality. To address the concern that sea lice from fish farms would cause population extinction of wild salmon, we analyzed 10–20 y of fish farm data and 60 y of pink salmon data. We show that the number of pink salmon returning to spawn in the fall predicts the number of female sea lice on farm fish the next spring, which, in turn, accounts for 98% of the annual variability in the prevalence of sea lice on outmigrating wild juvenile salmon. However, productivity of wild salmon is not negatively associated with either farm lice numbers or farm fish production, and all published field and laboratory data support the conclusion that something other than sea lice caused the population decline in 2002. We conclude that separating farm salmon from wild salmon—proposed through coordinated fallowing or closed containment—will not increase wild salmon productivity and that medical analysis can improve our understanding of complex issues related to aquaculture sustainability.

McGlauflin, M. T., Schindler, D. E., Seeb, L. W., Smith, C. T., Habicht, C., & Seeb, J. E. (2011). Spawning habitat and geography influence population structure and juvenile migration timing of sockeye salmon in the Wood River lakes, Alaska. *Transactions of the American Fisheries Society*, *140*(3), 763–782. doi:10.1080/00028487.2011.584495

The strict homing of sockeye salmon *Oncorhynchus nerka* results in reproductively isolated populations that often spawn in close proximity and share rearing habitat. High spawning fidelity enables these populations to adapt to local conditions, resulting in a wide range of life history characteristics and genetic variation within individual watersheds. The Wood River system in southwestern Alaska provides a pristine, well-studied system in which to examine fine-scale population structure and its influences on juvenile life histories. Adult sockeye salmon spawn in lake beaches, rivers, and small tributaries throughout this watershed, and juveniles rear in five nursery lakes. We genotyped 30 spawning populations and 6,066 migrating smolts at 45 single nucleotide polymorphism loci, two of which are candidates for positive selection in the study system. We show that there is significant genetic structure ($F_{ST} = 0.032$) in the Wood River lakes and that divergence is generally related to spawning rather than nursery habitat (hierarchical analysis of molecular variance; $P < 0.05$). Four groups of populations were identified based on genetic structure and used to determine the composition of unknown mixtures of migrating smolts using a Bayesian modeling framework. We demonstrate that smolt migration timing is related to genetic structure; stream and river populations dominate catches in early June, while beach spawners and the populations in Lake Kulik are more prevalent from mid-June to early September. Age-2 smolts are primarily produced by the Lake Kulik and beach spawning populations, showing that genetic differences may reflect divergent freshwater and migration life history strategies. These results indicate that local adaptation to spawning habitat influences genetic divergence in the Wood River lakes, affecting both adult and juvenile life stages of sockeye salmon.

McKinnell, S., & Reichardt, M. (2012). Early marine growth of juvenile Fraser River sockeye salmon (*Oncorhynchus nerka*) in relation to juvenile pink (*Oncorhynchus gorbuscha*) and sockeye salmon abundance. *Canadian Journal of Fisheries and*

***Aquatic Sciences*, *69*(9), 1499–1512. doi:10.1139/f2012-078**
Mortality of salmon in the ocean is considered to be greatest during the first few months and that its magnitude is an inverse of growth. First year marine growth (M1) in two Fraser River sockeye salmon (*Oncorhynchus nerka*) populations was positively correlated, reflecting a shared oceanic experience as postsmolts. M1 declined abruptly in both populations after 1977, corresponding to a well-documented change in climate. The reduction in average M1 was not accompanied by a detectable reduction in average survival. In both populations, M1 was significantly greater in even years when juvenile pink salmon (*Oncorhynchus gorbuscha*) are abundant in the Strait of Georgia, suggesting that interspecific competition there has little effect on M1. All correlations of M1 with regional pink salmon or sockeye salmon abundances, lagged to align ocean entry years, were negative, but few (pink) or none (sockeye) were statistically significant. The negative correlations were due to the long-term changes pink salmon abundance increasing, sockeye M1 smaller). Odd year dominance of juvenile pink salmon in northern British Columbia, Canada, is persistent and corresponds with the biennial pattern of M1 variation in Fraser River sockeye salmon and may be the source of the significant odd-even year line effect on M1.

McMichael, G. A., Hanson, A. C., Harnish, R. A., & Trott, D. M. (2013). Juvenile salmonid migratory behavior at the mouth of the Columbia River and within the plume. *Animal Biotelemetry*, *1*(1), 1–16. doi:10.1186/2050-3385-1-14
Background: Early ocean experience is a critical time period that affects juvenile salmonid survival. Understanding juvenile salmonid behavior in nearshore marine environments and how oceanic conditions (such as dynamic river plume habitats) affect salmonid migration will contribute to salmonid survival studies and conservation and management efforts. Relatively few studies have been conducted on juvenile salmonid behavior as they migrate out the mouth of the Columbia River and some studies suggest that juvenile salmonids typically migrate north immediately upon entry into the ocean from the Columbia River. We present findings from a study that used acoustic telemetry to determine the migratory direction, residence time, and travel rate of juvenile salmonids as they left the Columbia River and entered the marine environment. Results A total of 8,159 acoustic-tagged salmonid smolts were detected at the mouth of the Columbia River. Of the fish detected at the mouth, an estimated 16% of yearling Chinook salmon, 10% of steelhead, and 26% of subyearling Chinook salmon were detected on a sparse array deployed outside the mouth of the Columbia River in the vicinity of the plume. The travel rate of Chinook salmon smolts decreased as they left the river and entered the marine environment, whereas the travel rate of steelhead increased. Chinook salmon also spent more time in the transitional area between the river mouth and plume compared to steelhead. In early spring, yearling Chinook salmon and steelhead were predominately detected on the plume array towards the edge of the shelf and to the south. Later in the season, yearling Chinook salmon and steelhead smolts were more often detected north of the river mouth. Subyearling Chinook salmon were most often detected on the portion of the plume array to the north of the river mouth. Conclusions: Our study showed that salmonid smolt migration out of the river into the nearshore marine environment appears to vary across species, season, and age class, and may be influenced by local environmental conditions. Direction of movement upon ocean entry cannot be assumed

and is likely influenced by oceanic conditions such as wind and currents. We also present, for the first time, the utility of the Juvenile Salmon Acoustic Telemetry System (JSATS) to monitor the behavior of juvenile fish in the marine environment. Our results will help inform future studies using telemetry and hydroacoustics as well as trawl surveys to assess nearshore ocean juvenile salmonid distribution, behavior, and survival.

Melnychuk, M. C., Christensen, V., & Walters, C. J. (2013). Meso-scale movement and mortality patterns of juvenile coho salmon and steelhead trout migrating through a coastal fjord. *Environmental Biology of Fishes*, *96*(2-3), 325–339. doi:10.1007/s10641-012-9976-6

Early marine life is thought to be a critical period affecting recruitment of Pacific salmon populations, but movements and mortality patterns of juvenile salmon after ocean entry have been poorly documented. Transect surveys by boat with towed hydrophone and acoustic receiver, along with lines of stationary receivers, were used to quantify early ocean movement and mortality patterns of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) tagged with acoustic transmitters (>700 tagged). Salmon smolts showed no behavioural preference with respect to distance from shorelines while migrating through Howe Sound, a coastal fjord. There was no evidence of spatial bias in mortality locations in terms of distance either to shorelines or from the river mouth, suggesting that mortality locations were scattered soon after ocean entry rather than concentrated right at the river mouth. Movement patterns of some tags (annual estimates of 5–20% of smolts that survived the downstream migration) were suggestive of estuarine predation, with detected tags likely inside predator stomachs. Using only detection data from mobile transects, a distance-based mortality rate was estimated for coho smolts while accounting for imperfect detection efficiency of transect surveys. The estimate of 2.4% per km during the 40 km migration through the fjord was comparable to average annual mortality rates estimated using detection data from stationary acoustic receivers, but required pooling multiple years of data. This suggests that mobile transect surveys of tagged migrating fish are likely insufficient for estimating annual mortality rates, but mobile detection data can complement those from stationary receiver arrays to further refine mortality estimates and provide information about fish movement patterns between lines of stationary receivers. This work provides an important methodological comparison between biotelemetry approaches for migrating fishes as well as the most comprehensive description to date of spatial marine mortality patterns of juvenile coho salmon and steelhead trout.

Melnychuk, M. C., Korman, J., Haush, S., Welch, D. W., McCubbing, D. J. F., & Walters, C.

J. (2014). Marine survival difference between wild and hatchery-reared steelhead trout determined during early downstream migration. *Canadian Journal of Fisheries and Aquatic Sciences*, *in press*.

We observed large survival differences between wild and hatchery-reared steelhead trout during the juvenile downstream migration immediately after release, which persisted through adult life. Following a railway spill of sodium hydroxide into the Cheakamus River, British Columbia, a short-term conservation hatchery rearing program was implemented for steelhead. 25 We used acoustic telemetry and mark-recapture models to

estimate survival of wild and/or hatchery-reared steelhead during four years of the smolt migration, with both groups released in 2008. After adjusting for estimated freshwater residualisation, 7–13% of wild smolts and 30– 40% of hatchery smolts died in the first 3 km of the migration. Estimated survival from release to ocean entry was 71–84% for wild fish and 26–40% for hatchery fish, and to exit from the Strait 30 of Georgia system was 22–33% for wild fish and 3.5–6.7% for hatchery fish. A calculated 2.3- fold survival difference established during the downstream migration was similar to that after the return of adult spawners, as return rates were 8.0% for wild fish and 4.1% for hatchery fish. Contrary to current understanding, a large proportion of salmon mortality in the smolt-to-adult period, commonly termed "marine mortality", may actually occur prior to ocean entry.

Melnychuk, M. C., Walters, C. J., Christensen, V., Bothwell, M. L., & Welch, D. W. (2012). Effects of solar ultraviolet radiation exposure on early ocean survival and fry-to-smolt growth of juvenile salmon. *Marine Ecology Progress Series*, *457*, 251–264. doi:10.3354/meps09426

Marine survival rates of many juvenile salmon populations have declined in recent decades. Although several potential causes have been proposed, there has been little conclusive evidence for which factors are responsible or not responsible for these declines. We experimentally addressed the hypothesis that exposure of coho salmon *Oncorhynchus kisutch* or sockeye salmon *O. nerka* to solar ultraviolet-B radiation (UVB) during freshwater rearing of fry and parr life-history stages increases mortality at the time of smoltification and ocean entry. Juvenile coho and sockeye salmon were reared in outdoor hatchery tanks either exposed to full spectrum sunlight or shielded from UVB radiation by plastic screens for up to 9 mo prior to release. Smolts were tagged with acoustic transmitters and detected with hydrophone receivers during their downriver and early ocean migration. Survival of treatment groups was compared using Cormack-Jolly-Seber and Burnham mark-recapture models. While exposure to UVB resulted in decreased growth of juvenile coho salmon, survivorship during the early marine period was unaffected by the UVB treatment for both populations. This first attempt to experimentally address the hypothesis of impaired survival resulting from solar UVB radiation has shown that other factors are more likely responsible for observed declines in salmon marine survival rates.

Melnychuk, M. C., Welch, D. W., & Walters, C. J. (2010). Spatio-temporal migration patterns of Pacific salmon smolts in rivers and coastal marine waters. *PLoS ONE*, *5*(9), e12916. doi:10.1371/journal.pone.0012916

Background: Migrations allow animals to find food resources, rearing habitats, or mates, but often impose considerable predation risk. Several behavioural strategies may reduce this risk, including faster travel speed and taking routes with shorter total distance. Descriptions of the natural range of variation in migration strategies among individuals and populations is necessary before the ecological consequences of such variation can be established. Methodology/Principal Findings: Movements of tagged juvenile coho, steelhead, sockeye, and Chinook salmon were quantified using a large-scale acoustic tracking array in southern British Columbia, Canada. Smolts from 13 watersheds (49 watershed/species/year combinations) were tagged between 2004–2008 and combined

into a mixed-effects model analysis of travel speed. During the downstream migration, steelhead were slower on average than other species, possibly related to freshwater residualization. During the migration through the Strait of Georgia, coho were slower than steelhead and sockeye, likely related to some degree of inshore summer residency. Hatchery-reared smolts were slower than wild smolts during the downstream migration, but after ocean entry, average speeds were similar. In small rivers, downstream travel speed increased with body length, but in the larger Fraser River and during the coastal migration, average speed was independent of body length. Smolts leaving rivers located towards the northern end of the Strait of Georgia ecosystem migrated strictly northwards after ocean entry, but those from rivers towards the southern end displayed split-route migration patterns within populations, with some moving southward.
Conclusions/Significance: Our results reveal a tremendous diversity of behavioural migration strategies used by juvenile salmon, across species, rearing histories, and habitats, as well as within individual populations. During the downstream migration, factors that had strong effects on travel speeds included species, wild or hatchery-rearing history, watershed size and, in smaller rivers, body length. During the coastal migration, travel speeds were only strongly affected by species differences.

Melnychuk, M. C., Welch, D. W., Walters, C. J., & Christensen, V. (2007). Riverine and early ocean migration and mortality patterns of juvenile steelhead trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia. *Hydrobiologia*, *582*(1), 55–65. doi:10.1007/s10750-006-0541-1
High mortality (65–73%) occurred in the first month of the smolt migration in a population of wild steelhead trout. We used acoustic telemetry to monitor the downstream, estuarine, and early ocean migration of tagged smolts and estimate their mortality rates. After entering the Strait of Georgia most smolts migrated north through Johnstone and Queen Charlotte Straits rather than south through the Strait of Juan de Fuca. Of 51 smolts tagged in 2004 (49 in 2005), 36–38 (41–42) survived to leave freshwater and 14–19 (13–14) survived to leave the Strait of Georgia system. Mortality rates in separate segments of the migration were correlated with segment distances. An additional component of mobile sampling showed that few smolts died during the migration through Howe Sound. Migration rates averaged 0.7–0.9 body lengths per second (BL s^{-1}) downstream and 1.0–2.6 BL s^{-1} in ocean waters. Aggregated detection probabilities of 92–96% on lines of ocean receivers suggest that migration routes of small fishes can be quantified over several hundred kilometres, and survival rates can be estimated for even a modest number of tagged fish. Quantifying mortality patterns during the smolt migration could help to determine causes of low marine survival rates observed in recent years.

Michel, C. J., Ammann, A. J., Chapman, E. D., Sandstrom, P. T., Fish, H. E., Thomas, M. J., Singer, G. P., Lindley, S. T., Klimley, A. P., & MacFarlane, R. B. (2013). The effects of environmental factors on the migratory movement patterns of Sacramento River yearling late-fall run Chinook salmon (*Oncorhynchus tshawytscha*). *Environmental Biology of Fishes*, *96*(2-3), 257–271. doi:10.1007/s10641-012-9990-8
Understanding smolt migration dynamics is a critical step in the preservation and conservation of imperiled salmonids in California's Sacramento River system. Late-fall

run Chinook salmon yearling smolts were acoustically tagged and tracked during their outmigration through California's Sacramento River and San Francisco Estuary during 2007-2009. Migration rates were 14.3 km · day ($^{-1}$) (±1.3 S.E.) to 23.5 km · day($^{-1}$) (± 3.6 S.E.), similar to rates published for other West Coast yearling Chinook salmon smolt emigrations. Region-specific movement rates were fastest through the upper river regions, and slowest in the Sacramento/San Joaquin River Delta. River travel times were recorded for smolts travelling through a series of ten monitor-delimited reaches. Using these, a smolt travel time model determined by two parameters (movement rate and rate of population spreading) was then used to determine the influence of different factors on the model's fit, using model selection with Akaike's Information Criterion. The model that allowed for both year and reach to be expressed additively for both travel time and population spreading rate estimates, while accounting for a "release" effect, was the best supported model. Finally, several models incorporated environmental data as a linear predictor of movement rates. The addition of the environmental variables, in order of importance, river width to depth ratio, river flow, water turbidity, river flow to mean river flow ratio, and water velocity all resulted in improved model fit. Water temperature did not improve model fit. These environmental associations are discussed and potential improvements on the travel time model are suggested.

Miller, J. A., Gray, A., & Merz, J. (2010). Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon *Oncorhynchus tshawytscha*. *Marine Ecology Progress Series*, *408*, 227–240. doi:10.3354/meps08613
Chinook salmon is an anadromous species that varies in size at freshwater emigration, which is hypothesized to increase population resiliency under variable environmental regimes. In California's Central Valley (USA), the majority of naturally spawned juveniles emigrate in 2 pulses: small juveniles (referred to as fry), typically ≤55 mm fork length (FL), emigrate from natal streams in February–March, whereas larger juveniles (smolts), typically >75 mm FL, emigrate in mid-April–May. In some river systems, there is a smaller pulse of emigrants of intermediate size (parr), typically 56 to 75 mm FL. Although the relative contribution of these migratory phenotypes to the adult population is unknown, management activities focus on survival of larger emigrants and most artificially produced fish (98%) are released from hatcheries at parr and smolt sizes. We reconstructed individual length at freshwater emigration for a sample of adult Central Valley Chinook salmon from 2 emigration years using chemical (Sr:Ca and Ba:Ca) and structural otolith analyses. The adult sample was comprised of individuals that emigrated as parr (mean = 48%), followed by smolts (32%) and fry (20%). Fry-sized emigrants likely represent natural production because fish ≤55 mm FL comprise <2% of the hatchery production. The distribution of migratory phenotypes represented in the adult sample was similar in both years despite apparent interannual variation in juvenile production, providing evidence for the contribution of diverse migratory phenotypes to the adult population. The contribution of all 3 migratory phenotypes to the adult population indicates that management and recovery efforts should focus on maintenance of life-history variation rather than the promotion of a particular phenotype.

Miller, J. A., Teel, D. J., Baptista, A., & Morgan, C. A. (2013). Disentangling bottom-up and top-down effects on survival during early ocean residence in a population of

Chinook salmon (*Oncorhynchus tshawytscha*). *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(4), 617–629. doi:10.1139/cjfas-2012-0354
We evaluated the relative importance of "bottom-up" (production-limited) and "top-down" (predator-mediated) processes during early marine residence in a population of Chinook salmon (*Oncorhynchus tshawytscha*) from the upper Columbia River, USA. We examined length, mass, and condition index of age-0 juveniles collected in the ocean during June and September across 11 years in relation to conditions in the river, estuary, and coastal ocean and to future adult returns. Characteristics of juveniles in September, but not June, were related to adult returns. During years when coastal waters were relatively cool and productive, juveniles captured in September displayed relatively low condition and reduced otolith growth compared with years when coastal waters were relatively warm and unproductive; this contrast indicates that top-down effects such as selective mortality or competition are important during early marine residence. Key physical (river plume volume during emigration) and biological (condition) variables and their interaction accounted for >95% of the variation in adult returns. Future research should focus on evaluating predators and competitors and understanding how river plume structure influences survival.

Miller, S. E., Adkison, M. D., & Haldorson, L. J. (2012). Differences in stability effects on the marine survival of hatchery pink salmon (*Oncorhynchus gorbuscha*) within the upwelling and downwelling domains of the northeast Pacific Ocean. *Fisheries Oceanography*, *21*(6), 430–444. doi:10.1111/j.1365-2419.2012.00636.x
Regional coastal conditions have a strong influence on juvenile salmon survival during their critical first months in the marine environment. Salmon (genus *Oncorhynchus*) survival has been thought to be favored within the high latitude downwelling domain if water column stabilities increase, whereas stability may have the opposite effect in upwelling-dominated lower latitudes. In this study, the relationships between water column stabilities during early marine residence of pink salmon (*Oncorhynchus gorbuscha*) in both the upwelling and downwelling domains of the northeast Pacific Ocean and marine survival rates for hatchery stocks ranging from Vancouver Island, British Columbia, to Kodiak Island, Alaska, were explored. Contrary to expectation, there was no clear difference in the effect of stability on marine survival rates in the downwelling and upwelling domains. In both domains, marine survival rates increased for pink salmon stocks that experienced below-average stability on the inner shelf during early marine residence. Stability effects from the outer shelf showed no consistent relationship to marine survival within the northeast Pacific.

Miller, S. E., Adkison, M. D., & Haldorson, L. (2012). Relationship of water column stability to the growth, condition, and survival of pink salmon (*Oncorhynchus gorbuscha*) in the northern coastal Gulf of Alaska and Prince William Sound. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*(5), 955–969. doi:10.1139/f2012-031
Water column stability has been hypothesized to affect growth and ultimately survival of juvenile fish. We estimated the relationships between stability and the growth, condition, and marine survival of several stocks of pink salmon (*Oncorhynchus gorbuscha*) within Prince William Sound (PWS), Alaska, USA, and the northern coastal Gulf of Alaska

(GOA) shelf. There was a stronger correlation among the biological parameters of the fish than between the biological parameters and physical conditions. While stability and fish condition during early marine residence in PWS were important to year-class survival, stability of the water column that juveniles experienced as they migrated to the open waters of the GOA did not play a key role in determining survival to adulthood. Below-average stability just prior to capture within PWS combined with positive fish condition was related to increased year-class survival. Our results are similar to previous studies that concluded that slower and weaker development of stratification with a deeper mixed layer depth may be important for juvenile pink salmon survival in PWS

Miller, T. W., & Brodeur, R. D. (2007). Diets of and trophic relationships among dominant marine nekton within the northern California Current ecosystem. *Fishery Bulletin*, *105*(4), 548–559.

In this study we analyzed the diets of 26 nekton species collected from two years (2000 and 2002) off Oregon and northern California to describe dominant nekton trophic groups of the northern California Current (NCC) pelagic ecosystem. We also examined interannual variation in the diets of three nekton species. Cluster analysis of predator diets resulted in nekton trophic groups based on the consumption of copepods, euphausiids, brachyuran larvae, larval juvenile fishes, and adult nekton. However, many fish within trophic groups consumed prey from multiple trophic levels—euphausiids being the most widely consumed. Comparison of diets between years showed that most variation occurred with changes in the contribution of euphausiids and brachyuran larvae to nekton diets. The importance of euphausiids and other crustacean prey to nekton indicates that omnivory is an important characteristic of the NCC food web; however it may change during periods of lower or higher upwelling and ecosystem production.

Miller, T. W., Brodeur, R. D., Rau, G., & Omori, K. (2010). Prey dominance shapes trophic structure of the northern California Current pelagic food web: evidence from stable isotopes and diet analysis. *Marine Ecology Progress Series*, *420*, 15–26. doi:10.3354/meps08876

Eastern boundary current (EBC) upwelling zones are among the most productive of marine ecosystems globally and have been generalized in terms of their food web structure. Little empirically based evidence exists to suggest that there is any one form of trophic control of EBC systems and, because of logistical constraints, knowledge of food web structure is limited in these large marine ecosystems. To determine principal trophic links within the pelagic food web, we combined stable isotope and diet analysis of 21 dominant species of nekton found within the northern California Current, a highly productive EBC upwelling ecosystem. Samples of nekton and zooplankton were collected in June and August 2000 and 2002 from the shelf-slope waters of northern California to Washington. Results showed most nekton consumed mixed diets of zooplankton and larval-juvenile or adult fishes, indicating the importance of omnivory in this system. Euphausiids were overwhelmingly the most prevalent zooplankton taxa in the diets of nekton across multiple trophic levels, accounting for >50% of the index of relative importance in 10 of 21 nekton species analyzed. Nitrogen stable isotopes ($\delta^{15}N$) reflected trophic patterns observed in the diets, with most nekton species (~62%) falling between trophic levels (TL) of full zooplanktivores (TL = 3) and full piscivores (TL = 4).

The prevalence of omnivory observed here is probably due to high primary production that supports an abundance of large zooplankton prey, such as euphausiids, which may be a more available prey resource for a broad range of predators. A modification of this form of bottom-up control, termed bottom-up omnivory, is presented.

Moore, M., Berejikian, B. A., & Tezak, E. P. (2012). Variation in the early marine survival and behavior of natural and hatchery-reared Hood Canal steelhead. *PLoS One*, *7*(11), e49645. doi:10.1371/journal.pone.0049645

Background: Hatchery-induced selection and direct effects of the culture environment can both cause captively bred fish populations to survive at low rates and behave unnaturally in the wild. New approaches to fish rearing in conservation hatcheries seek to reduce hatchery-induced selection, maintain genetic resources, and improve the survival of released fish. Methodology/Principal Findings: This study used acoustic telemetry to compare three years of early marine survival estimates for two wild steelhead populations to survival of two populations raised at two different conservation hatcheries located within the Hood Canal watershed. Steelhead smolts from one conservation hatchery survived with probabilities similar to the two wild populations (freshwater: 95.8–96.9%, early marine: 10.0–15.9%), while smolts from the other conservation hatchery exhibited reduced freshwater and early marine survival (freshwater: 50.2–58.7%, early marine: 2.6–5.1%). Freshwater and marine travel rates did not differ significantly between wild and hatchery individuals from the same stock, though hatchery smolts did display reduced migration ranges within Hood Canal. Between-hatchery differences in rearing density and vessel geometry likely affected survival and behavior after release and contributed to greater variation between hatcheries than between wild populations. Conclusions/Significance: Our results suggest that hatchery-reared smolts can achieve early marine survival rates similar to wild smolt survival rates, and that migration performance of hatchery-reared steelhead can vary substantially depending on the environmental conditions and practices employed during captivity.

Moore, M., Berejikian, B. A., & Tezak, E. P. (2013). A floating bridge disrupts seaward migration and increases mortality of steelhead smolts in Hood Canal, Washington State. *PLoS ONE*, *8*(9), e73427. doi:10.1371/journal.pone.0073427

Background: Habitat modifications resulting from human transportation and power-generation infrastructure (e.g., roads, dams, bridges) can impede movement and alter natural migration patterns of aquatic animal populations, which may negatively affect survival and population viability. Full or partial barriers are especially problematic for migratory species whose life histories hinge on habitat connectivity. Methodology/Principal Findings: The Hood Canal Bridge, a floating structure spanning the northern outlet of Hood Canal in Puget Sound, Washington, extends 3.6 meters underwater and forms a partial barrier for steelhead migrating from Hood Canal to the Pacific Ocean. We used acoustic telemetry to monitor migration behavior and mortality of steelhead smolts passing four receiver arrays and several single receivers within the Hood Canal, Puget Sound, and Strait of Juan de Fuca. Twenty-seven mortality events were detected within the vicinity of the Hood Canal Bridge, while only one mortality was recorded on the other 325 receivers deployed throughout the study area. Migrating steelhead smolts were detected at the Hood Canal Bridge array with greater frequency, on

more receivers, and for longer durations than smolts migrating past three comparably configured arrays. Longer migration times and paths are likely to result in a higher density of smolts near the bridge in relation to other sites along the migration route, possibly inducing an aggregative predator response to steelhead smolts. Conclusions/Significance: This study provides strong evidence of substantial migration interference and increased mortality risk associated with the Hood Canal Bridge, and may partially explain low early marine survival rates observed in Hood Canal steelhead populations. Understanding where habitat modifications indirectly increase predation pressures on threatened populations helps inform potential approaches to mitigation.

Moore, M. E., Berejikian, B. A., & Tezak, E. P. (2010). Early marine survival and behavior of steelhead smolts through Hood Canal and the Strait of Juan de Fuca. *Transactions of the American Fisheries Society*, *139*(1), 49–61. doi:10.1577/T09-012.1

The depressed status of Puget Sound populations of steelhead *Oncorhynchus mykiss* contrasts with the healthier condition of those along the coast of Washington and suggests that there is substantial smolt mortality during the migration through Puget Sound to the Pacific Ocean. Acoustic telemetry transmitters and stationary receivers were used to investigate the survival, migration timing, and migratory behavior of 159 steelhead smolts in 2006 and 187 smolts in 2007 from four Hood Canal (part of Puget Sound) streams and one stream flowing into the Strait of Juan de Fuca. The estimated population-specific survival rates for wild and hatchery smolts from the river mouths to the northern end of Hood Canal (28.1–75.4 km) ranged from 55% to 86% in 2006 and from 62% to 84% in 2007. Survival was much lower from the northern end of Hood Canal to the Strait of Juan de Fuca (135 km) in 2006 (23–49%) and could not be reliably measured in 2007. Travel rates through Hood Canal (8–10 km/d) were significantly lower than those estimated as the fish migrated through northern Puget Sound and the Strait of Juan de Fuca (26–28 km/d), while the mortality rates per unit of distance traveled were very similar in the two segments. The high daily mortality rates estimated during the early marine phase of the steelhead life cycle (2.7%/d) suggest that mortality rates decrease substantially after steelhead enter the Pacific Ocean.

Moore, M. E., Goetz, F. A., Van Doornik, D. M., Tezak, E. P., Quinn, T. P., Reyes-Tomassini, J. J., & Berejikian, B. A. (2010). Early marine migration patterns of wild coastal cutthroat trout (*Oncorhynchus clarki clarki*), steelhead trout (*Oncorhynchus mykiss*), and their hybrids. *PLoS ONE*, *5*(9), e12881. doi:10.1371/journal.pone.0012881

Background: Hybridization between coastal cutthroat trout (*Oncorhynchus clarki clarki*) and steelhead or rainbow trout (*Oncorhynchus mykiss*) has been documented in several streams along the North American west coast. The two species occupy similar freshwater habitats but the anadromous forms differ greatly in the duration of marine residence and migration patterns at sea. Intermediate morphological, physiological, and performance traits have been reported for hybrids but little information has been published comparing the behavior of hybrids to the pure species. Methodology/Principal Findings: This study used acoustic telemetry to record the movements of 52 cutthroat, 42 steelhead x cutthroat hybrids, and 89 steelhead smolts, all wild, that migrated from Big Beef Creek into Hood Canal (Puget Sound, Washington). Various spatial and temporal metrics were used to

compare the behavior of the pure species to their hybrids. Median hybrid residence time, estuary time, and tortuosity values were intermediate compared to the pure species. The median total track distance was greater for hybrids than for either cutthroat or steelhead. At the end of each track, most steelhead (80%) were located near or north of the Hood Canal, as expected for this seaward migrating species, whereas most cutthroat (89%) were within 8 kilometers of the estuary. Most hybrids (70%) were detected leaving Hood Canal, though a substantial percentage (20%) remained near the Big Beef Creek estuary. More hybrids (7.5%) than pure cutthroat (4.5%) or steelhead (0.0%) were last detected in the southern reaches of Hood Canal. Conclusions/Significance: Given the similarity in freshwater ecology between the species, differences in marine ecology may play an important role in maintaining species integrity in areas of sympatry.

Morris, J. F., Trudel, M., Thiess, M. E., Sweeting, R. M., Fisher, J., Hinton, S. A., Fergusson, E. A., Orsi, J. A., Farley Jr., E. V., & Welch, D. W. (2007). Stock-specific migrations of juvenile coho salmon derived from coded-wire tag recoveries on the continental shelf of western North America. In *American Fisheries Society Symposium,57,* 81-104.

A conceptual model of juvenile coho salmon *Oncorhynchus kisutch* migration from Oregon, Washington, the Columbia–Snake River system, British Columbia, and southeast Alaska was derived using coded-wire-tag data from juvenile salmon surveys conducted between 1995 and 2004. Over this 10-year period, 914 coded-wire-tagged (CWT) juvenile coho salmon were recovered. In general, the migratory behavior of juvenile coho salmon observed in this study was consistent with previous studies showing that juvenile salmon generally undertake a northward migration and utilize the continental shelf as a migration highway. However, this study also revealed that both regional and specific river stocks of coho salmon from all parts of the North American coast are composed of fast components that take a rapid and direct migration in the summer to as far west as Kodiak Island, Alaska and slow components that migrate over a relatively short distance from their natal rivers and reside over winter on the shelf. The Columbia–Snake River system, coastal Oregon, and coastal Washington had the highest proportion of fast CWT migrants among regions. Furthermore, specific stocks within the lower Columbia River had the highest proportion of fast CWT migrants both within the Columbia–Snake River watershed and along the entire west coast of North America. Distances migrated along the shelf were positively correlated to size at capture during the summer for almost all regional stocks, indicating that fast-migrating juvenile coho salmon have faster growth rates. The widespread dispersion along the continental shelf as a consequence of a mix of slow and fast migrants and the subsequent offshore migration into different regions of the Gulf of Alaska may have been selected over evolutionary time scales. This strategy would have ensured the long-term survival of individual stocks by spreading the risk of mortality among oceanic regions.

Morton, A., & Routledge, R. D. (2006). Fulton's condition factor: Is it a valid measure of sea lice impact on juvenile salmon? *North American Journal of Fisheries Management*, *26*(1), 56–62. doi:10.1577/M05-068.1

Condition factor formulas have been developed and are used to assist in assessing the state of fish health. Fulton's condition factor has been used to measure anthropogenic

impacts on fish, such as oil spills, and has provided results that, at times, are contentious. Recently, it has been used to suggest that infestation rates of sea lice *Lepeophtheirus salmonis* currently reported for juvenile pink salmon *Oncorhynchus gorbuscha* and chum salmon *O. keta* in the Broughton archipelago, British Columbia, may have no impact on fish health. Here, we show that Fulton's condition factor values will remain high in salmon fry lethally infected with sea lice until shortly before death. Furthermore, we report that as condition factor values declined, the affected fish exhibited high predator risk behavior. We conclude that Fulton's condition factor does not provide a reliable indicator of the impact of sea lice infestations on juvenile pink and chum salmon.

Morton, A., Routledge, R., & Krkosek, M. (2008). Sea louse infestation in wild juvenile salmon and Pacific herring associated with fish farms off the east-central coast of Vancouver Island, British Columbia. ***North American Journal of Fisheries Management*****, *28*(2), 523–532. doi:10.1577/M07-042.1**

Reports of infestations of sea lice *Lepeophtheirus salmonis* and *Caligus clemensi* in juvenile salmonids in Pacific Canada have been restricted to pink salmon *Oncorhynchus gorbuscha* and chum salmon *O. keta* from one salmon-farming region, the Broughton Archipelago of British Columbia. Here, we report on 2 years of sea louse field surveys of wild juvenile pink and chum salmon, as well as wild sockeye salmon *O. nerka* and larval Pacific herring *Clupea pallasii*, in another salmon farming region, the Discovery Islands region of British Columbia. For pink and chum salmon we tested for the dependency of sea louse abundance on temperature, salinity, sampling period, host species, and farm exposure category. For both louse species, farm exposure was the only consistently significant predictor of sea lice abundance. Fish exposed to salmon farms were infected with more sea lice than those in the peripheral category. Sea louse abundance on sockeye salmon and Pacific herring followed the same trends, but sample sizes were too low to support formal statistical analysis. The Pacific herring were translucent and lacked scales, and they were primarily parasitized by *C. clemensi*. These results suggest that the association of salmon farms with sea lice infestations of wild juvenile fish in Pacific Canada now extends beyond juvenile pink and chum salmon in the Broughton Archipelago. Canada's most abundant and economically valuable salmon populations, as well as British Columbia's most valuable Pacific herring stock, migrate through the Discovery Islands; hence, parasite transmission from farm to wild fish in this region may have important economic and ecological implications.

Morton, A., Routledge, R., McConnell, A., & Krkošek, M. (2011). Sea lice dispersion and salmon survival in relation to salmon farm activity in the Broughton Archipelago. ***ICES Journal of Marine Science: Journal du Conseil*****, *68*(1), 144–156. doi:10.1093/icesjms/fsq146**

The risk of salmon lice (*Lepeophtheirus salmonis*) transmission to wild juvenile Pacific salmon has spurred management change to reduce lice on salmon farms. We studied the abundance of planktonic lice preceding the juvenile salmon outmigration as well as the abundance of lice on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in two distinct migration routes, one containing only fallow farms and the other active farms that applied a parasiticide. Results indicate that fallowing reduces the abundance and flattens the spatial distribution of lice relative to that expected in areas

without farms. Active farms remained the primary source of lice, but transmission was reduced 100-fold relative to previous epizootics in the study area. On the migration route containing active farms, ~50% of the juvenile salmon showed evidence of louse damage to surface tissues and the estimated direct louse-induced mortality was <10%, not including indirect effects of infection on predation risk or competition. The survival of the pink salmon cohort was not statistically different from a reference region without salmon farms. Although repeated use of a single parasiticide can lead to resistance, reducing louse transmission from farmed salmon may help conserve some wild Pacific salmon populations.

Moss, J. H., & Beauchamp, D. A. (2007). Functional response of juvenile pink and chum salmon: effects of consumer size and two types of zooplankton prey. *Journal of Fish Biology*, *70*(2), 610–622. doi:10.1111/j.1095-8649.2007.01340.x
Feeding rate experiments were conducted for pink salmon *Oncorhynchus gorbuscha* fry [mean fork length (LF) 39 mm], juveniles (103–104 mm LF) and juvenile chum salmon *Oncorhynchus keta* (106–107 mm LF). Fishes were presented with small copepod (*Tisbi sp.*) or larger mysid shrimp (*Mysidopsis bahia*) prey at varying densities ranging from 1 to 235 prey l^{-1} in feeding rate experiments conducted at water temperatures ranging from 10.5 to 12.0° C under high light levels and low turbidity conditions. Juvenile pink and chum salmon demonstrated a type II functional response to mysid and copepod prey. Mysid prey was readily selected by both species whereas the smaller bodied copepod prey was not. When offered copepods, pink salmon fry fed at a higher maximum consumption rate (2.5 copepods min^{-1}) than larger juvenile pink salmon (0.4 copepods min^{-1}), whereas larger juvenile chum salmon exhibited the highest feeding rate (3.8 copepods min^{-1}). When feeding on mysids, the maximum feeding rate for larger juvenile pink (12.3 mysids min^{-1}) and chum (11.5 mysids min^{-1}) salmon were similar in magnitude, and higher than feeding rates on copepods. Functional response models parameterized for specific sizes of juvenile salmon and zooplankton prey provide an important tool for linking feeding rates to ambient foraging conditions in marine environments, and can enable mechanistic predictions for how feeding and growth should respond to spatial-temporal variability in biological and physical conditions during early marine life stages.

Moss, J. H., Beauchamp, D. A., Cross, A. D., Farley, E. V., Murphy, J. M., Helle, J. H., Walker, R. V., & Myers, K. W. (2009). Bioenergetic model estimates of interannual and spatial patterns in consumption demand and growth potential of juvenile pink salmon (*Oncorhynchus gorbuscha*) in the Gulf of Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography*, *56*(24), 2553–2559. doi:10.1016/j.dsr2.2009.03.005
A bioenergetic model of juvenile pink salmon (*Oncorhynchus gorbuscha*) was used to estimate daily prey consumption and growth potential of four ocean habitats in the Gulf of Alaska during 2001 and 2002. Growth potential was not significantly higher in 2002 than in 2001 at an alpha level of 0.05 (P=0.073). Average differences in growth potential across habitats were minimal (slope habitat=0.844 g d^{-1}, shelf habitat=0.806 g d^{-1},

offshore habitat=0.820 g d^{-1}, and nearshore habitat=0.703 g d^{-1}) and not significantly different (P=0.630). Consumption demand differed significantly between hatchery and wild stocks (P=0.035) when examined within year due to the interaction between hatchery verses wild origin and year. However, the overall effect of origin across years was not significant (P=0.705) due to similar total amounts of prey consumed by all juvenile pink salmon in both study years. We anticipated that years in which ocean survival was high would have had high growth potential, but this relationship did not prove to be true. Therefore, modeled growth potential may not be useful as a tool for forecasting survival of Prince William Sound hatchery pink salmon stocks. Significant differences in consumption demand and a two-fold difference in nearshore abundance during 2001 of hatchery and wild pink salmon confirmed the existence of strong and variable interannual competition and the importance of the nearshore region as being a potential competitive bottleneck.

Moss, J. H., Murphy, J. M., Farley, E. V., Eisner, L. B., & Andrews, A. G. (2009). Juvenile pink and chum salmon distribution, diet, and growth in the northern Bering and Chukchi seas. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 191–196.
Loss of non-seasonal sea ice and a general warming trend in the Bering Sea has altered the composition, distribution, and abundance of marine organisms inhabiting the region. Juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon were found in significant numbers throughout the Chukchi Sea and Bering Strait regions during early autumn 2007, reflecting significant utilization of Arctic marine habitat by Pacific salmon. Linear models of juvenile pink and chum salmon body size corrected for Day of Year were parameterized to estimate daily growth rates and habitat-specific differences in body size using 6 years of survey data. Model results revealed that juvenile pink salmon inhabiting the eastern Bering Sea grew at an average rate of 1.17 mm•day^{-1} and juvenile chum salmon grew at a rate of 1.21 mm•day^{-1}. The U.S. BASIS survey area was expanded northward to include the Chukchi Sea during 2007, where larger juvenile pink and chum salmon were found in higher abundances relative to pink and chum inhabiting the eastern Bering Sea. Food habits analyses revealed that juvenile pink and chum salmon fed upon high energy prey in the Chukchi Sea, and that the majority of chum salmon encountered there were from either Alaskan or Russian stocks.

Mueter, F. J., Boldt, J. L., Megrey, B. A., & Peterman, R. M. (2007). Recruitment and survival of Northeast Pacific Ocean fish stocks: temporal trends, covariation, and regime shifts. *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(6), 911–927. doi:10.1139/f07-069
Two measures of productivity for fish stocks (recruitment and stock–recruit residuals) within two large marine ecosystems (Gulf of Alaska and eastern Bering Sea – Aleutian Islands) showed significant positive covariation within several groups of species and significant negative covariation between certain others. For example, stock–recruit residuals of gadids (Gadidae) in the Bering Sea were inversely related to those of shelf flatfishes (Pleuronectidae), suggesting that environmental forcing affects these groups in opposite ways. Salmon (*Oncorhynchus* spp.), Pacific herring (*Clupea pallasii*), and groundfish stocks each showed strong patterns of covariation within these taxonomic groups and within ecosystems, and both salmon and groundfish stocks showed positive

covariation between the two ecosystems. However, we found little evidence of covariation between salmon and herring stocks or between these stocks and demersal stocks. Recruitment and stock–recruit residuals in individual stocks did not show a consistent response toknown climatic regime shifts. However, combined indices of productivity across stocks showed decadal-scale variability (regime-like patterns), suggesting that both pelagic productivity (mostly salmon) and demersal productivity increased in response to the well-documented 1976–1977 climatic regime shift, whereas the 1988–1989 regime shift produced inconsistent or short-lived responses.

Murphy, J. M., Templin, W. D., Farley Jr, E. V., & Seeb, J. E. (2009). Stock-structured distribution of western Alaska and Yukon juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from United States BASIS surveys, 2002–2007. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 51–59.

We describe migratory patterns of western Alaska and Yukon Chinook salmon (*Oncorhynchustshawytscha*) using stock-structured distribution data from United States Bering-Aleutian Salmon InternationalSurveys (BASIS), 2002–2007. Juvenile Chinook salmon were distributed within water depths less than 50 m and their highest densities were found close to river mouths of primary Chinook salmon-producing rivers in the eastern Bering Sea (Yukon, Kuskokwim, and Nushagak rivers) through their first summer at sea. This reflects a later marine dispersal from freshwater entry points than typically found in Gulf of Alaska stream-type Chinook salmon and resulted in the presence of juvenile Chinook salmon in shallow, non-trawlable habitats during the surveys. Juvenile Chinook salmon stock proportions in the northern shelf region (north of 60°N) were: 44% Upper Yukon, 24% Middle Yukon, 31% Coastal Western Alaska, and 1% other western Alaska stock groups. Juvenile Chinook salmon stock proportions present in the southern shelf region (south of 60°N) were: 95% Coastal Western Alaska,1% Upper Yukon, and 4% other western Alaska stock groups. It is believed that these stock mixtures do not support significant northward migration of stocks from the southern shelf, and reflect limited mixing of salmon from the two production regions during their first summer at sea. Spatial distribution patterns and coded-wire tag recoveries provide evidence that the distribution of Yukon River Chinook salmon extends northward into the Chukchi Sea during their first summer at sea. Although the juveniles present in the Chukchi Sea represent a minor portion of the total Yukon River juvenile population, continued warming of the Arctic could increase the proportion of Yukon River Chinook salmon migrating north into the Chukchi Sea.

Myers, K. W., Klovach, N. V., Gritsenko, O. F., Urawa, S., & Royer, T. C. (2007). Stock-specific distributions of Asian and North American salmon in the open ocean, interannual changes, and oceanographic conditions. *North Pacific Anadromous Fish Commission Bulletin*, *4*, 159–177.

Knowledge of migration routes, migration timing, and resident areas for populations of Pacific salmon in the open ocean is vital to understanding their status and role in North Pacific marine ecosystems. In this paper we review information from the literature, as well as some previously unpublished data, on stock-specific distribution and migration patterns of salmon in the open ocean, interannual variation in these patterns, and associated ocean conditions, and we consider what this information can tell us about

ocean conditions on small- to mid-size scales. We conclude that climate-driven changes in open-ocean feeding areas and along the migratory routes of Asian and North American salmon can result in predictable interannual changes in stock-specific distribution, migration patterns, and other biological characteristics. Global climate change is currently causing more frequent and unpredictable environmental changes in the open ocean habitats through which salmon migrate. Data on changes in the distribution and migration of indicator stocks of adult salmon returning from the open ocean might provide an "advance warning" of interannual changes in North Pacific marine ecosystems.

Nance, S. L., Riederer, M., Zubkowski, T., Trudel, M., & Rhodes, L. D. (2010). Interpreting dual ELISA and qPCR data for bacterial kidney disease of salmonids. *Diseases of Aquatic Organisms*, *91*(2), 113–119. doi:10.3354/dao02252

Although there are a variety of methods available for the detection of *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease in salmon and trout, the enzyme-linked immunosorbent assay (ELISA) is probably the most widely used method. However, ELISA measures bacterial antigen, which does not necessarily reflect the number of cells present. We hypothesized that dual analysis of kidney tissue by ELISA and a quantitative real-time polymerase chain reaction assay (qPCR) would provide complementary information about antigen level and the number of bacterial genomes. We found that DNA extracted from the insoluble fraction of the ELISA tissue preparation produced the same qPCR result as DNA extracted directly from frozen tissue, permitting true dual analysis of the same tissue sample. We examined kidney tissue in this manner from individual free-ranging juvenile Chinook salmon and antibiotic-treated captive subadult Chinook salmon and observed 3 different patterns of results. Among the majority of fish, there was a strong correlation between the ELISA value and the qPCR value. However, subsets of fish exhibited either low ELISA values with elevated qPCR values or higher ELISA values with very low qPCR values. These observations suggest a conceptual model that allows inferences about the state of infection of individual fish based on dual ELISA/qPCR results. Although this model requires further assessment through experimental infections and treatments, it may have utility in broodstock selection programs that currently apply egg-culling practices based on ELISA alone.

Nendick, L., Sackville, M., Tang, S., Brauner, C. J., & Farrell, A. P. (2011). Sea lice infection of juvenile pink salmon (*Oncorhynchus gorbuscha*): effects on swimming performance and postexercise ion balance. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(2), 241–249. doi:10.1139/F10-150

Sea lice (*Lepeophtheirus salmonis*) infection negatively affected swimming performance and postswim body ion concentrations of juvenile pink salmon (*Oncorhynchus gorbuscha*) at a 0.34 g average body mass but not at 1.1 g. Maximum swimming velocity (U_{max}) was measured on over 350 individual pink salmon (0.2–3.0 g), two-thirds of which had a sea lice infection varying in intensity (one to three sea lice per fish) and life stage (chalimus 1 to preadult). For fish averaging 0.34 g (caught in a nearby river free of sea lice and transferred to seawater before being experimentally infected), the significant reduction in U_{max} was dependent on sea lice life stage, not intensity, and U_{max} decreased only after the chalimus 2 life stage. Experimental infections also significantly elevated

postswim whole body concentrations of sodium (by 23%–28%) and chloride (by 22%–32%), but independent of sea lice developmental stage or infection intensity. For fish averaging 1.1 g (captured in seawater with existing sea lice), the presence of sea lice had no significant effect on either U_{max} or postswim whole body ions. Thus, a single *L. salmonis* impacted swimming performance and postswim whole body ions of only the smallest pink salmon and with a sea louse stage of chalimus 3 or greater.

Neville, C.E., Beamish, R. J., & Chittenden, C. M. (2010). The use of acoustic tags to monitor

the movement and survival of juvenile chinook salmon in the Strait of Georgia. ***North Pacific Anadromous Fish Commission Document*****,** ***1286*****, 19 pp.**

A total of 278 acoustic tags were placed in juvenile chinook salmon that were captured and released in the Strait of Georgia in 2007 and 2008. These tags could be detected at receiver arrays within the Strait of Georgia and at a receiver array at a northern exit point in Queen Charlotte Strait and a southern exit point in Juan de Fuca Strait. There were 83 (30%) of these fish detected at least once after they were released. Of the 100 fish tagged in September 23-24, 2007 only six fish were dete cted leaving the Strait of Georgia and all detections were at the southern exit point in Juan de Fuca Strait. Of the 30 fish tagged in the central Strait of Georgia in June 19-20, 2008, only one fish was detected leaving the Strait of Georgia through Queen Charlotte Strait. None were detected leaving the Strait of Georgia of the 78 fish tagged in the central Strait of Georgia in July 16-19, 2008. Only one was detected leaving the Strait of Georgia through Juan de Fuca Strait of the 40 fish tagged in the Gulf Islands area in July 14-15, 2008. None of the 30 tagged fish that were reared in the net pen and released in the Gulf Islands area were detected at any receiver. A tagging mortality and tag loss study indicated that the tagging procedures were an unlikely source of low detection rates of fish leaving the Strait of Georgia. It was also unlikely that the tagged fish remained in the Strait of Georgia over the winter and into the spring of the following year as trawl studies capture very few juvenile chinook salmon in the Strait of Georgia in the winter. Therefore, we concluded that there were large mortalities of the tagged fish which we interpret to indicate that the early marine mortality of chinook salmon within the Strait of Georgia is the major regulator of their brood-year strength.

Oka, G., Irvine, J. R., Holt, C., Trudel, M., Tucker, S., Gillespie, D., & Fitzpatrick, L. (2012).

Temporal Growth Patterns of Big Qualicum River Chum Salmon (*Oncorhynchus keta*) in the North Pacific Ocean. ***North Pacific Anadromous Fish Commission Document*****,** ***1429*****, 13 pp.**

Increases in salmon abundance in the Pacific Ocean over the past three to four decades have been attributed to favourable environmental conditions and enhanced hatchery production. However, the effects of inter- and intra- species competition for food resources in the ocean remains inconclusive. Chum salmon (*Oncorhynchus keta*) are of particular interest because of the large numbers of hatchery releases and some evidence of density dependence. Scales from Big Qualicum River chum salmon gathered during 1971-2010 were examined to evaluate marine growth during this period. A consistent temporal trend was observed for all growth years for the dominant age classes of chum

salmon; growth was most rapid in the early 1980s and 2000s and slowest in years centred around 1990. Future work to continue statistical analysis of these data and examine temporal patterns in growth of other populations and species is recommended.

Orsi, J. A., Clausen, D. M., Wertheimer, A., Courtney, D. L., & Pohl, J. (2006). Diel epipelagic distribution of juvenile salmon, rockfish, sablefish and ecological interactions with associated species in offshore habitats of the Northeast Pacific Ocean. *North Pacific Anadromous Fish Commission Document*, *956*, 26 pp.
Diel epipelagic sampling for juvenile Pacific salmon (*Oncorhynchus* spp.), rockfish (*Sebastes* spp.), sablefish (*Anoplopoma fimbria*), and associated species was conducted to identify factors that may affect year-class success of these commercially important species. Surface trawls were fished from 10 to 20 August 2005, in the upper 20 m of the water column along transects up to 78 km offshore in the coastal northeast Pacific Ocean near 58° N. Along two transects, three habitats were sampled over a 24-hr period: the continental shelf (<200 m depth), the continental slope (400-750 m depth), and the abyss (>2,000 m depth). A total of 38,747 fish and squid representing 24 species were sampled in 56 trawl hauls. Of the targeted juvenile fish species, a total of 587 salmon, 11 rockfish, and 70 sablefish were captured. Sampling during day (1500-1900) and night (2200-0200) periods indicated that biomass of fish and squid was 3.9 times higher at night pooled across the habitats in the two transects. No distinct patterns between day or night occurrence were noted for juvenile pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), or coho salmon (*O. kisutch*); however, juvenile Chinook salmon (*O. tshawytscha*) were encountered only at night. Catches of juvenile rockfish and sablefish were quite low in this study, and larger sample sizes of these fish are needed to adequately determine their diel distribution. Diel differences were apparent with forage species such as Pacific herring (*Clupea pallasi*), capelin (*Mallotus villosus*), and eulachon (*Thaleichthys pacificus*) that were almost exclusively sampled at night. The offshore distribution patterns of target species were distinctly different, with the most common occurrences of juvenile salmon over continental shelf habitats, juvenile sablefish over continental shelf and slope habitats, and juvenile rockfish over slope and abyss habitats. Pacific herring, capelin, eulachon, and Pacific sardines (*Sardinops sagax*) were found over continental shelf habitats, whereas small squid and myctophids occurred primarily in slope and abyssal habitats. The greatest overall catch biomass was of jellyfish (gelatinous species), which was consistently higher than that of all fish and squid combined, usually by an order of magnitude. Individual fish or squid species with highest average weight per haul were pomfret (*Brama japonica*), adult coho salmon, Humboldt squid (*Dosidicus gigas*), and blue sharks (*Prionace glauca*). The occurrence of the latter two warm-water species and Pacific sardines was of interest because this study occurred during an anomalously warm year and the capture of Pacific sardines and Humboldt squid represent northern range extensions for these species. Stomach content analysis of potential predator species of the target species showed that only adult coho salmon were predating on juvenile salmon and sablefish, and only pomfret were predating on juvenile rockfish. Further sampling of the target species is needed in these habitats during more normal environmental conditions to validate these observations.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Wing, B. L., Wertheimer, A. C. &

Heard, W. R. (2006). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2005. *North Pacific Anadromous Fish Commission Document*, *956*, 108 pp.

Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated biophysical data were collected by the Southeast Coastal Monitoring Project along primary marine migration corridors in the southern and northern regions of southeastern Alaska. Up to 17 stations were sampled in four time periods (40 sampling days) from May to August
2005. This survey marked the ninth consecutive year of systematic monitoring of how juvenile salmon interact in marine ecosystems, and was implemented to identify the relationships among biophysical parameters that influence the habitat use, marine growth, predation, stock interactions, and year-class strength of salmon. Typically, at each station, fish, zooplankton, physical profile data, and water samples were collected using a surface rope trawl, conical and bongo nets, a conductivity-temperature-depth profiler, and a water sampler during daylight. Surface (3- m) temperatures and salinities ranged from 9.3 to 15.7 ºC and 13.8 to 31.5 PSU over the season. A total of 6,874 fish and squid, representing 19 taxa, were captured in 92 rope trawl hauls from June to August. Juvenile salmon comprised 96% of the total fish and squid catch in each region. Juvenile salmon occurred frequently in both regions, with pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) occurring in 63-86% of the trawl hauls, and juvenile Chinook salmon occurring in 20-25% of the trawl hauls. Of the 6,651 salmonids caught, over 99% were juveniles. In both regions, only two non-salmonid species represented >1% of the catch: market squid (*Loligo* spp.) in the southern region (2%) and crested sculpin (*Blepsias bilobus*) in the northern region (2%). Temporal and spatial differences were observed in the catch rates, size, condition, and stock of origin of juvenile salmon species. Catch rates of juvenile salmon were highest in June for all species except pink salmon, which had the highest catch rates in August. Size of juvenile salmon increased steadily throughout the season; mean fork lengths in June, July, and August were, respectively: 92, 127, and 170 mm for pink; 108, 124, and 191 mm for chum; 115, 123, and 180 mm for sockeye; 184, 207, and 239 mm for coho; and 205, 245, and 255 for Chinook salmon. Coded-wire tags were recovered from 17 juvenile coho, 6 juvenile Chinook, and 2 immature Chinook salmon; all but six of these fish were from hatchery and wild stocks of southeastern Alaska origin. The non-Alaska stocks were juvenile coho and Chinook salmon originating from Oregon and Washington. Alaska enhanced stocks were also identified by thermal otolith marks from 53% of the chum, 18% of the sockeye, 9% of the coho, and 50% of the Chinook salmon. Onboard stomach analysis of 63 potential predators, representing eight species, revealed one predation instance on juvenile salmon by a spiny dogfish (*Squalus acanthias*). Forecasting models using catch-per-unit effort (CPUE) of juvenile pink salmon in strait habitat of the northern region in 2003 and 2004 produced accurate predictions of southeastern Alaska pink salmon harvests in 2004 and 2005. However, the models using 2005 CPUE as a predictor overestimated harvest of pink salmon in 2006, indicating that CPUE alone is not sufficient to consistently predict year class strength. These results suggest that in southeastern Alaska, juvenile salmon exhibit seasonal patterns of habitat use and abundance, and display species- and stock-dependent migration patterns. Long-term

monitoring of key stocks of juvenile salmon, on both intra- and interannual bases, will enable researchers to better understand ecological interactions that affect interannual variation in salmon abundance and the role that salmon play in North Pacific marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Wing, B. L., Wertheimer, A. C. & Heard, W. R. (2007). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2006. *North Pacific Anadromous Fish Commission Document*, 1057, 72 pp.

Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated biophysical data were collected along primary marine migration corridors in the northern and southern regions of southeastern Alaska in 2006. Up to 21 stations were sampled over four time periods (39 sampling days) from May to August. This survey marks 10 consecutive years of systematic monitoring on how juvenile salmon interact in marine ecosystems, and was implemented to identify the relationships among biophysical parameters that influence the habitat use, marine growth, predation, stock interactions, and year-class strength of salmon. Typically, at each station, fish, zooplankton, surface water samples, and physical profile data were collected using a surface rope trawl, conical and bongo nets, water sampler, and a conductivity-temperature-depth profiler during daylight. Surface (3-m) temperatures and salinities ranged from 7.1 to 15.4 ºC and 15.1 to 32.0 PSU from May to August. A total of 10,641 fish and squid, representing 20 taxa, were captured in 94 rope trawl hauls from June to August. Juvenile salmon comprised about 98% of the total fish and squid catch in each region. Juvenile salmon occurred frequently in the trawl hauls, with pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho salmon (*O. kisutch*) occurring in 52-100% of the trawls in both regions, whereas, juvenile Chinook salmon (*O. tshawytscha*) occurred in 25% and 28% of the hauls in the southern and northern regions. Of the 10,451 salmonids caught, over 99% were juveniles. In both regions, only two non-salmonid species represented catches of >27 individuals: walleye pollock (*Theragra chalcogramma*) in the southern region and Pacific herring (*Clupea pallasi*) in the northern region. Temporal and spatial differences were observed in the catch rates, size, condition, and stock of origin of juvenile salmon species. Catch rates of juvenile salmon in both regions were generally highest in June for all species except Chinook, which had the highest catch rates in July. Size of juvenile salmon increased from June and July; mean fork lengths were: 102 and 121 mm for pink; 112 and 138 mm for chum; 110 and 131 mm for sockeye; 168 and 200 mm for coho; and 202 and 223 mm for Chinook salmon. Coded-wire tags were recovered from 13 juvenile coho salmon, two juvenile and one immature Chinook salmon; all but two were from hatchery and wild stocks of southeastern Alaska origin. The non-Alaska stocks were juvenile Chinook salmon originating from the Similkameen River and the Wells Hatchery within the Columbia River Basin. Alaska enhanced stocks were also identified by thermal otolith marks from 77% of the chum and 7% of the sockeye salmon. Onboard stomach analysis of 95 potential predators, representing 12 species, revealed one predation incident on juvenile salmon by an adult coho salmon. This research suggests that in southeastern Alaska, juvenile salmon exhibit seasonal patterns of habitat use and

display species- and stock-dependent migration patterns. Long-term monitoring of key stocks of juvenile salmon, on both intra- and interannual bases, will enable researchers to understand how growth, abundance, and ecological interactions affect year-class strength and to better understand the role salmon play in North Pacific marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Wing, B. L., Wertheimer, A. C. & Heard, W. R. (2008). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2007. *North Pacific Anadromous Fish Commission Document*, 1110, 82 pp.

Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated biophysical data were collected along primary marine migration corridors in the northern and southern regions of southeastern Alaska in 2007. Up to 17 stations were sampled in epipelagic waters over four time periods (27 sampling days) from May to August. This survey marks 11 consecutive years of systematically monitoring how juvenile salmon interact in marine ecosystems, and was implemented to identify the relationships among biophysical parameters that influence the habitat use, marine growth, predation, stock interactions, and year-class strength of salmon. Typically, at each station, fish, zooplankton, surface water samples, and physical profile data were collected using a surface rope trawl, conical and bongo nets, water sampler, and a conductivity-temperature-depth profiler during daylight. Surface (3-m) temperatures and salinities ranged from 7.7 to 15.3 ºC and 12.3 to 30.6 PSU from May to August. A total of 48,170 fish and squid, representing 17 taxa, were captured in 97 rope trawl hauls from June to August. Juvenile salmon comprised about 7% of the total fish and squid catch. Juvenile salmon occurred frequently in the trawl hauls, with pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho salmon (*O. kisutch*) present in 51-92% of the trawls in the southern and northern regions, whereas juvenile Chinook salmon (*O. tshawytscha*) occurred in about 23% of the hauls. Of the 3,412 salmonids caught, over 97% were juveniles. Only two non-salmonid species represented catches of >30 individuals in either region: Pacific herring (*Clupea pallasi*) in the southern region (n = 44,637) and crested sculpin (*Blepsias bilobus*) in the northern region (n = 34). Catch rates of juvenile salmon in both regions were generally highest in June for all species except pink salmon. However, in the more extended, 11-yr time series in the northern region, juvenile pink salmon catches were among the lowest observed in June and July 2007, suggesting a poor adult return in the subsequent year. Mean size of juvenile salmon generally increased from June to July; however, condition residuals were lower than the long-term average for most species. Coded-wire tags were recovered from 14 juvenile coho salmon and five Chinook salmon (1 juvenile and 4 immature). All but one fish were from hatchery and wild stocks originating in southeastern Alaska. The non-Alaskan stock was a Chinook salmon that originated from the Upper Columbia River. Alaska enhanced stocks were also identified by thermal otolith marks from 67% of the chum and 4% of the sockeye salmon examined. Onboard stomach analysis of 95 potential predators, representing 8 species, did not provide evidence of predation on juvenile salmon. This research suggests that in southeastern Alaska, juvenile salmon exhibit seasonal patterns of habitat use and display species- and stock-dependent migration patterns. This third season of comparing

biophysical parameters between the northern and southern regions of southeastern Alaska suggests that summer conditions differ between the regions. Long-term monitoring of key stocks of juvenile salmon, on seasonal and interannual time scales, will enable researchers to understand how growth, abundance, and ecological interactions affect year-class strength of salmon and to better understand their role in North Pacific marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Wing, B. L., Wertheimer, A. C. & Heard, W. R. (2009). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2008. *North Pacific Anadromous Fish Commission Document*, 1181, 72 pp.

Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated biophysical data were collected from the marine waters of the northern region of southeastern Alaska in 2008. This annual survey marks 12 consecutive years of systematically monitoring how juvenile salmon interact in marine ecosystems, and was implemented to identify the relationships among biophysical parameters that influence habitat use, marine growth, predation, stock interactions, and year-class strength of juvenile salmon. This report summarizes findings from the 2008 survey year, and contrasts these findings to selected biophysical parameters of the prior 11 sampling years. Up to 13 stations were sampled in epipelagic waters over four time periods (20 sampling days) from May to August. Typically, at each station, fish, zooplankton, surface water samples, and physical profile data were collected during daylight using a surface rope trawl, conical and bongo nets, water sampler, and a conductivity-temperature-depth profiler. Surface (3-m) temperatures and salinities ranged from 6.8 to 11.6 ºC and 18.2 to 32.0 PSU from May to August. A total of 5,186 fish, representing 16 taxa, were captured in 56 rope trawl hauls from June to August. Juvenile salmon comprised about 97% of the total fish catch. Juvenile salmon occurred frequently in the trawl hauls, with pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho salmon (*O. kisutch*) present in 66-86% of the trawls, whereas juvenile Chinook salmon (*O. tshawytscha*) occurred less commonly, in about 39% of the hauls. Exceptionally few juvenile salmon were captured in June. Peak monthly catch rates of juvenile salmon differed by species: pink, chum, and coho were highest in July, whereas sockeye and Chinook were highest in August. Coded-wire tags were recovered from 11 juvenile coho salmon and three Chinook salmon (one juvenile and two immature). All fish were from hatchery and wild stocks originating in southeastern Alaska. Alaska enhanced stocks were also identified by thermal otolith marks from 39% of the chum and 4% of the sockeye salmon examined. Onboard stomach analysis of 20 potential predators, representing four species, did not provide evidence of predation on juvenile salmon. Biophysical measures from 2008 differed from prior years, in many respects. Integrated (20-m) temperatures and salinities were anomalously low and zooplankton densities were anomalously high in 2008. In addition, for most juvenile salmon species, unusual CPUE patterns, small fish size, and low condition residuals suggested that migration timing shifted to later than average. Long-term monitoring of key stocks of juvenile salmon, on seasonal and interannual time scales, will enable researchers to understand how growth, abundance, and ecological interactions affect

year-class strength of salmon and to better understand their roles in North Pacific marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Wing, B. L., & Heard, W. R. (2010). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2009. ***North Pacific Anadromous Fish Commission Document*****, 1280, 83 pp.**

Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated biophysical data were collected from the marine waters of the northern and southern regions of southeastern Alaska in 2009. This annual survey marks 13 consecutive years of systematically monitoring how juvenile salmon interact in marine ecosystems, and was implemented to identify the relationships among biophysical parameters that influence habitat use, marine growth, predation, stock interactions, and year-class strength of juvenile salmon. This report also contrasts the 2009 findings with selected biophysical parameters from the prior 12 sampling years. Up to 17 stations were sampled in epipelagic waters over four time periods (20 sampling days) from May to August. Typically, at each station, fish, zooplankton, surface water samples, and physical profile data were collected during daylight using a surface rope trawl, conical and bongo nets, a water sampler, and a conductivity-temperature-depth profiler. Surface (3-m) temperatures and salinities ranged from approximately 8 to 15 ºC and 19 to 31 PSU from May to August. Nearly 11,000 fish, representing 12 taxa, were captured in 60 rope trawl hauls in July and August in the two regions. No trawling was conducted in June, in contrast to all other years. Juvenile salmon comprised about 97% of the total fish catch. Juvenile pink (*O.gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho salmon (*O. kisutch*) occurred in 56-98% of the trawls, while juvenile Chinook salmon (*O. tshawytscha*) occurred in < 13% of the hauls. All juvenile salmon species occurred more frequently in northern region trawls than in southern region trawls in July. In the northern region, catch rates of juvenile pink, chum, and coho salmon were higher in July than in August, whereas catches of sockeye salmon were higher in August. Coded-wire tags were recovered from 18 juvenile coho salmon from hatchery and wild stocks originating in southeastern Alaska. Alaska enhanced stocks were also identified by thermal otolith marks from 47% of the chum and 18% of the sockeye salmon examined. Onboard stomach analysis of 108 potential predators, representing seven species, did not provide evidence of predation on juvenile salmon. Biophysical measures from 2009 differed from prior years, in many respects. Integrated (20-m) temperature anomalies were all positive and salinity anomalies were negative; in particular, the May temperature anomaly was the 2nd highest on record. Anomalies of zooplankton total density were positive each month, a trend which has persisted for four years. In addition, size anomalies for juvenile salmon were positive, a shift from the previous two years. Condition residual anomalies were unusually high for juvenile salmon species in August. These data, in conjunction with basin-scale biophysical parameters, are currently being used to forecast pink salmon harvest in southeastern Alaska. Long-term monitoring of key stocks of juvenile salmon, on seasonal and interannual time scales, will enable researchers to understand how growth, abundance, and ecological interactions affect year-class strength of salmon and to better understand their roles in North Pacific marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Heard, W. R., & Farley Jr., E. V. (2011). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2010. *North Pacific Anadromous Fish Commission Document*, 1342, 87 pp.

Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated environmental (biophysical) data were collected from the marine waters of the northern region of southeastern Alaska in 2010. This annual survey, conducted by the Southeast Coastal Monitoring (SECM) project, marks 14 consecutive years of systematically monitoring how juvenile salmon utilize in marine ecosystems, and was implemented to identify the relationships among biophysical parameters that influence habitat use, marine growth, predation, stock interactions, and year-class strength of juvenile salmon. This report also contrasts the 2010 findings with selected biophysical parameters from the prior 13 sampling years. Up to 13 stations were sampled in epipelagic waters monthly, totaling 21 sampling days, from May to August. Fish, zooplankton, surface water samples, and physical profile data were typically collected during daylight at each station using a surface rope trawl, conical and bongo nets, a water sampler, and a conductivity-temperature-depth profiler. Surface (3-m) temperatures and salinities ranged from approximately 9 to 14 ºC and 17 to 32 PSU from May to August. More than 39,000 fish, representing 26 taxa, were captured in 67 rope trawl hauls fished from June to August. Juvenile salmon comprised about 97% of the total fish catch. Juvenile pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) salmon occurred in 71-87% of the trawls, while juvenile Chinook salmon (*O. tshawytscha*) occurred in 9% of the hauls. Unusually high numbers of juvenile salmon were captured in strait habitat in both June and July, although CPUE was greatest in June for all species except sockeye salmon. Coded-wire tags were recovered from 15 juvenile coho salmon and one juvenile Chinook salmon from hatchery and wild stocks originating in southeastern Alaska and Washington. Alaska enhanced stocks were also identified by thermal otolith marks from 67% of the chum and 16% of the sockeye salmon examined. Onboard stomach analysis revealed predation on highly abundant juvenile salmon by adult coho salmon, a common predator, and adult pink salmon, a rare predator. Biophysical measures from 2010 differed from prior years, in many respects. May integrated (20-m) temperature anomalies were generally positive and salinity anomalies were generally negative; in particular, the positive May temperature anomaly was the highest on record. Zooplankton monthly total densities were near longterm averages, reversing the trend for strongly positive anomalies over the past four years. For juvenile pink, chum, and sockeye salmon, low condition residuals in June were followed by small size and low energy density in July. Regional biophysical data from SECM are used in conjunction with basin-scale biophysical parameters to forecast pink salmon harvest in southeastern Alaska. Longterm monitoring of key stocks of juvenile salmon, on seasonal and interannual time scales, will enable researchers to understand how growth, abundance, and ecological interactions affect year-class strength of salmon and to better understand their roles in North Pacific marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, M. V., Heard, W. R., & Farley Jr., E. V. (2012).

Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2011. *North Pacific Anadromous Fish Commission Document*, 1428, 102 pp.
Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and associated biophysical data were collected from the marine waters of the northern region of southeastern Alaska (SEAK) in 2011. This annual survey, conducted by the Southeast Coastal Monitoring (SECM) project, marks 15 consecutive years of systematically monitoring how juvenile salmon utilize marine ecosystems during a period of climate change. The survey was implemented to identify the relationships between year-class strength of juvenile salmon and biophysical parameters that influence their habitat use, marine growth, prey fields, predation, and stock interactions. This report also contrasts the 2011 findings with selected biophysical factors from the prior 14 sampling years. Thirteen stations were sampled monthly in epipelagic waters from May to August (total of 21 sampling days). Fish, zooplankton, surface water samples, and physical profile data were typically collected during daylight at each station using a surface rope trawl, Norpac and bongo nets, a water sampler, and a conductivity-temperature-depth profiler. Surface (3-m) temperatures and salinities ranged from approximately 6 to 14 ºC and 15 to 32 PSU, respectively, from May to August across inshore, strait, and coastal habitats. A total of 6,640 fish and squid, representing 27 taxa, were captured in 96 rope trawl hauls fished from June to August. Juvenile salmon comprised approximately 78% of the total fish catch. Juvenile pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) salmon occurred in 42-80% of the hauls by month and habitat, while juvenile Chinook salmon (*O. tshawytscha*) occurred in ≤ 17% of the hauls. Abundance of juvenile salmon was relatively low in 2011; peak catch-per-unit-effort (CPUE) in strait habitat occurred in August for all species except chum salmon (June). Coded-wire tags were recovered from 10 coho salmon and 6 Chinook salmon from hatchery and wild stocks originating in SEAK and Washington. Alaska enhanced stocks were also identified by thermal otolith marks from 60%, 21%, and 5% of chum, sockeye, and coho salmon examined, respectively. Predation on juvenile salmon was observed in 3 of 9 species examined. Biophysical measures from 2011 differed from prior years, in many respects. Compared to the 15-yr longterm mean values, temperature anomalies were negative, salinity anomalies were positive, zooplankton density was low, and condition residuals were negative forjuvenile pink, chum, and sockeye salmon. The SECM juvenile salmon stock assessment and biophysical data are used in conjunction with basin-scale biophysical data to forecast pink salmon harvest in SEAK. Longterm seasonal monitoring of key stocks of juvenile salmon and associated ecologically-related species, including fish predators and prey, permits researchers to understand how growth, abundance, and interactions affect year-class strength of salmon during climate change in marine ecosystems.

Orsi, J. A., Fergusson, E. A., Sturdevant, Farley Jr., E. V. & Heintz, R. (2013). Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of Southeastern Alaska, May– August 2012. *North Pacific Anadromous Fish Commission Document*, 1485, 92 pp.
Juvenile Pacific salmon (*Oncorhynchus* spp.), ecologically-related species, and

associated bio physical data were collected from the marine waters of the northern region of southeastern Alaska (SEAK) in 2012. This annual survey, conducted by the Southeast Coastal Monitoring (SECM) project, marks 16 consecutive years of systematically monitoring how juvenile salmon utilize marine ecosystems during a period of climate change. The survey was implemented to identify the relationships between year-class strength of juvenile salmon and biophysical parameters that influence their habitat use, marine growth, prey fields, predation, and stock interactions. Thirteen stations were sampled monthly in epipelagic waters from May to August (total of 23 sampling days). Fish, zooplankton, surface water samples, and physical profile data were typically collected during daylight at each station using a surface rope trawl, Norpac and bongo nets, a water sampler, and a conductivity-temperature-depth profiler. Surface (3-m) temperatures and salinities ranged from approximately 7 to 14 ºC and 16 to 32 PSU across inshore, strait, and coastal habitats for the four months. A total of 46,144 fish and squid, representing 29 taxa, were captured in 96 rope trawl hauls fished from June to August. Juvenile salmon comprised approximately 96% of the total fish catch. Juvenile pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) salmon occurred in 73-84% of the hauls by month and habitat, while juvenile Chinook salmon (*O. tshawytscha*) occurred in 20% of the hauls. Abundance of juvenile salmon was high in 2012; peak CPUE occurred in July in strait habitat and in August in coastal habitat. Coded-wire tags were recovered from 27 coho salmon and 6 Chinook salmon, mainly including hatchery and wild stocks originating in SEAK and captured in strait habitat; an additional 18 adipose-clipped individuals without tags (presumably originating from the Pacific Northwest) were recovered mainly in coastal habitat. Alaska enhanced stocks comprised 71%, 30%, and 9% of chum, sockeye, and coho salmon, respectively. Predation on juvenile salmon was observed in 3 of 9 fish species examined. The longterm seasonal time series of SECM juvenile salmon stock assessment and biophysical data is used in conjunction with basin-scale ecosystem metrics to annually forecast pink salmon harvest in SEAK. Longterm seasonal monitoring of key stocks of juvenile salmon and associated ecologically-related species, including fish predators and prey, permits researchers to understand how growth, abundance, and interactions affect year-class strength of salmon during climate change in marine ecosystems.

Orsi, J. A., Harding, J. A., Pool, S. S., Brodeur, R. D., Haldorson, L. J., Murphy, J. M., Moss, J. H., Farley Jr, E. V., Sweeting, R. M., Morris, J. F. T., Trudel, M., Beamish, R. J., Emmett, R. L., & Fergusson, E. A. (2007). Epipelagic fish assemblages associated with juvenile Pacific salmon in neritic waters of the California Current and the Alaska Current. In *American Fisheries Society Symposium, 57,* 105-155
We compared epipelagic fish assemblages associated with juvenile (ocean-age 0) Pacific salmon *Oncorhynchus* spp. from neritic waters of the California Current and Alaska Current regions in the spring–summer and summer–fall periods of 2000–2004. Catches originated from rope trawl surveys conducted between latitudes37°N and 60°N and spanned more than 1,100 km in the coastal and inshore habitats of each region. Catch data were used from the epipelagic sampling of waters from near surface to depths of about 18 m, primarily over the continental shelf. Catch composition, frequency of occurrence, and density were evaluated between regions and habitats for day sampling. Diel (night and day) catch comparisons were also made at a few localities in each region.

In day catches from both regions, a total of 1.69 million fish and squid representing 52 fish families and 118 fish species were sampled from 2,390 trawl hauls. Ninety-seven percent of the daytime catch was composed of 11 fish families and squid in coastal and inshore habitats of each region: clupeids dominated catches in the California Current (72% and 76% of catch, respectively), and salmonids dominated catches in the Alaska Current (46% and 62% of catch, respectively). Juveniles comprised 81–99% of salmon sampled in both coastal and inshore habitats of each region. Frequencies of occurrence were highest for juvenile salmon in both regions, but average densities were highest for Pacific herring *Clupea pallasii* and Pacific sardine *Sardinops sagax* in the California Current region. Cluster analyses revealed distinct geographic breakpoints in coastal species assemblages off central Vancouver Island and in inshore species assemblages in southeastern Alaska. Species were found to cluster into six groups from coastal localities and four groups from inshore localities. Indicator species analysis and nonmetric multidimensional scaling revealed that most species of juvenile salmonids were located in northern localities. Although juvenile salmon had the most uniform distribution of any species group, their densities relative to associated species were dramatically lower in the California Current, suggesting a higher degree of interactions between juvenile salmon and other species in this region. Diel comparisons in both regions indicated substantially higher catches at night, particularly of clupeids, osmerids, and gadids. Salmonids were a relatively minor component of the night catch in both regions due to dramatic diel shifts in community structure. Additional study of diel interactions of juvenile salmon and associated species is needed to quantify habitat utilizationdynamics in marine ecosystems.

Osterback, A.-M. K., Frechette, D. M., Shelton, A. O., Hayes, S. A., Bond, M. H., Shaffer, S.

A., & Moore, J. W. (2013). High predation on small populations: avian predation on imperiled salmonids. *Ecosphere*, *4*(9), art116. doi:10.1890/ES13-00100.1

Generalist predators can contribute to extinction risk of imperiled prey populations even through incidental predation. Quantifying predation on small populations is important to manage their recovery, however predation is often challenging to observe directly. Recovery of prey tags at predator colonies can indirectly provide minimum estimates of predation, however overall predation rates often remain unquantifiable because an unknown proportion of tags are deposited off-colony. Here, we estimated overall predation rates on threatened wild juvenile steelhead (*Oncorhynchus mykiss*) by generalist adult Western Gulls (*Larus occidentalis*) in six central California (USA) watersheds. We estimated predation rates by gulls from the recapture of PIT (passive integrated transponder) tags that were originally inserted into steelhead and were subsequently deposited at a Western Gull breeding colony, Año Nuevo Island (ANI). We combined three independent datasets to isolate different processes: (1) the probability a tagged steelhead was consumed during predation, (2) the probability a consumed tag was transported to ANI, and (3) the probability a transported tag was detected at ANI. Together, these datasets parameterized a hierarchical Bayesian model to quantify overall predation rates while accounting for tag loss between when prey were tagged and subsequent tag detection at ANI. Results from the model suggest that low recovery rates of PIT tags from steelhead at ANI were mostly driven by low probabilities of

transportation (≤0.167) of consumed tags to ANI. Low transportation probabilities equate to high per-capita probabilities of predation (≥0.306/yr) at the three watersheds in closest proximity to ANI, whereas predation rates were uncertain at watersheds farther from ANI due to very low transportation rates. This study provides the first overall estimate of Western Gull predation rates on threatened wild juvenile steelhead and suggests gull predation on salmonids is a larger source of mortality than was previously estimated from minimum predation rates. This study thus represents an important example of high rates of incidental predation by a generalist consumer on an imperiled prey and provides a quantitative framework to inform robust estimates of predation rates on small populations that can be applied to other systems where direct observation of predation is not feasible.

Parsons, T. R., & Whitney, F. A. (2012). Did volcanic ash from Mt. Kasatoshi in 2008 contribute to a phenomenal increase in Fraser River sockeye salmon (*Oncorhynchus nerka*) in 2010? *Fisheries Oceanography*, *21*(5), 374–377. doi:10.1111/j.1365-2419.2012.00630.x

The effect of a widely distributed phytoplankton bloom triggered by volcanic ash from Alaska (Hamme et al., 2010. *Geophys. Res. Lett. 37*) on juvenile Fraser River sockeye is discussed in terms of the timing of ocean migration and trophic structure of the Gulf of Alaska. Our hypothesis is that the occurrence of a massive diatom bloom in the Gulf greatly enhanced energy ascendancy in the ocean at a time of year when adolescent sockeye migrated from the coast in 2008. We contend this increase in food availability was an important factor for the survival and growth of juvenile sockeye which led to one of the strongest sockeye returns on record in 2010 of 34 million, compared with perhaps the weakest return on record of 1.7 million the previous year.

Patanasatienkul, T., Sanchez, J., Rees, E., Krkošek, M., Jones, S., & Revie, C. (2013). Sea lice infestations on juvenile chum and pink salmon in the Broughton Archipelago, Canada, from 2003 to 2012. *Diseases of Aquatic Organisms*, *105*(2), 149–161. doi:10.3354/dao02616

Juvenile pink salmon *Oncorhynchus gorbuscha* and chum salmon *O. keta* were sampled by beach or purse seine to assess levels of sea lice infestation in the Knight Inlet and Broughton Archipelago regions of coastal British Columbia, Canada, during the months of March to July from 2003 to 2012. Beach seine data were analyzed for sea lice infestation that was described in terms of prevalence, abundance, intensity, and intensity per unit length. The median annual prevalence for chum was 30%, ranging from 14% (in 2008 and 2009) to 73% (in 2004), while for pink salmon, the median was 27% and ranged from 10% (in 2011) to 68% (in 2004). Annual abundance varied from 0.2 to 5 sea lice per fish with a median of 0.47 for chum and from 0.1 to 3 lice (median 0.42) for pink salmon. Annual infestation followed broadly similar trends for both chum and pink salmon. However, the abundance and intensity of *Lepeophtheirus salmonis* and *Caligus clemensi*, the 2 main sea lice species of interest, were significantly greater on chum than on pink salmon in around half of the years studied. Logistic regression with random effect was used to model prevalence of sea lice infestation for the combined beach and purse seine data. The model suggested inter-annual variation as well as a spatial clustering effect on the prevalence of sea lice infestation in both chum and pink salmon. Fish length had an effect on prevalence, although the nature of this effect differed

according to host species.

Peacock, S. J., Connors, B. M., Krkošek, M., Irvine, J. R., & Lewis, M. A. (2014). Can reduced predation offset negative effects of sea louse parasites on chum salmon? *Proceedings of the Royal Society B: Biological Sciences*, *281*(1776), 20132913. doi:10.1098/rspb.2013.2913

The impact of parasites on hosts is invariably negative when considered in isolation, but may be complex and unexpected in nature. For example, if parasites make hosts less desirable to predators then gains from reduced predation may offset direct costs of being parasitized. We explore these ideas in the context of sea louse infestations on salmon. In Pacific Canada, sea lice can spread from farmed salmon to migrating juvenile wild salmon. Low numbers of sea lice can cause mortality of juvenile pink and chum salmon. For pink salmon, this has resulted in reduced productivity of river populations exposed to salmon farming. However, for chum salmon, we did not find an effect of sea louse infestations on productivity, despite high statistical power. Motivated by this unexpected result, we used a mathematical model to show how a parasite-induced shift in predation pressure from chum salmon to pink salmon could offset negative direct impacts of sea lice on chum salmon. This shift in predation is proposed to occur because predators show an innate preference for pink salmon prey. This preference may be more easily expressed when sea lice compromise juvenile salmon hosts, making them easier to catch. Our results indicate how the ecological context of host–parasite interactions may dampen, or even reverse, the expected impact of parasites on host populations.

Peacock, S. J., Krkošek, M., Proboszcz, S., Orr, C., & Lewis, M. A. (2012). Cessation of a salmon decline with control of parasites. *Ecological Applications*, *23*(3), 606–620. doi:10.1890/12-0519.1

The resilience of coastal social–ecological systems may depend on adaptive responses to aquaculture disease outbreaks that can threaten wild and farm fish. A nine-year study of parasitic sea lice (*Lepeophtheirus salmonis*) and pink salmon (*Oncorhynchus gorbuscha*) from Pacific Canada indicates that adaptive changes in parasite management on salmon farms have yielded positive conservation outcomes. After four years of sea lice epizootics and wild salmon population decline, parasiticide application on salmon farms was adapted to the timing of wild salmon migrations. Winter treatment of farm fish with parasiticides, prior to the out-migration of wild juvenile salmon, has reduced epizootics of wild salmon without significantly increasing the annual number of treatments. Levels of parasites on wild juvenile salmon significantly influence the growth rate of affected salmon populations, suggesting that these changes in management have had positive outcomes for wild salmon populations. These adaptive changes have not occurred through formal adaptive management, but rather, through multi-stakeholder processes arising from a contentious scientific and public debate. Despite the apparent success of parasite control on salmon farms in the study region, there remain concerns about the long-term sustainability of this approach because of the unknown ecological effects of parasticides and the potential for parasite resistance to chemical treatments.

Peterman, R. M., & Dorner, B. (2012). A widespread decrease in productivity of sockeye salmon (*Oncorhynchus nerka*) populations in western North America. *Canadian*

***Journal of Fisheries and Aquatic Sciences*, *69*(8), 1255–1260. doi:10.1139/f2012-063**
We used data on 64 stocks of sockeye salmon (*Oncorhynchus nerka*) from British Columbia (B.C.), Washington, and Alaska to determine whether recent decreases in abundance and productivity observed for Fraser River, B.C., sockeye have occurred more widely. We found that decreasing time trends in productivity have occurred across a large geographic area ranging from Washington, B.C., southeast Alaska, and up through the Yakutat peninsula, Alaska, but not in central and western Alaska. Furthermore, a pattern of predominantly shared trends across southern stocks and opposite trends between them and stocks from western Alaska was present in the past (1950–1985), but correlations have intensified since then. The spatial extent of declining productivity of sockeye salmon has important implications for management as well as research into potential causes of the declines. Further research should focus on mechanisms that operate at large, multiregional spatial scales, and (or) in marine areas where numerous correlated sockeye stocks overlap.

Peterson, W. T. (2009). Copepod species richness as an indicator of long term changes in the coastal ecosystem of the northern California Current. *CalCOFI Rep*, *50*, 73–81.
Since at least the late 1960s, the coastal waters of the northern California Current have been warming 0.08 C per decade (summer) and 0.06 C per decade (winter. Over the same time period, for summers when the Pacific Decadal Oscillation (PDO) was negative and when zooplankton samples were available for study, copepod species richness increased from 6.9 species during 1969-1973, to 7.8 from 1999-2002, and 8.9 from 2007-08. During summers when PDO was positive, species richness increased from 9.1 (1990-92) to 12.2 (2003-06). The trend towards warmer sea surface temperatures and higher species richness suggests that the coastal branch of the northern California Current receives less water from the cold sub-Arctic Pacific Ocean and more water from the subtropical water mass offshore of Oregon. These changes have been accompanied by a reduction in survival of coho salmon (*Oncorhynchus kisutch*) from the 1970s (range of 6-12%) to an average of 3% over the past decade. Significant correlations between copepod species richness and coho salmon survival suggest that a time series of species richness may be sufficient to create an index for changes in food-chain structure.

Peterson, W. T., Morgan, C. A., Fisher, J. P., & Casillas, E. (2010). Ocean distribution and habitat associations of yearling coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*) salmon in the northern California Current. *Fisheries Oceanography*, *19*(6), 508–525. doi:10.1111/j.1365-2419.2010.00560.x
Yearling juvenile coho and Chinook salmon were sampled on 28 cruises in June and September 1981–85 and 1998–07 in continental shelf and oceanic waters off the Pacific Northwest. Oceanographic variables measured included temperature, salinity, water depth, and chlorophyll concentration (all cruises) and copepod biomass during the cruises from 1998–07. Juvenile salmonids were found almost exclusively in continental shelf

waters, and showed a patchy distribution: half were collected in ~5% of the collections

and none were collected in ~40% of the collections. Variance-to-mean ratios of the

catches were high, also indicating patchy spatial distributions for both species. The salmon were most abundant in the vicinity of the Columbia River and the Washington coast in June; by September, both were less abundant, although still found mainly off Washington. In June, the geographic center-of-mass of the distribution for each species was located off Grays Harbor, WA, near the northern end of our sampling grid, but in September, it shifted southward and inshore. Coho salmon ranged further offshore than Chinook salmon: in June, the average median depth where they were caught was 85.6 and 55.0 m, respectively, and in September it was 65.5 and 43.7 m, respectively. Abundances of both species were significantly correlated with water depth (negatively), chlorophyll (positively) and copepod biomass (positively). Abundances of yearling Chinook salmon, but not of yearling coho salmon, were correlated with temperature (negatively). We discuss the potential role of coastal upwelling, submarine canyons and krill in determining the spatial distributions of the salmon.

Petrosky, C. E., & Schaller, H. A. (2010). Influence of river conditions during seaward migration and ocean conditions on survival rates of Snake River Chinook salmon and steelhead. *Ecology of Freshwater Fish*, *19*(4), 520–536. doi:10.1111/j.1600-0633.2010.00425.x

Improved understanding of the relative influence of ocean and freshwater factors on survival of at-risk anadromous fish populations is critical to success of conservation and recovery efforts. Abundance and smolt to adult survival rates of Snake River Chinook salmon and steelhead decreased dramatically coincident with construction of hydropower dams in the 1970s. However, separating the influence of ocean and freshwater conditions is difficult because of possible confounding factors. We used long time-series of smolt to adult survival rates for Chinook salmon and steelhead to estimate first year ocean survival rates. We constructed multiple regression models that explained the survival rate patterns using environmental indices for ocean conditions and in-river conditions experienced during seaward migration. Survival rates during the smolt to adult and first year ocean life stages for both species were associated with both ocean and river conditions. Best-fit, simplest models indicate that lower survival rates for Chinook salmon are associated with warmer ocean conditions, reduced upwelling in the spring, and with slower river velocity during the smolt migration or multiple passages through powerhouses at dams. Similarly, lower survival rates for steelhead are associated with warmer ocean conditions, reduced upwelling in the spring, and with slower river velocity and warmer river temperatures. Given projections for warming ocean conditions, a precautionary management approach should focus on improving in-river migration conditions by increasing water velocity, relying on increased spill, or other actions that reduce delay of smolts through the river corridor during their seaward migration.

Pinnix, W. D., Nelson, P. A., Stutzer, G., & Wright, K. A. (2013). Residence time and habitat use of coho salmon in Humboldt Bay, California: an acoustic telemetry study. *Environmental Biology of Fishes*, *96*(2-3), 315–323. doi:10.1007/s10641-012-

0038-x
We monitored the movement of coho salmon (*Oncorhynchus kisutch*) smolts with acoustic transmitters from freshwater, through the freshwater/estuary ecotone, through the estuary, and to ocean entry to determine residence time and habitat use in Humboldt Bay, California. Tagged fish were monitored with a fixed receiver network and mobile tracking conducted from a boat. Coho salmon observed during the two-year study resided in Humboldt Bay beginning at least as early as late April and resided through the beginning of July. Coho salmon smolts spent more time in the freshwater/estuary ecotone compared to the lower estuary and spent an average of 10–12 days migrating to Humboldt Bay. Coho salmon smolts resided in Humboldt Bay, a marine embayment, for an average of 15–22 days prior to leaving the bay for the open ocean. Coho salmon smolts, as observed from mobile tracking, used deep channels and channel margins more often than floating eelgrass mats, pilings, and docks. In addition, tagged fish were more often detected in the central portions of Humboldt Bay characterized by deep channels with narrow intertidal margins. There were fewer detections in other portions of the bay characterized by shallow channels with large intertidal mudflats and eelgrass meadows. Relatively short transmitter life (70 days) precluded determining the latest date of coho salmon smolt residency in Humboldt Bay. In addition, tag size limited use to the largest emigrating smolts and may not represent the behaviors of the smaller-sized smolts which were more abundant.

Pool, S. S., Brodeur, R. D., Goodman, N. L., & Daly, E. A. (2008). Abundance, distribution, and feeding patterns of juvenile coho salmon (*Oncorhynchus kisutch*) in the Juan de Fuca Eddy. *Estuarine, Coastal and Shelf Science*, *80*(1), 85–94. doi:10.1016/j.ecss.2008.07.009
The Juan de Fuca Eddy is a seasonal, counter-clockwise gyre off the mouth of the Strait of Juan de Fuca between Washington, USA and British Columbia, Canada that may provide favorable feeding habitat for juvenile coho salmon (*Oncorhynchus kisutch*) during their early marine existence. In late September 2002, physical and biological sampling was conducted along two transects of the eddy region. Surface rope trawling was conducted to capture juvenile salmon and other nekton, along with bongo and neuston net tows to examine potential mesozooplanktonic salmon prey. Presence of the Juan de Fuca Eddy was confirmed with vertical water profiles. In addition, nutrient and chlorophyll *a* concentrations collected from 3-m depth were within the range observed in previous studies within the eddy region. In the mesozooplankton community, euphausiids, chaetognaths, and decapod megalopae were common. In the diet of juvenile coho salmon, euphausiids and decapod megalopae were dominant by percent number, and larval and juvenile fish were dominant by percent weight. Feeding intensity (percent body weight) based on stomach contents was variable, but not significantly different among stations. To compare the Juan de Fuca Eddy region with an upwelling area, we sampled along a transect off La Push (LP), Washington, USA which is south of the eddy. The eddy region was found to be less productive than the LP transect. Nutrients were lower, chlorophyll *a* concentrations were higher, and zooplankton abundance was generally higher along the LP transect than in the eddy region. In addition, more juvenile coho salmon were captured from the LP transect than the eddy region. Prey items in stomachs of salmon from the LP transect were heterogeneous compared to those from the

eddy region. Feeding intensity along the LP transect was slightly lower and more variable than in the eddy region, and differences in feeding intensity among LP stations were significant. In addition, feeding intensities among stations nested within regions were significantly different.

Pool, S. S., Reese, D. C., & Brodeur, R. D. (2012). Defining marine habitat of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, and coho salmon, *O. kisutch*, in the northern California Current System. *Environmental Biology of Fishes*, *93*(2), 233–243. doi:10.1007/s10641-011-9909-9

We investigated habitat use by juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) to identify environmental characteristics that may define their optimal marine habitat. We utilized physical and biological data from four cruises in the northern California Current system from Newport, Oregon, to Crescent City, California, in June and August 2000 and 2002. A non-parametric statistical method was used to analyze and select environmental parameters that best defined ocean habitat for each species. Regression trees were generated for all cruises combined to select the most important habitat variables. Chlorophyll *a* concentration best defined habitat of yearling Chinook salmon, while decapod larvae, salinity, and neuston biovolume defined habitat of yearling coho salmon. Using criteria from the regression tree analysis, GIS maps were produced to show that the habitat of yearling Chinook salmon was widespread over the continental shelf and the habitat of yearling coho salmon was variable and mainly north of Cape Blanco.

Preikshot, D., Beamish, R. J., & Neville, C. M. (2013). A dynamic model describing ecosystem-level changes in the Strait of Georgia from 1960 to 2010. *Progress in Oceanography*, *115*, 28–40. doi:10.1016/j.pocean.2013.05.020

We developed an ecosystem model of the Strait of Georgia which emulates biomass and mortality changes between 1960 and 2009 to study ecosystem mechanisms governing dynamics in fished species and marine mammals. The model uses hindcast annual variation in bottom-up production, fisheries catches and predator-prey dynamics to simulate observed changes in fish, mammal and bird populations in the Strait of Georgia. This model emulates the timing and magnitude of historic changes in biomass and mortality of Coho and Chinook salmon as well as other major species like Pacific herring, orcas, harbour seals, lingcod, spiny dogfish and marine birds. Simulated production trends indicate the Strait of Georgia had relatively high production from the mid-1970s to late 1980s and entered a lower production regime in the early 1990s that has persisted to 2009. The simulations also indicate that the mean trophic level of vertebrates declined over the period 1990 to 2009. This model provides a tool to evaluate potential ecosystem changes in the Strait of Georgia.

Preikshot, D., Beamish, R. J., & Sweeting, R. (2010). Changes in the diet composition of juvenile sockeye salmon in the Strait of Georgia from the 1960s to the present. *North Pacific Anadromous Fish Commission Document*, *1285*, 17 pp.

Studies of the diet of juvenile sockeye salmon in the Strait of Georgia over the past 40 years show a trend of decreasing consumption of copepods and increasing consumption of decapod zooea and larvae. Presently, amphipods and decapods are the dominant prey

items on the diet, representing approximately 60% of a relativey restricted number of items. The dominance of decapods in the diet appeared to be unique among the diets of juvenile salmon examined in other studies. Amphipods were usually the most common diet item in all examined studies of juvenile sockeye salmon diets. Studies of the diets of juvenile sockeye salmon, including our own, provide patchy information about a critical period in the establishment of brood year abundance. More comprehensive studies are needed that monitor the diets of juvenile sockeye salmon throughout the early marine period in relation to the composition of their zooplankton prey items.

Preikshot, D., Beamish, R. J., Sweeting, R. M., Neville, C. M., & Beacham, T. D. (2012). The residence time of juvenile Fraser River sockeye salmon in the Strait of Georgia. ***Marine and Coastal Fisheries*****, *4*(1), 438–449. doi:10.1080/19425120.2012.683235**

Mortality in the early marine period in a particular habitat is related to the severity of the factors causing mortality and the time that juvenile Pacific salmon *Oncorhynchus* spp. spend in the habitat. Juvenile sockeye salmon *O. nerka* produced in the Fraser River rear in the Strait of Georgia immediately upon leaving freshwater. We used catches from trawl and purse seine surveys to develop two estimates of their average residence time in the Strait of Georgia and present a third estimate which pertains to Chilko Lake smolts in particular. The average time between the entry of the last 1% of juvenile sockeye salmon into the Strait of Georgia and the departure of the last juveniles was 54 d. The average time between the point when the maximum number of juvenile sockeye salmon entered the Strait of Georgia and the point when the maximum abundance in the strait occurred was 43 d. Individuals from the Chilko Lake population were shown to spend a minimum of 31–43 d in the Strait of Georgia, indicating that an average residence time of about 43–54 d is plausible.

Price, M. H. H., Glickman, B. W., & Reynolds, J. D. (2013). Prey selectivity of Fraser River sockeye salmon during early marine migration in British Columbia. ***Transactions of the American Fisheries Society*****, *142*(4), 1126–1133. doi:10.1080/00028487.2013.799517**

Mortality of salmon during early marine life has long been thought to be a critical factor in limiting overall abundance. One of the key hypotheses proposed to explain the long-term productivity decline of Canada's iconic Fraser River Sockeye Salmon *Oncorhynchus nerka*, is deficient habitat conditions experienced during early marine life. Our study is a first step towards testing this hypothesis, with an aim of understanding food availability and prey choice of juvenile salmon early in their coastal migration. We investigated zooplankton density, diet composition, and foraging selectivity of juvenile Fraser Sockeye Salmon during the 2009 and 2010 migrations and determined whether the timing of their migration was related to feeding success. Sockeye Salmon diets showed high prey diversity and a preference for euphausiid, amphipod, decapod, terrestrial insect, fish, egg, and cumacean prey. Calanoid copepods, the most abundant available prey, were not strongly selected in either year. Zooplankton densities were highest in the tidally mixed Discovery Passage–Johnstone Strait area. The fish appeared to have an adequate prey resource pool during their early marine migration, and in the 2 years of our study we observed similar feeding success throughout the migration period. Importantly, we found no evidence of food limitations that might indicate that juveniles suffered food

deprivation. Further research is needed to test the generality of these findings, including the potential impacts of warming ocean temperatures on the timing and availability of prey during migration.

Price, M. H. H., Morton, A., & Reynolds, J. D. (2010). Evidence of farm-induced parasite infestations on wild juvenile salmon in multiple regions of coastal British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, *67*(12), 1925–1932. doi:10.1139/F10-105

Salmon farms are spatially concentrated reservoirs of fish host populations that can disrupt natural salmonid host–parasite dynamics. Sea lice frequently infect farm salmon and parasitize sympatric wild juvenile salmonids, with negative impacts on survival in Europe and Pacific Canada. We examined louse parasitism of wild juvenile chum salmon (*Oncorhynchus keta*) and pink salmon (*Oncorhynchus gorbuscha*) from three salmon farming regions in British Columbia (Finlayson, Broughton Archipelago, and Georgia Strait). We compared sites of low and high exposure to farms and included an area without farms (Bella Bella) to assess baseline infection levels. Louse prevalence and abundance were lowest and most similar to natural baseline levels at low-exposure sites and highest at high-exposure sites in all farm regions. A significantly greater proportion of the lice were *Lepeophtheirus salmonis* at high-exposure sites. Exposure to salmon farms was the only consistently significant factor to explain the variation in prevalence data, with a secondary role played by salinity. Our results support the hypothesis that salmon farms are a major source of sea lice on juvenile wild salmon in salmon farming regions and underscore the importance of using management techniques that mitigate threats to wild stocks.

Price, M. H. H., Proboszcz, S. L., Routledge, R. D., Gottesfeld, A. S., Orr, C., & Reynolds, J. D. (2011). Sea louse infection of juvenile sockeye salmon in relation to marine salmon farms on Canada's west coast. *PLoS ONE*, *6*(2), e16851. doi:10.1371/journal.pone.0016851

Background: Pathogens are growing threats to wildlife. The rapid growth of marine salmon farms over the past two decades has increased host abundance for pathogenic sea lice in coastal waters, and wild juvenile salmon swimming past farms are frequently infected with lice. Here we report the first investigation of the potential role of salmon farms in transmitting sea lice to juvenile sockeye salmon (*Oncorhynchus nerka*). Methodology/Principal Findings: We used genetic analyses to determine the origin of sockeye from Canada's two most important salmon rivers, the Fraser and Skeena; Fraser sockeye migrate through a region with salmon farms, and Skeena sockeye do not. We compared lice levels between Fraser and Skeena juvenile sockeye, and within the salmon farm region we compared lice levels on wild fish either before or after migration past farms. We matched the latter data on wild juveniles with sea lice data concurrently gathered on farms. Fraser River sockeye migrating through a region with salmon farms hosted an order of magnitude more sea lice than Skeena River populations, where there are no farms. Lice abundances on juvenile sockeye in the salmon farm region were substantially higher downstream of farms than upstream of farms for the two common species of lice: *Caligus clemensi* and *Lepeophtheirus salmonis*, and changes in their proportions between two years matched changes on the fish farms. Mixed-effects models

show that position relative to salmon farms best explained *C. clemensi* abundance on sockeye, while migration year combined with position relative to salmon farms and temperature was one of two top models to explain *L. salmonis* abundance. Conclusions/Significance: This is the first study to demonstrate a potential role of salmon farms in sea lice transmission to juvenile sockeye salmon during their critical early marine migration. Moreover, it demonstrates a major migration corridor past farms for sockeye that originated in the Fraser River, a complex of populations that are the subject of conservation concern.

Putman, N. F., Scanlan, M. M., Billman, E. J., O'Neil, J. P., Couture, R. B., Quinn, T. P., Lohmann, K. J. Noakes, D. L. G. (2014). An inherited magnetic map guides ocean navigation in juvenile Pacific salmon. *Current Biology*. doi:10.1016/j.cub.2014.01.017

Migratory marine animals exploit resources in different oceanic regions at different life stages, but how they navigate to specific oceanic areas is poorly understood [1, 2 and 3]. A particular challenge is explaining how juvenile animals with no prior migratory experience are able to locate specific oceanic feeding habitats that are hundreds or thousands of kilometers from their natal sites [1, 2, 3, 4, 5, 6 and 7]. Although adults reproducing in the vicinity of favorable ocean currents can facilitate transport of their offspring to these habitats [7, 8 and 9], variation in ocean circulation makes passive transport unreliable, and young animals probably take an active role in controlling their migratory trajectories [10, 11, 12 and 13]. Here we experimentally demonstrate that juvenile Chinook salmon (*Oncorhynchus tshawytscha*) respond to magnetic fields like those at the latitudinal extremes of their ocean range by orienting in directions that would, in each case, lead toward their marine feeding grounds. We further show that fish use the combination of magnetic intensity and inclination angle to assess their geographic location. The "magnetic map" of salmon appears to be inherited, as the fish had no prior migratory experience. These results, paired with findings in sea turtles [12, 13, 14, 15, 16, 17, 18, 19, 20 and 21], imply that magnetic maps are phylogenetically widespread and likely explain the extraordinary navigational abilities evident in many long-distance underwater migrants.

Quinn, T. P., Chamberlin, J., & Brannon, E. L. (2011). Experimental evidence of population-specific marine spatial distributions of Chinook salmon, *Oncorhynchus tshawytscha*. *Environmental Biology of Fishes*, *92*(3), 313–322. doi:10.1007/s10641-011-9841-z

Migratory behavior can be affected by attributes of the animals themselves such as size and growth rate, external factors such as biotic and abiotic features of the environment, and also genetic tendencies. To better understand the role of genetics in the migratory behavior of Chinook salmon, *Oncorhynchus tshawytscha*, we report the results of an experiment in which two populations (University of Washington (UW) hatchery and Elwha River) and their hybrid offspring were reared at, tagged, and released from a single site, the UW hatchery, at a common size and date. The patterns of recoveries in fisheries differed markedly with respect to spatial distribution and also age of the fish. A larger proportion of the Elwha River fish were recovered in Puget Sound in their first year of marine life than the other groups (40.7% vs. 11.2% for UW and 7.0% for the hybrids). The Elwha River fish also showed a higher proportion of northerly recoveries (21.9%)

than UW fish (1.7%), and hybrids showed an intermediate value (8.1%). In contrast, no Elwha River fish were recovered south along the Washington coast compared to 1.3% of the hybrids and 7.7% of the UW fish. The specific mechanisms controlling the migration patterns of the populations remain unclear but the results strongly indicated a genetic influence on distribution patterns.

Quinn, T. P., Shaffer, J. A., Brown, J., Harris, N., Byrnes, C., & Crain, P. (2013). Juvenile Chinook salmon, *Oncorhynchus tshawytscha*, use of the Elwha river estuary prior to dam removal. *Environmental Biology of Fishes*, 1–10. doi:10.1007/s10641-013-0173-z

The estuary of the Elwha River, on Washington's Olympic Peninsula, has been degraded and simplified over the past century from sediment retention behind two large dams, levee construction, and channelization. With the removal of Elwha Dam and initiation of Glines Canyon Dam's removal in fall 2011, sediment deposits will change the estuary and affect anadromous and nearshore marine fishes. Juvenile Chinook salmon commonly use estuaries and the river's population is part of an Evolutionarily Significant Unit listed as Threatened under the U.S. Endangered Species Act. This study reports on monthly sampling in part of the river's estuary from March 2007 through September 2011 to characterize the seasonal changes in relative abundance of yearlings and sub-yearlings, and size distributions prior to dam removal. Most (69 %) of the yearlings were caught in April, when this life history type was released from the hatchery, and to a lesser extent in May (28 %) and June (3 %). Yearlings caught in the estuary were smaller than those released from the hatchery (means: 153 mm ± 28 SD vs. 175 mm ± 5 SD), suggesting more rapid departure by larger fish. Sub-yearlings were much more abundant in the estuary, and were caught from March through November, increasing in mean fork length by 8.7 mm month-1. The hatchery-origin sub-yearlings were not marked externally and so were not distinguishable from natural origin fish. However, 39 % of the sub-yearlings were caught prior to June, when sub-yearlings were released from the hatchery, indicating substantial use of the estuary by natural-origin fish. Thus, even in a reduced state after a century of dam operation, the highly modified estuary was used over many months by juvenile Chinook salmon. The information on juvenile Chinook salmon prior to dam removal provides a basis for comparison to patterns in the future, when the anticipated increase in estuarine complexity may further enhance habitat use by juvenile Chinook salmon.

Rechisky, E. L., Welch, D. W., Porter, A. D., Jacobs, M. C., & Ladouceur, A. (2009). Experimental measurement of hydrosystem-induced delayed mortality in juvenile Snake River spring Chinook salmon (*Oncorhynchus tshawytscha*) using a large-scale acoustic array. *Canadian Journal of Fisheries and Aquatic Sciences*, *66*(7), 1019–1024. doi:10.1139/F09-078

Out-migrating Snake River salmon smolts must pass eight major hydro dams before reaching the Pacific Ocean. Direct mortality at the dams is generally low; however, the cumulative stress caused by dam passage is hypothesized to result in delayed mortality, which occurs beyond the impounded section of the river. We tested the delayed mortality hypothesis by comparing in-river and early ocean survival of hatchery-origin spring Chinook salmon (*Oncorhynchus tshawytscha*) from the Snake River to a mid-Columbia River population that passes through only four dams and has higher smolt to adult return

rates. Smolts >140 mm fork length were implanted with acoustic transmitters and tracked with the Pacific Ocean Shelf Tracking (POST) array to as far as Alaska. There was no detectable difference in survivorship to the first ocean detection line, 274 km beyond the final dam (S_{Snake} = 29% ± 4%, S_{Yakima} = 28% ± 5%), indicating that the survival disparity observed in adult return rates may develop later in the marine life history phase. Our study is the first to estimate survival in the coastal ocean and demonstrates the utility of a large-scale array in testing previously intractable hypotheses.

Rechisky, E. L., Welch, D. W., Porter, A. D., Hess, J. E., & Narum, S. R. (2014). Testing for delayed mortality effects in the early marine life history of Columbia River Basin yearling Chinook salmon. *Marine Ecology Progress Series*, *496*, 159–180. doi:10.3354/meps10692

Juvenile Snake River Chinook salmon *Oncorhynchus tshawytscha* pass through 8 major hydroelectric dams during their >700 km migration to the sea, or are transported downriver to avoid these dams. Both of these anthropogenic processes may decrease fitness and lead to delayed mortality in the estuary and coastal ocean, and thus reduce the rate at which adults return to spawn. Using a large-scale telemetry array, we tested whether there was support for (1) hydrosystem-induced delayed mortality (hydro-DM) of yearlings migrating from the Snake River relative to yearlings migrating from the mid-Columbia River, and (2) transportation-induced delayed mortality (transport-DM) for transported Snake River yearlings relative to yearlings which migrated in-river. We also tested for differential early marine survival between yearlings migrating from the Snake and upper Columbia Rivers. In 2010, seaward migrating yearling Chinook were captured at dam bypasses and origin was based on capture location; in 2011, dam-caught fish were identified using genetic stock identification. Survival of all groups during the initial 750 km, >1 mo long migration through the estuary and coastal ocean to northwestern Vancouver Island ranged between 14 and 19% in 2010 and was lower in 2011 (1.5-8%). We found no support for hydro-DM, as survival of in-river migrating Snake and mid-Columbia River yearlings was indistinguishable. We found mixed results for our transportation study, with no support for transport-DM in 2010, and weak support in 2011. Our study provides further evidence that freshwater management strategies may not increase the rate of Chinook salmon returning to the Snake River if prior freshwater experience has no substantial influence on subsequent survival in the ocean.

Rechisky, E. L., Welch, D. W., Porter, A. D., Jacobs-Scott, M. C., & Winchell, P. M. (2013). Influence of multiple dam passage on survival of juvenile Chinook salmon in the Columbia River estuary and coastal ocean. *Proceedings of the National Academy of Sciences*, *110*(17), 6883–6888. doi:10.1073/pnas.1219910110

Multiple dam passage during seaward migration is thought to reduce the subsequent survival of Snake River Chinook salmon. This hypothesis developed because juvenile Chinook salmon from the Snake River, the Columbia River's largest tributary, migrate >700 km through eight hydropower dams and have lower adult return rates than downstream populations that migrate through only 3 or 4 dams. Using a large-scale telemetry array, we tested whether survival of hatchery-reared juvenile Snake River spring Chinook salmon is reduced in the estuary and coastal ocean relative to a downstream, hatchery-reared population from the Yakima River. During the initial 750-

km, 1-mo-long migration through the estuary and coastal ocean, we found no evidence of differential survival; therefore, poorer adult returns of Snake River Chinook may develop far from the Columbia River. Thus, hydrosystem mitigation efforts may be ineffective if differential mortality rates develop in the North Pacific Ocean for reasons unrelated to dam passage.

Rechisky, E. L., Welch, D. W., Porter, A. D., Jacobs-Scott, M. C., Winchell, P. M., & McKern, J. L. (2012). Estuarine and early-marine survival of transported and in-river migrant Snake River spring Chinook salmon smolts. *Scientific Reports*, *2*. doi:10.1038/srep00448

Many juvenile Snake River Chinook salmon are transported downriver to avoid

hydroelectric dams in the Columbia River basin. As mortality to the final dam is ~50%,

transported fish should return as adults at roughly double the rate of nontransported fish; however, the benefit of transportation has not been realized consistently. "Delayed" mortality caused by transportation-induced stress is one hypothesis to explain reduced returns of transported fish. Differential timing of ocean entry is another. We used a large-scale acoustic telemetry array to test whether survival of transported juvenile spring Chinook is reduced relative to in-river migrant control groups after synchronizing ocean entry timing. During the initial 750 km, 1 month long migration after release, we found no evidence of decreased estuarine or ocean survival of transported groups; therefore, decreased survival to adulthood for transported Chinook is likely caused by factors other than delayed effects of transportation, such as earlier ocean entry.

Reese, C., Hillgruber, N., Sturdevant, M., Wertheimer, A., Smoker, W., & Focht, R. (2009). Spatial and temporal distribution and the potential for estuarine interactions between wild and hatchery chum salmon (*Oncorhynchus keta*) in Taku Inlet, Alaska. *Fishery Bulletin*, *107*(4), 433–450.

We investigated estuarine spatial and temporal overlap of wild and marked hatchery chum salmon (*Oncorhynchus keta*) fry; the latter included two distinct size groups released near the Taku River estuary (Taku Inlet) in Southeast Alaska(early May releases of ~ 1.9 g and late May releases of ~ 3.9 g wet weight). Our objectives were to compare abundance, body size, and condition of wild chum salmon fry and hatchery chum salmon fry raised under early and late rearing strategies in different habitats of Taku Inlet and to document environmental factors that could potentially explain the distribution, size, and abundance of these chum salmon fry. We used a sampling design stratified into inner and outer inlet and neritic and littoral habitats. Hatchery fry were rare in the inner estuary in both years but outnumbered wild fry 20:1 in the outer estuary. Hatchery fry were significantly larger than wild fry in both littoral and neritic samples. Abundances of wild and hatchery fry were positively correlated in the outer inlet, indicating the formation of mixed schools of hatchery and wild fry. Spatial and temporal overlap was greatest between wild and early hatchery fry in the outer inlet in both habitats. The early hatchery release coincided with peak abundances of wild fry in the outer inlet, and the distribution of wild and early hatchery fry overlapped for about three weeks. Our results demonstrate

that the timing of release of hatchery fry may affect interactions with wild fry.

Rensel, J. E., Haigh, N., & Tynan, T. J. (2010). Fraser River sockeye salmon marine survival decline and harmful blooms of *Heterosigma akashiwo*. *Harmful Algae*, *10*(1), 98–115. doi:10.1016/j.hal.2010.07.005

A two-decade decline of Fraser River sockeye salmon, historically the most valuable west coast Canadian and United States salmon fishery, was linked with blooms of the harmful raphidophyte flagellate *Heterosigma akashiwo* in the Strait of Georgia ("Strait"), British Columbia. This region has the most intense and prolonged *Heterosigma* blooms of all B.C. regions analyzed. Marine survival of Chilko stock averaged 2.7% in years when juvenile sockeye salmon seawater migration in the Strait coincided with major *Heterosigma* blooms versus 10.9% in no or minor bloom index years. Since the mid 1990s, September young-of-the-year ("YOY") herring abundance was strongly correlated with marine survival rates of Chilko stock Fraser River sockeye salmon and *Heterosigma* bloom timing in the Strait. Juvenile sockeye salmon and YOY herring co-occur for only six weeks in mid-May through June during initial salmon migration in the Strait. Sockeye salmon marine survival rates were therefore determined in that early period. Fraser River discharge was a bloom-controlling factor with earlier and larger spring and early summer flows linked to major blooms in that period. *Heterosigma* is a most versatile and allelopathic harmful algal bloom species and may adversely affect sockeye salmon through acute and chronic toxicity or food web impoverishment.

Rhodes, L. D., Durkin, C., Nance, S. L., & Rice, C. A. (2006). Prevalence and analysis of *Renibacterium salmoninarum* infection among juvenile Chinook salmon *Oncorhynchus tshawytscha* in North Puget Sound. *Diseases of Aquatic Organisms*, *71*(3), 179–190. doi:10.3354/dao071179

Renibacterium salmoninarum causes bacterial kidney disease (BKD), a chronic and sometimes fatal disease of salmon and trout that could lower fitness in populations with high prevalences of infection. Prevalence of R. salmoninarum infection among juvenile Chinook salmon *Oncorhynchus tshawytscha* inhabiting neritic marine habitats in North Puget Sound, Washington, USA, was assessed in 2002 and 2003. Fish were collected by monthly surface trawl at 32 sites within 4 bays, and kidney infections were detected by a quantitative fluorescent antibody technique (qFAT). The sensitivity of the qFAT was within an order of magnitude of the quantitative real-time PCR (qPCR) sensitivity. Prevalence of infection was classified by fish origin (marked/hatchery vs. unmarked/likely natural spawn), month of capture, capture location and stock origin. The highest percentages of infected fish (63.5 to 63.8%) and the greatest infection severity were observed for fish collected in Bellingham Bay. The lowest percentages were found in Skagit Bay (11.4 to 13.5%); however, there was no difference in prevalence between marked and unmarked fish among the capture locations. The optimal logistic regression model of infection probabilities identified the capture location of Bellingham Bay as the strongest effect, and analysis of coded wire tagged (CWT) fish revealed that prevalence of infection was associated with the capture location and not with the originating stock. These results suggest that infections can occur during the early marine life stages of Chinook salmon that may be due to common reservoirs of infection or horizontal transmission among fish stocks.

Rhodes, L. D., Rice, C. A., Greene, C. M., Teel, D. J., Nance, S. L., Moran, P., Durkin, C. A., Gezhegne, S. B. (2011). Nearshore ecosystem predictors of a bacterial infection in juvenile Chinook salmon. *Marine Ecology Progress Series*, *432*, 161–172. doi:10.3354/meps09160

Disease epidemiology requires information about ecological and environmental conditions to identify factors that can influence disease progression. Bacterial kidney disease (BKD) is an endemic disease among Pacific Northwest salmonids that causes significant morbidity and mortality in artificially propagated stocks, but risk factors for infection among free-living salmon are unknown. We evaluated infection by the causative agent of BKD, *Renibacterium salmoninarum*, in 1752 fish across 52 sampling sites monthly from May to November 2003 as a component of a broader study of neritic habitat use in Puget Sound by juvenile Chinook salmon *Oncorhynchus tshawytscha*. Infection intensity was ≤10 cells per slide for 77% of the fish. Correlations between the density of Chinook salmon with infection prevalence and with infection intensity were observed across multiple spatial scales. Capture location was a stronger predictor of infection than fish origin (based on coded wire tags) or genetic stock. Influential risk factors by logistic regression were temperature, densities of marked and unmarked Chinook salmon, and density of river lamprey *Lampetra ayresis*. *Renibacterium salmoninarum* were found in gut contents and kidney of river lamprey, suggesting this species may be a transmission vector. The low infection intensity, lack of an effect of fish origin, effect of capture bay, and strong associations with Chinook salmon density are consistent with horizontal transmission of *R. salmoninarum* during the juvenile neritic phase, posing a potential for infectious interaction between sympatric hatchery and wild fish.

Rice, C. A., Duda, J. J., Greene, C. M., & Karr, J. R. (2012). Geographic patterns of fishes and jellyfish in Puget Sound surface waters. *Marine and Coastal Fisheries*, *4*(1), 117–128. doi:10.1080/19425120.2012.680403

We explored patterns of small pelagic fish assemblages and biomass of gelatinous zooplankton (jellyfish) in surface waters across four oceanographic subbasins of greater Puget Sound. Our study is the first to collect data documenting biomass of small pelagic fishes and jellyfish throughout Puget Sound; sampling was conducted opportunistically as part of a juvenile salmon survey of daytime monthly surface trawls at 52 sites during May–August 2003. Biomass composition differed spatially and temporally, but spatial differences were more distinct. Fish dominated in the two northern basins of Puget Sound, whereas jellyfish dominated in the two southern basins. Absolute and relative abundance of jellyfish, hatchery Chinook salmon *Oncorhynchus tshawytscha*, and chum salmon *O. keta* decreased with increasing latitude, whereas the absolute and relative abundance of most fish species and the average fish species richness increased with latitude. The abiotic factors with the strongest relationship to biomass composition were latitude, water clarity, and sampling date. Further study is needed to understand the spatial and temporal heterogeneity in the taxonomic composition we observed in Puget Sound surface waters, especially as they relate to natural and anthropogenic influences.

Rice, C. A., Greene, C. M., Moran, P., Teel, D. J., Kuligowski, D. R., Reisenbichler, R. R.,

Beamer, E. M., Karr, J. R., & Fresh, K. L. (2011). Abundance, stock origin, and length of marked and unmarked juvenile Chinook salmon in the surface waters of Greater Puget Sound. *Transactions of the American Fisheries Society*, *140*(1), 170–189. doi:10.1080/00028487.2010.550253

This study focuses on the use by juvenile Chinook salmon *Oncorhynchus tshawytscha* of the rarely studied neritic environment (surface waters overlaying the sublittoral zone) in greater Puget Sound. Juvenile Chinook salmon inhabit the sound from their late estuarine residence and early marine transition to their first year at sea. We measured the density, origin, and size of marked (known hatchery) and unmarked (majority naturally spawned) juveniles by means of monthly surface trawls at six river mouth estuaries in Puget Sound and the areas in between. Juvenile Chinook salmon were present in all months sampled (April–November). Unmarked fish in the northern portion of the study area showed broader seasonal distributions of density than did either marked fish in all areas or unmarked fish in the central and southern portions of the sound. Despite these temporal differences, the densities of marked fish appeared to drive most of the total density estimates across space and time. Genetic analysis and coded wire tag data provided us with documented individuals from at least 16 source populations and indicated that movement patterns and apparent residence time were, in part, a function of natal location and time passed since the release of these fish from hatcheries. Unmarked fish tended to be smaller than marked fish and had broader length frequency distributions. The lengths of unmarked fish were negatively related to the density of both marked and unmarked Chinook salmon, but those of marked fish were not. These results indicate more extensive use of estuarine environments by wild than by hatchery juvenile Chinook salmon as well as differential use (e.g., rearing and migration) of various geographic regions of greater Puget Sound by juvenile Chinook salmon in general. In addition, the results for hatchery-generated timing, density, and length differences have implications for the biological interactions between hatchery and wild fish throughout Puget Sound.

Roegner, G. C., McNatt, R., Teel, D. J., & Bottom, D. L. (2012). Distribution, size, and origin

of juvenile Chinook salmon in shallow-water habitats of the lower Columbia River and estuary, 2002–2007. *Marine and Coastal Fisheries*, *4*(1), 450–472. doi:10.1080/19425120.2012.675982

We monitored fish assemblages monthly at estuarine and tidal freshwater sites in the lower Columbia River and estuary from January 2002 through September 2007 in order to identify specific salmon stocks and migration stages that may benefit from habitat restoration initiatives. We report landscape-scale and seasonal variation in abundance, size, hatchery production (based on adipose fin clips), and genetic stock of origin of juvenile Chinook salmon *Oncorhynchus tshawytscha*. From fish implanted with coded wire tags (CWTs), we also determined the sites of release and inferred migration patterns. Chinook salmon were found in diverse life history stages and forms, including fry migrants, fingerlings, and (fewer) yearlings. Abundance increased in February and decreased in August, but salmon were present in all months each year. Spatial gradients in abundance and size were strong, with fewer but larger fish in brackish than in tidal freshwater zones. Overall, 30% of the Chinook salmon measured were fry (≤60 mm) that were likely naturally produced fish. These occurred at higher mean monthly proportions

in tidal freshwater than in estuarine zones. In contrast, most larger fish were probably raised in hatcheries. Genetic stock assessment revealed that the majority of the Chinook salmon analyzed were from fall-run stock groups originating in the lower Columbia River, with 15% originating from other stock groups. Of these minority contributors, about 6% were identified as upper Columbia River summer–fall-run Chinook salmon while seven other stock groups accounted for the remainder, including 3% from transplants originating in southern Oregon's Rogue River. Recaptures of tagged fish revealed maximum migration times of 143 d for subyearlings and 52 d for yearlings, and both CWT and genetic data indicated that fall Chinook salmon from coastal rivers occasionally entered the estuary. These data demonstrated a widespread temporal and spatial distribution of subyearling Chinook salmon in shallow-water habitats of the lower Columbia River and estuary.

Rogers, L. A., Peacock, S. J., McKenzie, P., DeDominicis, S., Jones, S. R. M., Chandler, P., Foreman, M. G. G., Revie, C. W., & Krkošek, M. (2013). Modeling parasite dynamics on farmed salmon for precautionary conservation management of wild salmon. *PLoS ONE*, *8*(4), e60096. doi:10.1371/journal.pone.0060096

Conservation management of wild fish may include fish health management in sympatric populations of domesticated fish in aquaculture. We developed a mathematical model for the population dynamics of parasitic sea lice (*Lepeophtheirus salmonis*) on domesticated populations of Atlantic salmon (*Salmo salar*) in the Broughton Archipelago region of British Columbia. The model was fit to a seven-year dataset of monthly sea louse counts on farms in the area to estimate population growth rates in relation to abiotic factors (temperature and salinity), local host density (measured as cohort surface area), and the use of a parasiticide, emamectin benzoate, on farms. We then used the model to evaluate management scenarios in relation to policy guidelines that seek to keep motile louse abundance below an average three per farmed salmon during the March–June juvenile wild Pacific salmon (*Oncorhynchus* spp.) migration. Abiotic factors mediated the duration of effectiveness of parasiticide treatments, and results suggest treatment of farmed salmon conducted in January or early February minimized average louse abundance per farmed salmon during the juvenile wild salmon migration. Adapting the management of parasites on farmed salmon according to migrations of wild salmon may therefore provide a precautionary approach to conserving wild salmon populations in salmon farming regions.

Rohde, J., Kagley, A. N., Fresh, K. L., Goetz, F. A., & Quinn, T. P. (2013). Partial migration and diel movement patterns in Puget Sound coho salmon. *Transactions of the American Fisheries Society*, *142*(6), 1615–1628. doi:10.1080/00028487.2013.822421

Partial migration, a term referring to populations in which only a fraction of the individuals migrate, is a widespread phenomenon among fishes. However, it is not always clear whether there are only two alternatives (migration or residency) or a continuum of movement patterns. For example, Coho Salmon *Oncorhynchus kisutch* are anadromous, and most individuals rear over the continental shelf or in offshore waters of the North Pacific Ocean; however, some Coho Salmon (known as residents) spend all or part of their marine lives within Puget Sound. The movements of residents are poorly

documented, and it is unclear whether they ever leave Puget Sound and move to the coast of Washington and to what extent they move within Puget Sound. Accordingly, the goal of this study was to investigate the patterns of movement by immature Coho Salmon in Puget Sound at a series of spatial scales. We tagged 45 resident Coho Salmon in the central basin of Puget Sound with acoustic transmitters and detected their movements with fixed receivers in the Salish Sea. Seven individuals were detected as departing Puget Sound through the Strait of Juan de Fuca, but these fish did not differ in body size, origin (wild or hatchery), or tagging date from fish that remained in Puget Sound. The fish remaining as residents seldom moved between the marine basins of Puget Sound. Within the central basin, deeper/offshore sites had higher frequencies of detection and other indices of site use. Fish were more often present and moved more often at shallow sites close to shore during the night, whereas they were more often present and moved more at deep, offshore sites during the day. We suggest that rather than being a discrete behavior, residence in Puget Sound by Coho Salmon is part of a continuum of migratory behavior patterns.

Romer, J. D., Leblanc, C. A., Clements, S., Ferguson, J. A., Kent, M. L., Noakes, D., & Schreck, C. B. (2013). Survival and behavior of juvenile steelhead trout (*Oncorhynchus mykiss*) in two estuaries in Oregon, USA. *Environmental Biology of Fishes*, *96*(7), 849–863. doi:10.1007/s10641-012-0080-8

Anadromous salmonids are viewed as a prized commodity and cultural symbol throughout the Pacific coast of North America. Unfortunately, several native salmonid populations are threatened or at risk of extinction. Despite this, little is known about the behavior and survival of these fish as the juveniles transition from freshwater to the ocean. Our primary objectives were to estimate survival of juvenile steelhead migrating between trapping sites and the ocean and evaluate whether survival in the estuary varies temporally (within a year) or spatially (within and between estuaries) within the same distinct population segment. We also evaluated whether flow or fork length were correlated with survival and collected information on variables that have been demonstrated to affect smolt survival in other studies to lend insight regarding differences in survival estimates between basins. We compared run timing, migration rate, survival, condition factor, age composition and time of residence in the estuary for steelhead outmigrants from each basin and measured parasite loads in outmigrating steelhead to evaluate potential differences in parasite density and parasite community between basins. In 2009, we implanted acoustic transmitters in 139 wild steelhead smolts in two small rivers on the Oregon Coast. In general, only 40–50 % of the wild steelhead smolts tagged at upstream smolt traps were detected entering the ocean. The majority of mortality occurred in the lower estuary near the ocean. Wild steelhead smolts typically spent less than 1 day in the estuary in both basins. Using similar data from previous studies in the Nehalem and Alsea basins, we showed that survival appears to be negatively correlated with flow in most releases, and in 2009 fork length was not correlated with survival. Our observations provide baseline information on factors that could influence smolt survival through the estuary as well as smolt to adult survival in these basins, and emphasize the importance of monitoring smolt survival in the estuary.

Roni, P., Bennett, T., Holland, R., Pess, G., Hanson, K., Moses, R., McHenry, M., Ehinger,

W., & Walter, J. (2012). Factors affecting migration timing, growth, and survival of juvenile coho salmon in two coastal Washington watersheds. *Transactions of the American Fisheries Society*, *141*(4), 890–906. doi:10.1080/00028487.2012.675895
Recent improvements in tagging technology allow for the examination of the migration of individual fish, the detection of previously unidentified life histories, and the detailed examination of factors affecting growth, migration, and survival. Using passive integrated transponder tags and instream readers installed near tidewater, we examined the migration, growth, and survival of 18,642 juvenile coho salmon *Oncorhynchus kisutch* in two small western Washington rivers from 2005 to 2009. In most years, more than 50% of the juvenile coho salmon from a given brood year migrated to sea between 1 October and 31 December (fall migrants). These fall migrants were significantly smaller at tagging than fish that migrated between 1 January and 30 June (spring migrants) but were similar in size to fish that were never detected after tagging and assumed to have died. Annual coho salmon survival estimates from tagging to out-migration ranged from 31% to 40% for fall and spring migrants combined but from 5% to 15% for spring migrants only. The best fitting regression models indicated that survival differed by river and year and was negatively correlated with tagging location (river kilometer) and positively correlated with fish length: larger fish and those tagged lower in the watershed were more likely to survive. The number of days juvenile coho salmon spent in freshwater before migrating to sea was positively correlated with tagging location, fish length (mm), and habitat depth (m) and negatively with density (coho salmon/m^2). Our results suggest that fall or early winter migration is a common life history for juvenile coho salmon that is driven in part by fish size and location in the watershed. The exclusion of fall migrants may lead to underestimates of the total number of migrants and parr-to-smolt survival.

Ruggerone, G. T., Nielsen, J. L., & Agler, B. A. (2009). Climate, growth and population dynamics of Yukon River Chinook salmon. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 279–285.
Harvests of Yukon Chinook salmon increased in the mid-1970s, then declined during 1998 to 2007 in response to fewer returning salmon. We examined annual growth of age-1.3 and age-1.4 Yukon Chinook salmon scales, 1965–2004, and tested the hypothesis that shifts in Chinook salmon abundance were related to annual growth at sea. Annual scale growth trends were not significantly correlated with salmon abundance indices, sea surface temperature, or climate indices, although growth during the first year at sea appeared to have been affected by the 1977 and 1989 ocean regime shifts. Chinook salmon scale growth was dependent on growth during the previous year, a factor that may have confounded detection of relationships among growth, environmental conditions, and abundance. Scale growth during the second year at sea was greater in odd-numbered years compared with even-numbered years, leading to greater adult length of age-1.3 salmon in odd-numbered years. The alternating-year pattern in Chinook salmon growth was opposite that observed in Bristol Bay sockeye salmon, and it may be related to the higher trophic level of Chinook salmon and indirect competition with pink salmon. This finding highlights the need to investigate alternating-year patterns in salmon growth, prey abundance, and factors that influence these patterns, such as pink salmon.

Ruggerone, G. T., Nielsen, J. L., & Bumgarner, J. (2007). Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955–2002. *Deep Sea Research Part II: Topical Studies in Oceanography*, *54*(23–26), 2776–2793. doi:10.1016/j.dsr2.2007.08.016

We tested the hypothesis that increased growth of salmon during early marine life contributed to greater survival and abundance of salmon following the 1976/1977 climate regime shift and that this, in turn, led to density-dependent reductions in growth during late marine stages. Annual measurements of Bristol Bay (Bering Sea) and Chignik (Gulf of Alaska) sockeye salmon scale growth from 1955 to 2002 were used as indices of body growth. During the first and second years at sea, growth of both stocks tended to be higher after the 1976–1977 climate shift, whereas growth during the third year and homeward migration was often below average. Multiple regression models indicated that return per spawner of Bristol Bay sockeye salmon and adult abundance of western and central Alaska sockeye salmon were positively correlated with growth during the first 2 years at sea and negatively correlated with growth during later life stages. After accounting for competition between Bristol Bay sockeye and Asian pink salmon, age-specific adult length of Bristol Bay salmon increased after the 1976–1977 regime shift, then decreased after the 1989 climate shift. Late marine growth and age-specific adult length of Bristol Bay salmon was exceptionally low after 1989, possibly reducing their reproductive potential. These findings support the hypothesis that greater marine growth during the first 2 years at sea contributed to greater salmon survival and abundance, which in turn led to density-dependent growth during later life stages when size-related mortality was likely lower. Our findings provide new evidence supporting the importance of bottom-up control in marine ecosystems and highlight the complex dynamics of species interactions that continually change as salmon grow and mature in the ocean.

Rupp, D. E., Wainwright, T. C., Lawson, P. W., & Peterson, W. T. (2012). Marine environment-based forecasting of coho salmon (*Oncorhynchus kisutch*) adult recruitment. *Fisheries Oceanography*, *21*(1), 1–19. doi:10.1111/j.1365-2419.2011.00605.x

Generalized additive models (GAMs) were used to investigate the relationships between annual recruitment of natural coho salmon (*Oncorhynchus kisutch*) from Oregon coastal rivers and indices of the physical ocean environment. Nine indices were examined, ranging from large-scale ocean indicators, e.g., Pacific Decadal Oscillation (PDO), to indicators of the local ecosystem (e.g., coastal water temperature near Charleston, OR). Generalized additive models with two and three predictor variables were evaluated using a set of performance metrics aimed at quantifying model skill in short-term (approximately 1 yr) forecasting. High explanatory power and promising forecast skill resulted when the spring/summer PDO averaged over the 4 yr prior to the return year was used to explain a low-frequency (multi-year) pattern in recruitment and one or two additional variables accounted for year-to-year deviations from the low-frequency pattern. More variance was explained when averaging the predictions from a set of models (i.e., taking the ensemble mean) than by any single model. Making multiple forecasts from a set of models also provided a range of possible outcomes that reflected, to some degree, the uncertainty in our understanding of how salmon productivity is driven by physical ocean conditions.

Ruzicka, J. J., Wainwright, T. C., & Peterson, W. T. (2011). A model-based meso-zooplankton production index and its relation to the ocean survival of juvenile coho (*Oncorhynchus kisutch*). *Fisheries Oceanography*, *20*(6), 544–559. doi:10.1111/j.1365-2419.2011.00601.x

The ocean survival of coho salmon (*Oncorhynchus kisutch*) off the Pacific Northwest coast has been related to oceanographic conditions regulating lower trophic level production during their first year at sea. Coastal upwelling is recognized as the primary driver of seasonal plankton production but as a single index upwelling intensity has been an inconsistent predictor of coho salmon survival. Our goal was to develop a model of upwelling-driven meso-zooplankton production for the Oregon shelf ecosystem that was more immediately linked to the feeding conditions experienced by juvenile salmon than a purely physical index. The model consisted of a medium-complexity plankton model linked to a simple one-dimensional, cross-shelf upwelling model. The plankton model described the dynamics of nitrate, ammonium, small and large phytoplankton, meso-zooplankton (copepods), and detritus. The model was run from 1996 to 2007 and evaluated on an interannual scale against time-series observations of copepod biomass. The model's ability to capture observed interannual variability improved substantially when the copepod community size distribution was taken into account each season. The meso-zooplankton production index was significantly correlated with the ocean survival of hatchery coho salmon from the Oregon production area, although the coastal upwelling index that drove the model was not itself correlated with survival. Meso-zooplankton production within the summer quarter (July–September) was more strongly correlated with coho survival than was meso-zooplankton production in the spring quarter (April–June).

Sackville, M., Tang, S., Nendick, L., Farrell, A. P., & Brauner, C. J. (2011). Pink salmon (*Oncorhynchus gorbuscha*) osmoregulatory development plays a key role in sea louse (*Lepeophtheirus salmonis*) tolerance. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(6), 1087–1096. doi:10.1139/f2011-037

Sea lice (*Lepeophtheirus salmonis*) of fish-farm origin have been implicated in reducing populations of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia's Broughton Archipelago. Owing to the physically disruptive nature of louse attachment to fish skin in a hyperosmotic environment, we hypothesize that the impacts on fish performance are ionoregulatory in origin. Therefore, ionoregulatory status was measured in juvenile pink salmon artificially infected in the laboratory and naturally infected in the wild. Body

$[Na^+]$ of laboratory-infected fish (~1 week seawater (SW); 0.2–0.4 g) increased

significantly by 12% with a single chalimus-4 louse, and by 23% with 2–3 chalimus-3 lice. Mortality over this 24-day trial was 2.4% for fish initially infected with 1–3 lice.

Body [Na^+] for fish caught with natural infections (~4–12 weeks SW; 0.5–1.5 g) did not differ from uninfected controls. Combining data sets revealed a "no effect" threshold of 0.5 g for body [Na^+] of fish infected with one chalimus-4 louse. We propose that this size-related louse tolerance is associated with hypo-osmoregulatory development, adding to a previously suggested multifactorial mechanism based on epidermal and immune system development. We suggest management bodies consider this fish-mass threshold when planning to minimize risk to wild fish populations

Saksida, S. M., Greba, L., Morrison, D., & Revie, C. W. (2011). Sea lice on wild juvenile Pacific salmon and farmed Atlantic salmon in the northernmost salmon farming region of British Columbia. *Aquaculture*, *320*(3–4), 193–198. doi:10.1016/j.aquaculture.2011.07.018

The Kitasoo/Xai'xais First Nation established a program to monitor sea lice levels on seaward migrating wild juvenile salmon in their traditional territory which contains the most northerly salmon farming region of British Columbia. A total of 12 locations were routinely sampled during the period between 2005 and 2008 to gain a better understanding of the levels and patterns of sea lice infestation on wild salmonids in the region. Over 5000 juvenile salmon were collected and examined for sea lice. Around 78% were identified as pink salmon, 18% were chum salmon and the remainder classified as "other" salmon (coho and sockeye salmon). Two species of sea lice were observed: *Lepeophtheirus salmonis* and *Caligus clemensi*. Over 91% of all the juvenile salmon examined had no sea lice and there was no significant difference in *L. salmonis* prevalence levels among salmon species. However, chum salmon had significantly lower *C. clemensi* prevalence levels than either pink or "other" salmon. There were significant annual and regional differences in *L. salmonis* prevalence on juvenile pink salmon; the lowest prevalence in all sampling zones occurring in 2008, while channels containing salmon farms consistently had higher levels than those without salmon farms. Mean prevalence of *L. salmonis* in the channels with salmon farms ranged from 2% to 9% which is lower than levels published for the same region in different years or for other areas without salmon farms. *C. clemensi* prevalence on wild pink salmon was associated with sampling zone and the size of pink salmon; larger juvenile fish were more likely to be infected than smaller fish. During the period of wild juvenile salmon migration, the mean abundance of motile stages of *L. salmonis* on farmed salmon ranged from 0.13 to 0.79 lice per fish but there were no significant differences among years. In comparison, *C. clemensi* abundance levels on farms were significantly higher in 2005. Factors contributing to variations in these observations are discussed.

Saksida, S. M., Marty, G. D., Jones, S. R. M., Manchester, H. A., Diamond, C. L., Bidulka, J., & St-Hilaire, S. (2012). Parasites and hepatic lesions among pink salmon, *Oncorhynchus gorbuscha* (Walbaum), during early seawater residence. *Journal of Fish Diseases*, *35*(2), 137–151. doi:10.1111/j.1365-2761.2011.01330.x

Juvenile pink salmon, *Oncorhynchus gorbuscha* (Walbaum), in the Broughton Archipelago region of western Canada were surveyed over 2 years for sea lice

(*Lepeophtheirus salmonis* and *Caligus clemensi*), gross and microscopic lesions and evidence of infections with viruses and bacteria. The 1071 fish examined had an approximate ocean residence time no longer than 3 months. A high prevalence of degenerative liver lesions, renal myxosporean parasites and a low prevalence of skin lesions and sea lice were observed. No indications of viral or bacterial diseases were detected in either year. The monthly prevalence of sea lice in 2007 (18–51%) was higher than in 2008 (1–26%), and the infestation density exceeded the lethal threshold in only two fish. Degenerative hepatic lesions and renal myxosporean parasites occurred in approximately 40% of the pink salmon examined in June of both years, and the peak monthly prevalence of hepatocellular hydropic degeneration was greater in 2007 (32%, in May) than in 2008 (12%, in June). Logistic regression analysis found skin lesions and hepatocellular hydropic degeneration significantly associated with sea lice. Most parasites and lesions occurred during both years, but the prevalence was often higher in 2007. Fish weight was 35% less in June 2007 than in June 2008, but condition factor was not different. Further research is required to monitor inter-annual variations and aetiology of the liver lesions and to assess their potential role on pink salmon survival.

Sandstrom, P. T., Keegan, T., & Singer, G. (2013). Survival and movement patterns of central California coast native steelhead trout (*Oncorhynchus mykiss*) in the Napa River. *Environmental Biology of Fishes*, *96*(2-3), 287–302. doi:10.1007/s10641-012-0092-4

Drawing on acoustic telemetry this study identifies and describes local and regional scale survival and movement patterns of Central California Coast steelhead (*Oncorhynchus mykiss*), including their potential utilization of newly restored tidal marsh habitats in the Napa River system. Between April 8th and May 5th of 2010, 20 steelhead smolts ranging in fork length from 164 to 305 mm were collected, tagged with acoustic transmitters, and released in the upper Napa River (above tidal influence). We found no effect of release date ($P < 0.001$) or size ($P < 0.005$) on survival estimates based on model likelihoods. Cumulative survival from smolt release location to the Golden Gate Bridge over approximately 77 river kilometers (RKM) was 0.60 (SE = 0.16). Reach-specific survival was lowest in the initial 30 km reach (0.70 SE = 0.1). Survival was higher in San Pablo Bay (0.89 SE = 0.1) and San Francisco Bay (0.96 SE = 0.2). Sixty percent of the fish that entered the ocean were detected on a line of acoustic monitors at Point Reyes approximately 60 km north of the Golden Gate. Average movement rates of smolts were highest in San Pablo Bay (36.6 km·d-1 SE = 3.3) and San Francisco Bay (28.9 $km \cdot d^{-1}$ SE = 6.6). Smolts migrated more slowly in the river (9.0 $km \cdot d^{-1}$ SE = 0.9) and ocean (4.1 $km \cdot d^{-1}$ SE = 1.2). However, smolt movement rates in the river were dependent on location. Average movement rates of smolts were greatest shortly before their exit from the Napa River (83 $km \cdot d^{-1}$ SE = 13.2). Fish were not detected within the recently reconnected former salt production ponds (North, Central, and South units) adjacent to the Napa River. Based on the detection patterns of fish throughout the study area, it appears that most fish were moving at relatively high rates and were not exploring off-channel habitat.

Scheuerell, M. D., Zabel, R. W., & Sandford, B. P. (2009). Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon

(*Oncorhynchus* spp.). *Journal of Applied Ecology*, *46*(5), 983–990. doi:10.1111/j.1365-2664.2009.01693.x

1. Migration timing in animals has important effects on life-history transitions. Human activities can alter migration timing of animals, and understanding the effects of such disruptions remains an important goal for applied ecology. Anadromous Pacific salmon (*Oncorhynchus* spp.) inhabit fresh water as juveniles before migrating to the ocean where they gain >90% of their biomass before returning to fresh water as adults to reproduce. Although construction of dams has delayed juvenile migration for many populations, we currently lack a synthesis of patterns in migration timing and how they relate to subsequent survival to adulthood for Pacific salmon, especially for at-risk populations. 2. We studied two groups of Pacific salmon from the Columbia River basin in the northwestern United States currently listed under the U.S. Endangered Species Act. We examined how the proportion of juveniles surviving to return as adults varied with year of migration, date of arrival in the estuary, water temperature and coastal ocean upwelling using data from over 40 000 individually tagged Chinook salmon *Oncorhynchus tshawytscha* and steelhead *Oncorhynchus mykiss*. 3. In general, models with year, day and day^2 had much better support from the data than those with temperature and upwelling. For Chinook salmon, we also found a residual effect of temperature after controlling for day, but the effect was small for steelhead. 4. For both species, juveniles migrating from early to mid-May survived 4–50 times greater than those migrating in mid-June. As expected, however, the estimated peak in survival varied among years, presumably reflecting interannual variation in the nearshore physical environment and trophic dynamics that affect salmon during the critical juvenile life stage. 5. Synthesis and applications. Our results indicate a possible management objective would be to speed arrival to the estuary by increasing springtime river flows. These findings also provide some insight into the mechanisms underlying seasonal differences in survival patterns, but additional studies are needed to better resolve the issue. Future changes to river flow and water temperature associated with climate change and human activities may further alter migration timing, and thus this phenomenon deserves further attention.

Sebring, S. H., Carper, M. C., Ledgerwood, R. D., Sandford, B. P., Matthews, G. M., & Evans, A. F. (2013). Relative vulnerability of PIT-tagged subyearling fall Chinook salmon to predation by Caspian terns and double-crested cormorants in the Columbia River estuary. *Transactions of the American Fisheries Society*, *142*(5), 1321–1334. doi:10.1080/00028487.2013.806952

We quantified the percentage of PIT-tagged subyearling fall Chinook Salmon *Oncorhynchus tshawytscha* that were consumed by Caspian terns *Hydroprogne caspia* and double-crested cormorants *Phalacrocorax auritus* nesting on East Sand Island in the Columbia River estuary by electronically recovering PIT tags that were deposited on the bird colonies. We released 23 groups of PIT-tagged subyearling fall Chinook Salmon from hatcheries in the lower Columbia River downstream of Bonneville Dam from 2002 to 2010. Vulnerability to avian predation was compared between PIT-tagged subyearlings of two Columbia River basin stocks: tule and upriver bright (URB). Recoveries of PIT tags revealed that overall predation rates were significantly different between the tule stock (22%) and URB stock (3%); for fish that were detected as entering the lower Columbia River during the same week, predation rates also differed between stocks (tule:

21%; URB: 2%). Minimum predation rates on tule subyearlings originating from hatcheries downstream of Bonneville Dam were among the highest documented for any salmonid species in the Columbia River basin to date, occasionally exceeding 35% of the available fish. The ratio of URB fish consumed by the two avian predators indicated that the percentages were nearly equal (cormorant [%]: tern [%] = 51:49), whereas the ratio for tule-stock fish consumed by the two avian species was not uniform (cormorant: tern = 81:19). Differences in predation rates between the tule stock and the URB stock may be attributable to migration behaviors exhibited in the estuary. We estimate that more than 8 million tule fall Chinook Salmon subyearlings released from hatcheries annually are consumed by double-crested cormorants and Caspian terns nesting on East Sand Island; ongoing management actions by multiple federal, state, and tribal governments, if successful, will decrease predation on fall Chinook Salmon stocks.

Seeb, L. W., Seeb, J. E., Habicht, C., Farley, E. V., & Utter, F. M. (2011). Single-nucleotide polymorphic genotypes reveal patterns of early juvenile migration of sockeye salmon in the eastern Bering Sea. *Transactions of the American Fisheries Society*, *140*(3), 734–748. doi:10.1080/00028487.2011.584493

We estimate patterns of nearshore migration in the eastern Bering Sea for out-migrating Bristol Bay sockeye salmon *Oncorhynchus nerka* in their first year at sea. Over 3,000 juveniles were collected during the late summer of 2005–2007 as part of the Bering–Aleutian Salmon International Survey and tested with a regional genetic baseline of 45 single-nucleotide polymorphisms. Population-specific and westward migrations from natal rivers were evident. Populations from Wood River and northwestward predominated in the northern latitudes of Bristol Bay and the eastern Bering Sea and populations from the Egegik River and southwestward in the southern latitudes, while the populations spawning at the head of Bristol Bay had the highest proportions in the middle latitudes. These patterns were stable across years, apparently unaffected by marine productivity and temperature. This continuum of marine migratory patterns most likely reflects stable and population-specific adaptations to buffer the distribution of dynamically shifting marine resources. As monitoring continues, these juvenile surveys will accumulate information to refine predictions of the magnitude of adult returns to their respective rivers of origin and thereby assist in the management of this valuable resource.

Sharma, R., & Liermann, M. (2010). Using hierarchical models to estimate effects of ocean anomalies on north-west Pacific Chinook salmon *Oncorhynchus tshawytscha* recruitment. *Journal of Fish Biology*, *77*(8), 1948–1963. doi:10.1111/j.1095-8649.2010.02779.x

The high variability in survival over the past three decades of north-west Pacific Chinook salmon *Oncorhynchus tshawytscha* is summarized for 24 stocks and analysed using hierarchical Bayesian models. Results from a simple model indicate that recruitment anomalies appear to be correlated in time and space. A simple model with a covariate based on basin-scale effects (Pacific Decadal Oscillation and El Niño Southern Oscillation) and local-scale effects (sea surface temperature, SST anomaly) was introduced to explain this variability. The model still exhibited residual patterns that were removed when a random-walk component was added to the model. The analysis indicates

that recruitment is negatively related to SST anomaly for all stocks and the effect of basin-scale variables is negligible. The effect of climate over the next century is expected to result in estimated recruitment declining by an average of 13% for *O. tshawytscha* stocks coastwide.

Sharma, R., & Quinn, T. P. (2012). Linkages between life history type and migration pathways in freshwater and marine environments for Chinook salmon, *Oncorhynchus tshawytscha*. *Acta Oecologica*, *41*, 1–13. doi:10.1016/j.actao.2012.03.002

Chinook salmon, *Oncorhynchus tshawytscha*, are commonly categorized as ocean-type (migrating to the ocean in their first year of life) or stream-type (migrating after a full year in freshwater). These two forms have been hypothesized to display different ocean migration pathways; the former are hypothesized to migrate primarily on the continental shelf whereas the latter are hypothesized to migrate off the shelf to the open ocean. These differences in migration patterns have important implications for management, as fishing mortality rates are strongly influenced by ocean migration. Ocean-type Chinook salmon predominate in coastal rivers in the southern part of the species' range, whereas stream-type predominate in the interior and northerly rivers. This latitudinal gradient has confounded previous efforts to test the hypothesis regarding ocean migration pathways. To address this problem, we used a pair-wise design based on coded wire tagging data to compare the marine distributions of stream- and ocean-type Chinook salmon from a suite of rivers producing both forms. Both forms of Chinook salmon from the lower Columbia River, Oregon coast, lower Fraser River, and northern British Columbia rivers followed similar migration paths, contradicting the hypothesis. In contrast, recoveries of tagged Chinook salmon from the upper Columbia River, Snake River, and the upper Fraser River revealed migration patterns consistent with the hypothesis. These findings have important implications for our understanding of these life history types, and also for the conservation and management of declining, threatened, or endangered stream-type Chinook salmon populations in the US and Canada.

Sharma, R., Vélez-Espino, L. A., Wertheimer, A. C., Mantua, N., & Francis, R. C. (2013). Relating spatial and temporal scales of climate and ocean variability to survival of Pacific Northwest Chinook salmon (*Oncorhynchus tshawytscha*). *Fisheries Oceanography*, *22*(1), 14–31. doi:10.1111/fog.12001

Pacific Northwest Chinook, *Oncorhynchus tshawytscha*, have exhibited a high degree of variability in smolt-to-adult survival over the past three decades. This variability is summarized for 22 Pacific Northwest stocks and analyzed using generalized linear modeling techniques. Results indicate that survival can be grouped into eight distinct regional clusters: (1) Alaska, Northern BC and North Georgia Strait; (2) Georgia Strait; (3) Lower Fraser River and West Coast Vancouver Island; (4) Puget Sound and Hood Canal; (5) Lower Columbia Tules; (6) Columbia Upriver Brights, Willamette and Cowlitz; (7) Oregon and Washington Coastal; and (8) Klamath River and Columbia River Summers. Further analysis for stocks within each of the eight regions indicates that local ocean conditions following the outmigration of smolts from freshwater to marine areas had a significant effect on survival for the majority of the stock groups analyzed. Our analyses of the data indicate that Pacific Northwest Chinook survival covaries on a

spatial scale of 350–450 km. Lagged time series models are presented that link large-scale tropical Pacific conditions, intermediate-basin scale northeastern Pacific conditions, and local sea surface temperatures to survival of Pacific Northwest stocks.

Simmons, R. K., Quinn, T. P., Seeb, L. W., Schindler, D. E., & Hilborn, R. (2013). Role of estuarine rearing for sockeye salmon in Alaska (USA). ***Marine Ecology Progress Series*****, *481*, 211–223. doi:10.3354/meps10190**

A suite of adaptive traits allows Pacific salmon to exploit diverse habitats during their lives, facilitating their persistence in highly variable and heterogeneous environments. We investigated how juvenile sockeye salmon *Oncorhynchus nerka*, which typically rear in lakes before migrating rapidly to sea, make use of riverine and estuarine habitats in the Chignik Lake system (Alaska, USA) where lacustrine rearing capacity limits sockeye salmon productivity. Their distribution, growth, and genetic stock composition were examined during June to August, 2007 to 2009. Sockeye salmon inhabited the estuary for up to 3 mo each summer, representing 2 distinct age classes: Age-0 fry and parr, and Age 1+ smolts. The fry and parr grew rapidly in the estuary, attaining sizes comparable to the lake-reared smolts. Smolts also grew in the estuary in all years, although they occupied the estuary for a briefer period in years when they entered at a larger size. Using genetic mixture analyses, fry and parr in the estuary were assigned to a population that spawns in Chignik River immediately upstream of the estuary, whereas the smolts were assigned to 2 genetically distinct population groups associated with separate nursery lakes farther up in the basin. Our findings highlight the role of estuaries for juvenile sockeye salmon in systems with limited freshwater rearing capacity and high salmon density. The persistence of such populations depends in part on preserving a continuum of habitat types, especially in the southern range of the species where a shifting climate and human activities are expected to most greatly impact populations.

Spilseth, S. A., & Simenstad, C. A. (2011). Seasonal, diel, and landscape effects on resource partitioning between juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and threespine stickleback (*Gasterosteus aculeatus*) in the Columbia River estuary. ***Estuaries and Coasts*****, *34*(1), 159–171. doi:10.1007/s12237-010-9349-3**

The objective of this study was to determine if exploitative competition between between juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and threespine stickleback (*Gasterosteus aculeatus*) reduces the foraging opportunity of juvenile Chinook salmon in tidal channels of the Columbia River estuary. We sampled Chinook salmon and stickleback diets monthly and over a diel cycle in spatially distinct emergent marshes of the Columbia River estuary. Diets of the two fish species did not differ among marsh systems, but both fish species exhibited diel and seasonal differences in diet composition. Diet overlap between the two fish species was greatest in March and June. Exploitative competition was unlikely based on a comparison between consumption rates and estimated invertebrate production.

Sturdevant, M. V., Fergusson, E., Hillgruber, N., Reese, C., Orsi, J., Focht, R., Wertheimer, A. Smoker, B. (2012). Lack of trophic competition among wild and hatchery juvenile chum salmon during early marine residence in Taku Inlet, Southeast Alaska. ***Environmental Biology of Fishes*****, *94*(1), 101–116. doi:10.1007/s10641-011-**

9899-7

Early marine trophic interactions of wild and hatchery chum salmon (*Oncorhynchus keta*) were examined as a potential cause for the decline in harvests of adult wild chum salmon in Taku Inlet, Southeast Alaska. In 2004 and 2005, outmigrating juvenile chum salmon were sampled in nearshore habitats of the inlet (spring) and in epipelagic habitat at Icy Strait (summer) as they approached the Gulf of Alaska. Fish were frozen for energy density determination or preserved for diet analyses, and hatchery stocks were identified from the presence of thermal marks on otoliths. We compared feeding intensity, diets, energy density, and size relationships of wild and hatchery stocks (n = 3123) across locations and weeks. Only hatchery fish feeding intensity was negatively correlated with fish abundance. In both years, hatchery chum salmon were initially larger and had greater energy density than wild fish, but lost condition in early weeks after release as they adapted to feeding on wild prey assemblages. Diets differed between the stocks at all inlet locations, but did not differ for hatchery salmon between littoral and neritic habitats in the outer inlet, where the stocks overlapped most. Both diets and energy density converged by late June. Therefore, if density-dependent interactions affect wild chum salmon, these effects must be very rapid because survivors in Icy Strait showed few differences. Our study also demonstrates that hatchery release strategies used near Taku Inlet successfully promote early spatial segregation and prey partitioning, which reduce the probability of competition between wild and hatchery chum salmon stocks.

Sturdevant, M. V., Orsi, J. A., & Fergusson, E. A. (2012). Diets and trophic linkages of epipelagic fish predators in coastal Southeast Alaska during a period of warm and cold climate years, 1997–2011. *Marine and Coastal Fisheries*, *4*(1), 526–545. doi:10.1080/19425120.2012.694838

This study identifies important trophic links for epipelagic marine fish predators in Southeast Alaska to improve understanding of marine ecosystem dynamics in response to climate change. Fish predators can be viewed as autonomous samplers whose diets should integrate the available prey taxa commensurate with environmental conditions. We examined fish predators from annual (1997–2011) surveys conducted in May to September by the Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories in the marine waters of Southeast Alaska. This project has emphasized long-term monitoring of strait and coastal marine habitats used by juvenile Pacific salmon *Oncorhynchus* spp. and associated epipelagic fishes to understand how environmental variation affects the sustainability of salmon resources. From 1,295 surface trawl hauls, trophic links were identified for 2,473 fish representing 19 predator species, principally adult and immature salmon, immature walleye pollock *Theragra chalcogramma*, and spiny dogfish *Squalus acanthias*. The most common fish prey consumed were fish larvae, juvenile salmon, Pacific herring *Clupea pallasii*, capelin *Mallotus villosus*, walleye pollock, lanternfishes (Myctophidae), and Pacific sand lance *Ammodytes hexapterus*, whereas the most common invertebrate prey consumed were euphausiids, decapod larvae, pteropods, and amphipods. This study describes the degree of piscivory, incidence of juvenile salmon prey, and frequency and weight composition of prey in the diets of epipelagic fish predators, but it did not clearly detect an effect of warm-versus-cold climate years on the diets of key planktivorous or piscivorous predators over the 15-year time series. Identifying the persistence of trophic links in epipelagic waters over time is

important because climate-related changes in the upper water column have the potential to impact Southeast Alaska marine ecosystem dynamics and the productivity of important regional fisheries by altering key prey resources and trophic interactions.

Sutherland, B. J. G., Jantzen, S. G., Sanderson, D. S., Koop, B. F., & Jones, S. R. M. (2011). Differentiating size-dependent responses of juvenile pink salmon (*Oncorhynchus gorbuscha*) to sea lice (*Lepeophtheirus salmonis*) infections. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, *6*(2), 213–223. doi:10.1016/j.cbd.2011.04.001

Salmon infected with an ectoparasitic marine copepod, the salmon louse *Lepeophtheirus salmonis*, incur a wide variety of consequences depending upon host sensitivity. Juvenile pink salmon (*Oncorhynchus gorbuscha*) migrate from natal freshwater systems to the ocean at a young age relative to other Pacific salmon, and require rapid development of appropriate defenses against marine pathogens. We analyzed the early transcriptomic responses of naïve juvenile pink salmon of sizes 0.3 g (no scales), 0.7 g (mid-scale development) and 2.4 g (scales fully developed) six days after a low-level laboratory exposure to *L. salmonis* copepodids. All infected size groups exhibited unique transcriptional profiles. Inflammation and inhibition of cell proliferation was identified in the smallest size class (0.3 g), while increased glucose absorption and retention was identified in the middle size class (0.7 g). Tissue-remodeling genes were also up-regulated in both the 0.3 g and 0.7 g size groups. Profiles of the 2.4 g size class indicated cell-mediated immunity and possibly parasite-induced growth augmentation. Understanding a size-based threshold of resistance to *L. salmonis* is important for fisheries management. This work characterizes molecular responses reflecting the gradual development of innate immunity to *L. salmonis* between the susceptible (0.3 g) and refractory (2.4 g) pink salmon size classes.

Sweeting, R. M., & Beamish, R. J. (2009). A comparison of the diets of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in the Strait of Georgia from 1997–2007. *North Pacific Anadromous Fish Commission Bulletin*, *5*, 255–264.

Wild and hatchery-reared coho salmon (*Oncorhynchus kisutch*) have now co-existed in the Strait of Georgia for over 30 years, and have exhibited considerable variation in marine survival rates. This study is the first to compare diets of juvenile hatchery and wild coho salmon during the critical early marine period of this species. From 1997–2007, over 10,000 stomachs from juvenile coho salmon captured in the Strait of Georgia were examined. Diets in July were dominated by decapods (primarily crab megalops) and fish (primarily herring). In September, euphausiids and amphipods (primarily hyperiids) dominated. The variability between hatchery and wild coho salmon diet was larger in September than in July. Prey volume, stomach fullness and fork length were significantly correlated between hatchery and wild coho salmon in the July and September surveys. While coho salmon captured in September surveys had significantly higher percentages of empty stomachs than those from July, there were no significant differences in the percentage of empty stomachs between hatchery and wild coho salmon in either survey. Shifts in diet composition occurred both annually and seasonally, but the trends for both groups of coho salmon were the same. Thus, we conclude there were no significant differences observed between hatchery and wild coho salmon in either appetite (volume

of prey in the stomach) or in diet (composition of stomach contents) in either July or September surveys from 1997–2007 in the Strait of Georgia, British Columbia, Canada.

Sydeman, W. J., Santora, J. A., Thompson, S. A., Marinovic, B., & Lorenzo, E. D. (2013). Increasing variance in North Pacific climate relates to unprecedented ecosystem variability off California. *Global Change Biology*, *19*(6), 1662–1675. doi:10.1111/gcb.12165

Changes in variance are infrequently examined in climate change ecology. We tested the hypothesis that recent high variability in demographic attributes of salmon and seabirds off California is related to increasing variability in remote, large-scale forcing in the North Pacific operating through changes in local food webs. Linear, indirect numerical responses between krill (primarily *Thysanoessa spinifera*) and juvenile rockfish abundance (catch per unit effort (CPUE)) explained >80% of the recent variability in the demography of these pelagic predators. We found no relationships between krill and regional upwelling, though a strong connection to the North Pacific Gyre Oscillation (NPGO) index was established. Variance in NPGO and related central Pacific warming index increased after 1985, whereas variance in the canonical ENSO and Pacific Decadal Oscillation did not change. Anthropogenic global warming or natural climate variability may explain recent intensification of the NPGO and its increasing ecological significance. Assessing non-stationarity in atmospheric-environmental interactions and placing greater emphasis on documenting changes in variance of bio-physical systems will enable insight into complex climate-marine ecosystem dynamics.

Sydeman, W. J., Thompson, S. A., Field, J. C., Peterson, W. T., Tanasichuk, R. W., Freeland, H. J., Bograd, S. J. & Rykaczewski, R. R. (2011). Does positioning of the North Pacific Current affect downstream ecosystem productivity? *Geophysical Research Letters*, *38*(12). L12606. doi:10.1029/2011GL047212

Fluctuations in the positioning of major ocean currents can influence ecosystem dynamics, but previously the technology has been lacking to make direct observational assessments. Here, we test the hypothesis that positioning of the North Pacific Current (NPC) is related to biological attributes of the central-northern California Current Ecosystem (CCE). To test this hypothesis we use newly available data from the Argo array and compare it with a suite of well-known ecosystem indicators over 6 years, 2002 through 2007. We found increased biomass and productivity when the NPC was shifted poleward, and suggest that positioning influences advective transport of nutrients and perhaps key planktonic organisms from the sub-arctic domain thereby enhancing mid to upper trophic level species. This study is significant because climate change is predicted to cause poleward shifts in the westerlies that drive ocean currents and positioning of large marine gyre systems. Rather than reducing ecosystem productivity, poleward shifts in positioning of the NPC may be beneficial for many species of the central-northern CCE.

Tanasichuk, R. W., & Routledge, R. (2011). An investigation of the biological basis of return variability for sockeye salmon (*Oncorhynchus nerka*) from Great Central and Sproat lakes, Vancouver Island. *Fisheries Oceanography*, *20*(6), 462–478. doi:10.1111/j.1365-2419.2011.00596.x

We tested whether variations in stock characteristics (spawner and smolt abundance) and biotic conditions (prey variability, predation, competition) during the early marine period explained variations in the return of sockeye salmon (*Oncorhynchus nerka*) to Great Central and Sproat lakes, adjacent lakes on the west coast of Vancouver Island. There are two freshwater age groups in each lake; fish spend 1 or 2 yrs in freshwater after hatching. We tested the influences of stock and biotic factors on the return of each of the two age groups from each of the two lakes. Results of regression analyses showed that prey biomass variability best explained the variation in return for all lake-age groups. Euphausiid (*Thysanoessa spinifera*) and cladoceran (*Evadne*) prey biomass variability explained between 0.75 and 0.95 (adjusted R^2) of the variation in return. There appear to be instances of a mismatch between the seasonality of prey productivity and the apparent critical period of feeding for juvenile sockeye.

Tang, S., Lewis, A. G., Sackville, M., Nendick, L., DiBacco, C., Brauner, C. J., & Farrell, A. P. (2011). Diel vertical distribution of early marine phase juvenile pink salmon (*Oncorhynchus gorbuscha*) and behaviour when exposed to salmon louse (*Lepeophtheirus salmonis*). *Canadian Journal of Zoology*, *89*(9), 796–807. doi:10.1139/z11-049

We observed diel vertical migration patterns in juvenile pink salmon (*Oncorhynchus gorbuscha* (Walbaum, 1792)) and tested the hypothesis that fish behaviour is altered by exposure to sea lice copepodids. Experiments involved replicated field deployments of a large (9 m) plankton column, which provided a vertical distribution enclosure under natural light and salinity conditions. Diel vertical distributions of juvenile pink salmon were observed during the first 3 weeks of seawater acclimation in both the presence and the absence of the ectoparasitic salmon louse (*Lepeophtheirus salmonis* (Krøyer, 1838)). Immediately upon entering seawater, juvenile pink salmon preferred the top 1 m of the water column, but they moved significantly deeper down the vertical water column as seawater acclimation time increased. A significant diel migration pattern was observed, which involved a preference for the surface at night-time, compared with daytime. When fish in the column were exposed to *L. salmonis* copepodids for 3 h, 43%–62% of fish became infected, fish expanded theirvertical distribution range, and significant changes in vertical distribution patterns were observed.

Thayer, J. A., Field, J. C., & Sydeman, W. J. (2014). Changes in California Chinook salmon

diet over the past 50 years: relevance to the recent population crash. *Marine Ecology Progress Series*, *498*, 249–261. doi:10.3354/meps10608

Salmon are affected by variation in ocean productivity; thus, improved understanding of mechanisms behind variability in ocean survival should help management of these ecologically and economically important populations. Based on a cooperative fisheries research program, we compared central California Chinook salmon *Oncorhynchus tshawytscha* adult food habits from spring and summer in the mid-2000s with historical records from 1955 and the 1980s. Diet diversity decreased through time, and was particularly low in May and June of the 2000s. Previously important prey, including juvenile rockfish *Sebastes* spp., krill *Euphausiidae*, Pacific herring *Clupea pallesi* and market squid *Doryteuthis opalsecens*, declined or disappeared from the diet, while Pacific

sardine *Sardinops sagax* became very important prey in the 2000s; anchovy *Engraulis mordax* remained important throughout the study. Diet composition was correlated with regional mid-water trawls of prey abundance and also with local sea surface temperature (SST). Diet composition was related to the Sacramento Index of fall-run Chinook ocean abundance with a lag of 1 or 2 yr, and reflected the importance of prey availability during the second ocean year and smolt ocean-entry period, respectively. Spring is peak ocean entry for fall-run Chinook smolts, so declining prey diversity (specifically in May and June in the mid-2000s) may be related to recent population crashes. Seasonally, winter and fall diet data further demonstrated the significance of temporal variation in specific prey. This study highlights the importance of marine predator–prey interactions at an appropriate temporal resolution for understanding salmonid population dynamics.

Thompson, S. A., Sydeman, W. J., Santora, J. A., Black, B. A., Suryan, R. M., Calambokidis,

J., Peterson, W. T. & Bograd, S. J. (2012). Linking predators to seasonality of upwelling: Using food web indicators and path analysis to infer trophic connections. *Progress in Oceanography*, *101*(1), 106–120. doi:10.1016/j.pocean.2012.02.001

Upwelling in eastern boundary current systems is a primary driver of ecosystem productivity. Typically, peak upwelling occurs during spring and summer, but winter upwelling may also be important to ecosystem functions. In this study, we investigated the hypothesis that winter and spring/summer upwelling, operating through indirect trophic interactions, are important to a suite of top predators in the California Current. To test this hypothesis, we collated information on upwelling, chlorophyll-a concentrations, zooplankton and forage fish, and related these to predator responses including rockfish growth, salmon abundance, seabird productivity and phenology (timing of egg-laying), and whale abundance. Seabird diets served in part as food web indicators. We modeled pathways of response using path analysis and tested for significance of the dominant paths with multiple regression. We found support for the hypothesis that relationships between upwelling and top predator variables were mediated primarily by intermediate trophic levels. Both winter and summer upwelling were important in path models, as were intermediate lower and mid trophic level functional groups represented by chlorophyll-a, zooplankton, and forage fish. Significant pathways of response explained from 50% to 80% of the variation of seabird (Cassin's auklet (*Ptychoramphus aleuticus*) and common murre (*Uria aalge*)), humpback whale (*Megaptera novaeangliae*) and Chinook salmon (*Oncorhynchus tshawytscha*) dependent variables, whereas splitnose rockfish (*Sebastes diploproa*) showed no significant response pathways. Upwelling and trophic responses for salmon were established for both the year of ocean entry and the year of return, with zooplankton important in the year of ocean entry and forage fish important in the year of return. This study provides one of the first comparative investigations between upwelling and predators, from fish to marine mammals and birds within a geographically restricted area, demonstrates often difficult to establish "bottom-up" trophic interactions, and establishes the importance of seasonality of upwelling to various trophic connections and predator demographic traits. Understanding change in the seasonality of upwelling is therefore required to assess dynamics of commercially and recreationally important upper trophic level species in eastern boundary current ecosystems.

Thomson, R. E., Beamish, R. J., Beacham, T. D., Trudel, M., Whitfield, P. H., & Hourston, R. A. S. (2012). Anomalous ocean conditions may explain the recent extreme variability in Fraser River sockeye salmon production. *Marine and Coastal Fisheries*, *4*(1), 415–437. doi:10.1080/19425120.2012.675985

Record low returns of sockeye salmon *Oncorhynchus nerka* to the Fraser River in 2009 were followed by record high returns to the river in 2010, providing an unprecedented opportunity to examine links between oceanic factors and the survival of Pacific salmon stocks. The low returns in 2009 indicated poor early marine survival of juvenile sockeye salmon in 2007. The poor survival was likely due to low food levels arising from unfavorable wind and runoff conditions in the Strait of Georgia and the Queen Charlotte Sound–Hecate Strait region in the spring of 2007. Conversely, the high returns in 2010 were associated with a large smolt output from the Fraser River and good early marine survival in 2008. This enhanced survival was likely associated with adequate food levels arising from favorable oceanic conditions in the Strait of Georgia and the Queen Charlotte Sound–Hecate Strait region in the spring of 2008. We speculate that ocean factors during the subsequent marine years also affected brood year strength. Specifically, the back-to-back La Niña winters of 2007–2008 and 2008–2009 would have negatively influenced the survivability of the 2007 entry stocks, while the El Niño winter of 2009–2010 would have positively affected the survivability of the 2008 entry stocks. We conclude that poor early marine survival leads to low production. However, if large numbers of healthy fish survive the early marine entry, and if conditions during at least one of the two ocean winters in the Gulf of Alaska are favorable to stock survivability, then returns to the river can be high.

Toft, J. D., Cordell, J. R., Simenstad, C. A., & Stamatiou, L. A. (2007). Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. *North American Journal of Fisheries Management*, *27*(2), 465–480. doi:10.1577/M05-158.1

Shoreline modifications, such as bulkheads, riprap, and overwater structures, have altered many of the natural habitats in nearshore urbanized areas surrounding coastal cities, including those in Puget Sound, Washington. The effects of such structures on ecological processes are poorly known, especially those impacting juvenile salmonids *Oncorhynchus* spp. The goal of our study was to compare the relative abundance and behavior of juvenile salmonids and other fishes along various modified and undeveloped shoreline types. We used enclosure nets and snorkel surveys to sample fishes during high tides in areas adjacent to shore at five main habitat types: cobble beach, sand beach, riprap extending into the upper intertidal zone, deep riprap extending into the subtidal zone, and the edge of overwater structures. Bottom-dwelling fishes exhibited the only significant differences in density among cobble beach, sand beach, and riprap that extended into the upper intertidal zone. This suggests that substrate type and slope are important influences on fish densities when shoreline modifications only extend into the upper intertidal zone. Differences in pelagic fish density and behavior were more evident when shoreline modifications extended into shallow subtidal waters, truncating the shallow-water zone and creating deep water at the shoreline. We typically found higher fish densities, larger schools of salmon, and fewer terrestrial riparian insects in salmon diets at these sites. Juvenile salmonids avoided swimming beneath overwater structures,

whereas surfperch (family Embiotocidae), crabs (infraorder Brachyura), and sculpins (family Cottidae) were observed beneath or adjacent to pilings. Overall, our results indicate that shoreline modifications have the greatest effect on nearshore fish assemblages when the alterations extend from the supratidal zone into the subtidal zone. Our data suggest that the differences in fish behavior and usage between modified and unmodified shorelines were caused by physical and biological effects of the modifications, such as changes in water depth, slope, substrate, and shoreline vegetation.

Tomaro, L. M., Teel, D. J., Peterson, W. T., & Miller, J. A. (2012). When is bigger better? Early marine residence of middle and upper Columbia River spring Chinook salmon. *Marine Ecology Progress Series*, *452*, 237–252. doi:10.3354/meps09620

Early ocean residence is considered a critical period for juvenile salmon although specific survival mechanisms are often unidentified and may vary by species or life stage. Columbia River spring-run Chinook salmon *Oncorhynchus tshawytscha* abundance has declined dramatically since the early 1900s. To elucidate mechanisms of early marine survival, we tested the "bigger-is-better" and "stage-duration" aspects of the "growth-mortality" hypothesis, which posits that size and growth rate are important for future abundance. We tested the "match-mismatch" hypothesis to determine whether early marine growth was related to indices related to regional productivity, including spring transition timing and copepod community composition. We generated estimates of individual size at ocean entry and capture, marine growth rate, early marine migration rate, and emigration timing using data from ocean surveys, genetic stock-assignment, and otolith analyses of juveniles collected across 8 yr between 1998 and 2008. Size at capture and marine growth rate after ~30 d marine residence were positively related to future adult returns, whereas size at marine entry was not. Growth rate was not significantly related to indices of secondary production, but size at capture was significantly greater when lipid-rich copepods dominated. Although future adult abundance was not related to emigration timing, juveniles migrated more slowly when copepod biomass was high, perhaps responding to foraging conditions. Overall, processes during early ocean residence appear to be more important for cohort size establishment than those at marine entry. Approaches that combine genetic and otolith analyses have great potential to provide information on stock-specific variation in survival mechanisms.

Trudel, M., Fisher, J., Orsi, J. A., Morris, J. F. T., Thiess, M. E., Sweeting, R. M., Hinton, S., Fegusson, E. A. & Welch, D. W. (2009). Distribution and migration of juvenile Chinook salmon derived from coded wire tag recoveries along the continental shelf of western North America. *Transactions of the American Fisheries Society*, *138*(6), 1369–1391. doi:10.1577/T08-181.1

The effects of ocean conditions on highly migratory species such as salmon are difficult to assess owing to the diversity of environments they encounter during their marine life. In this study, we reconstructed the initial ocean migration routes of juvenile Chinook salmon *Oncorhynchus tshawytscha* originating from Oregon to Southeast Alaska using coded wire tag recovery data from Canadian Department of Fisheries and Oceans and National Marine Fisheries Service research surveys conducted between 1995 and 2006. Over this 12-year period, 1,862 coded-wire-tagged juvenile Chinook salmon were recovered along the coasts of Oregon, Washington, British Columbia, and Alaska from

March to November. Except for those from the Columbia River, most juvenile Chinook salmon remained within 100–200 km of their natal rivers until their second year at sea, irrespective of their freshwater history and adult run timing. Northward migration of most coastal stocks was initiated during their second or possibly third year at sea, whereas the Strait of Georgia and Puget Sound stocks primarily migrated onto the continental shelf after their first year at sea. In contrast, Columbia River Chinook salmon generally undertook a rapid northward migration that varied among life histories and stocks. Columbia River spring Chinook salmon were recovered as far north as Prince William Sound, Alaska, during their first summer at sea, whereas very few Columbia River fall Chinook salmon were recovered north of Vancouver Island. In addition to northern migrants, a fraction of the Columbia River spring and fall Chinook salmon actively migrated south of the Columbia River. The stock-specific initial ocean migration routes described in this study will aid in the identification of the appropriate spatial and temporal scales for assessing the processes regulating Chinook salmon recruitment in the marine environment.

Trudel, M., Jones, S. R., Thiess, M. E., Morris, J. F., Welch, D. W., Sweeting, R. M., Moss, J. H., Wing, B. L., Farley Jr., E. V., Murphy, J. M., Baldwin, R. E., & Jacobson, K. C. (2007). Infestations of motile salmon lice on Pacific salmon along the west coast of North America. ***American Fisheries Society Symposium, 57,*** **157-182.**

We report patterns of infestation with motile salmon lice, *Lepeophtheirus salmonis*, on Pacific salmon collected with a surface trawl in coastal waters of Oregon, Washington, British Columbia, and Alaska during 2002 and 2003. Salmon lice were observed on all salmon species examined and in all areas surveyed. The prevalence and abundance of lice infestation varied significantly among species, size-classes, seasons, regions, and years, with larger salmon being consistently more heavily infested than small salmon. The number of lice infesting the small size-class (100–400 mm) of salmon rarely exceeded 5 lice per fish with a mean abundance generally below 0.2 lice per fish. Lice prevalence and, to a lesser extent, lice abundance increased over time in small fish, with lower values during spring and higher values in the following winter, and continued to increase in larger and older fish. There were no apparent effects of water temperature on lice infestation in Pacific salmon. This study suggested that salmon infested with lice remained in coastal waters throughout the year. We suggest that lice on salmon that overwinter in coastal waters will contribute to a pool of infective copepodids in these habitats.

Trudel, M., Middleton, K., Tucker, S., Thiess, M. E., Morris, J. F. T., Candy, J. R., Mazumder, A., & Beacham, T. D. (2012). Estimating winter mortality in juvenile Marble River Chinook salmon. ***North Pacific Anadromous Fish Commission Document, 1426,*** **24 pp.**

Winter is generally considered a critical period for juvenile salmon due to low temperatures and food availability. However, mortality rates have not been quantified for juvenile salmon during the winter months. Here, we use changes in the catch-per-unit effort (CPUE) for five brood years (2004-2008) of juvenile Marble River Chinook salmon between fall and winter to estimate stock-specific overwinter mortality rates in juvenile salmon. This stock is ideal for estimating overwinter mortality, as the catch

distribution suggest that they remain in Quatsino Sound, British Columbia, for a year before migrating to the open ocean. CPUE of juvenile Marble River Chinook salmon in the Quatsino Sound system were 7- to 169-fold lower in the winter relative to the fall. CPUE varied significantly among brood years and seasons, but the interaction term between brood years and seasons was not significant. Overall, 80% of these fish died over winter, and mortality rates averaged 0.014-0.017 d -1. The variance in fish size did not decrease during winter. Taken together, these results indicates that overwinter mortality can be substantial and variable in juvenile salmon, but that it is size-independent, at least, for this population.

Trudel, M., Moss, J. H., Tucker, S., Candy, J. R., & Beacham, T. D. (2011). Stock-specific distribution of juvenile sockeye salmon in the Eastern Gulf of Alaska. ***North Pacific Anadromous Fish Commission Document*****, *1353*, 11 pp.**

Describing stock-specific migration behaviour is an important first step that is required to understand the effects of climate change and ocean conditions on the marine survival of Pacific salmon (*Oncorhynchus* spp.). In this study, we examined stock-specific distribution of juvenile sockeye salmon (*O. nerka*) in the Eastern Gulf of Alaska. Approximately 45% of the juvenile sockeye salmon analyzed in this study were caught beyond the 1,000 m isobath. DNA analyses revealed that the spatial distribution of juvenile sockeye salmon differed among stocks. A significant positive relationship between station depth and sockeye salmon size was observed only for Fraser River sockeye salmon. However, this relationship was weak, indicating that offshore movement of juvenile sockeye salmon was not strongly influenced by body size. These results suggest that juvenile sockeye may be leaving the continental shelf earlier than previously believed and further east than the Aleutian Islands.

Trudel, M., Thiess, M. E., Bucher, C., Farley, E. V., MacFarlane, R. B., Casillas, E., Fisher, J., Morris, J. F. T., Murphy, J. M., & Welch, D. W. (2007). Regional variation in the marine growth and energy accumulation of juvenile Chinook salmon and coho salmon along the west coast of North America. ***American Fisheries Society Symposium, 57,*** **205-232.**

Size-selective mortality combined with longer winters at high-latitudes is expected to exert strong directional selection on size, growth, and energy use and storage capacity in northern fish populations. Here, we tested the hypotheses that juvenile Pacific salmon grow faster, reach larger size, and accumulate higher energy reserves in the marine environment at northern latitudes using juvenile Chinook salmon *Oncorhynchus tshawytscha* and coho salmon *O. kisutch* collected on the continental shelf from the California coast to the Bering Sea. Size reached at the end of the growing season, the quantity of energy stored prior to the onset of winter, and summer growth of juvenile Chinook and coho salmon during their first year at sea varied significantly among regions of the continental shelf. Latitudinal trends were detected for the fall size of subyearling and yearling Chinook salmon and storage energy in yearling Chinook salmon. However, they were opposite to expectations, with values decreasing from southern to northern areas. Latitudinal trends were also apparent for summer growth in juvenile yearling Chinook salmon. However, in contrast to fall size and storage energy, higher growth rates were generally observed in northern rather than in southern regions. Similarly, summer

growth generally decreased from northern to southern regions in juvenile coho salmon. Storage energy did not exhibit a consistent trend with latitude in juvenile subyearling Chinook salmon and coho salmon. The different response of juvenile Chinook salmon and coho salmon to a latitudinal cline in temperature and the length of the growing season suggest that both species utilize the marine environment differently. We suggest that regional variations in juvenile salmon growth and energy accumulation may result from differences in prey quality (i.e., lipids), diet, and interspecific competition for prey resources.

Trudel, M., & Tucker, S. (2013). Depth distribution of 1SW Chinook salmon in Quatsino Sound, Brittish Columbia, during winter. *North Pacific Anadromous Fish Commission Document*, *1453*, 8 pp.

We conducted a trawl survey in Quatsino Sound, British Columbia, to determine the vertical distribution of Chinook salmon during their first winter at sea (1SW) and to test the hypothesis that 1SW Chinook salmon migrate to deeper waters as they get larger. Fifteen-minute tows were performed at 0m, 15m, 30m, and 45 m at seven locations within Quatsino Sound and associated Inlets. We also performed a 15-minute tow at 60 m in four of these locations. Catches peaked at 30-45 m at three locations and were low but stable at all other sites, indicating that the vertical distribution of 1SW Chinook salmon varied among sites within Quatsino Sound. Overall, the size of 1SW Chinook salmon increased with depth, though a bimodal size-frequency distribution was observed at 60 m. Further research will thus be required to understand the processes affecting the distribution of Chinook salmon in the marine environment

Tucker, S., Thiess, M. E., Morris, J. F. T., Mazumder, A., & Trudel, M. (2012). Concordant distribution, abundance, growth of juvenile pink, chum and sockeye salmon in Eastern Pacific coastal waters. *North Pacific Anadromous Fish Commission Document*, *1404*, 13 pp.

Competition is thought to be an important fact or affecting growth of Pacific salmon (*Oncorhynchus* spp.) in marine waters. Pink salmon (*O. gorbuscha*) are the most abundant species of the five Pacific salmon. As such, we hypothesized that high abundances of juvenile pink salmon might result in decreased abundances and/or growth of other planktivorous juvenile salmon species during the first growing season (summer-fall) at sea through direct competition for food. We evaluated spatial and temporal changes in growth rates and the seasonal catches between 1998 and 2011 of juvenile salmon and pelagic fishes, and the effects of oceanographic variables. Results suggest that, at least during the first marine growing season, interspecific competition is not manifested among salmon going to sea in the same year in northeastern Pacific stocks. Abundance of all salmon species were positively correlated and more likely driven by oceanographic features and processes at the base of the food chain.

Tucker, S., Trudel, M., Welch, D. W., Candy, J. R., Morris, J. F. T., Thiess, M. E., Wallace, C., Teel, D. J., Farley Jr., E. V., Crawford, W., & Beacham, T. D. (2009). Seasonal stock-specific migrations of juvenile sockeye salmon along the west coast of North America: implications for growth. *Transactions of the American Fisheries Society*, *138*(6), 1458–1480. doi:10.1577/T08-211.1

Knowledge of the migratory habits of juvenile Pacific salmon *Oncorhynchus* spp. is required to test the hypothesis that ocean food resources are a limiting factor in their production. Using DNA stock identification techniques, we reconstructed the regional and seasonal changes in the stock composition of juvenile sockeye salmon *O. nerka* (n = 4,062) collected from coastal Washington to the Alaska Peninsula in coastal trawl surveys from May to February 1996–2007. Individuals were allocated to 14 regional populations. The majority were allocated to stocks from the Fraser River system (42%), while west coast Vancouver Island stocks accounted for 15% of the total catch; Nass and Skeena River sockeye salmon constituted 14% and Rivers Inlet 6% of the total. The remainder of the stocks identified individually contributed less than 5% of the sockeye salmon analyzed. These proportions generally reflected the abundance of those populations. In spring and summer, the majority of fish were caught in close proximity to their rivers of origin, lending further support to the allocations. By fall, sockeye salmon were caught as far north and west as the Alaska Peninsula, the majority being caught from central British Columbia to Southeast Alaska. Juvenile sockeye salmon generally disappeared from the coast by winter, suggesting dispersion into the Gulf of Alaska. Within each region, the proportional stock composition changed as the seasons progressed, with northward (and in some cases, rapid) migration along the coast. We also demonstrated stock-specific differences in migration patterns. For each stock identified, body size and energy density were higher at northern latitudes, suggesting that there is an environmental or food web influence on growth or that faster growing fish initiated their northward migration earlier.

Tucker, S., Trudel, M., Welch, D. W., Candy, J. R., Morris, J. F. T., Thiess, M. E., Wallace, C. & Beacham, T. D. (2011). Life history and seasonal stock-specific ocean migration of juvenile Chinook salmon. *Transactions of the American Fisheries Society*, *140*(4), 1101–1119. doi:10.1080/00028487.2011.607035

The ocean feeding grounds of juvenile Pacific salmon *Oncorhynchus* spp. range over several thousand kilometers in which ocean conditions, prey quality and abundance, and predator assemblages vary greatly. Therefore, the fate of individual stocks may depend on where they migrate and how much time they spend in different regions. Juvenile (n = 6,266) and immature (n = 659) Chinook salmon *Oncorhynchus tshawytscha* were collected from coastal Washington to Southeast Alaska in coastal trawl surveys from February to November 1998–2008, which allowed us to reconstruct changes in stock composition for seasons and regions by means of DNA stock identification techniques. Individuals were allocated to 12 regional stocks. The genetic stock assignments were directly validated by showing that 96% of the 339 known-origin, coded-wire-tagged fish were accurately allocated to their region of origin. Overall, the analyses performed in this study support the main findings of previous work based on tagging. However, given that the sample sizes for all stocks were larger and additional stocks were analyzed, we can extend those results; coastal residency of local stocks in their first year at sea with differences between smolt classes for southern stocks. Notably, yearling Chinook salmon moved quickly into waters north of the west coast of Vancouver Island, including Southeast Alaska. Furthermore, subyearling salmon were found over shallower bottom depths than yearling fish. Summer catches in all regions were dominated by Columbia River yearling fish, which suggests a rapid northward migration. In contrast, very few

Columbia River subyearling fish were recovered north of Vancouver Island. Columbia River fish were a minor component of the catches in fall and winter, as fish originating from other southern stocks dominated catches off the west coast of Vancouver Island while northern British Columbia and Southeast Alaska stocks dominated northern regions during these time periods. In addition, we found no effect of hatchery origin on the distribution of fish.

Tucker, S., Trudel, M., Welch, D. W., Candy, J. R., Morris, J. F. T., Thiess, M. E., Wallace, C. & Beacham, T. D. (2012). Annual coastal migration of juvenile Chinook salmon: static stock-specific patterns in a highly dynamic ocean. ***Marine Ecology Progress Series*****, *449*, 245–262. doi:10.3354/meps09528**

While recent studies have evaluated the stock-specific coastal migration of juvenile Chinook salmon, it remains unclear if these seasonal patterns are consistent between years, particularly when ocean conditions change dramatically. Here we contrast the abundance, distribution and seasonal stock compositions of juvenile Chinook salmon between years in 3 oceanographic regions of the Pacific from southern British Columbia to southeast Alaska. Between 1998 and 2008, we surveyed salmon in various months from June through March, in different regions along the shelf. Variable conditions in the North Pacific Ocean, as well as large overall shifts in ocean regimes were extensively documented over this decade. We employed genetic stock identification to identify mixed-stock compositions; fish (n = 6274) were allocated to one of 15 regional and 40 sub-regional stocks. Catch-per-unit-effort and distribution of salmon, as denoted by centre of mass, varied significantly between seasons, regions and years. In a similar manner, fish body size and dry-weight varied significantly between years, seasons and regions. Despite these inter-annual differences in catch, distribution, fish growth performance and large variations in ocean conditions encountered by salmon over the time period of the study, we observed no response in terms of shifts in stock-specific distributions. Regional stock composition was similar between years, suggesting migration patterns for all stocks remain consistent despite fluctuations in the marine environment: local stocks remain resident in respective coastal areas during their first year at sea, except for Columbia River salmon, which move quickly into waters north of Vancouver Island in summer.

Van Doornik, D. M., Teel, D. J., Kuligowski, D. R., Morgan, C. A., & Casillas, E. (2007). Genetic analyses provide insight into the early ocean stock distribution and survival of juvenile coho salmon off the coasts of Washington and Oregon. ***North American Journal of Fisheries Management*****, *27*(1), 220–237. doi:10.1577/M06-130.1**

Estimating the stock proportions of mixed-stock fishery samples by means of genetic stock identification has played an important role in the management of salmon fisheries. In addition, stock identification of individual fish has applications for population studies, forensic cases, and management issues. We examined 11 microsatellite DNA loci in 84 populations of coho salmon *Oncorhynchus kisutch* sampled at 78 locations from southern British Columbia to northern California to construct a database of microsatellite allele frequencies. We then evaluated the applicability of the database for estimating stock proportions in a mixed fishery and assigning individuals to their regions of origin. The loci were highly polymorphic: observed heterozygosity ranged from 0.754 to 0.943.

Using genetic distance calculations, we identified six major geographic regions and 15 smaller subregions into which the populations grouped. Computer simulations and a sample of 143 coho salmon with known origins showed that the database was sufficient to make accurate stock proportion estimates to the 15 subregions. For the sample of fish with known origins, individual assignments to region of origin were 82.5% accurate for all samples and 97.8% accurate for those where P was greater than 0.95. We used the database to estimate stock proportions and densities of 2,344 coho salmon sampled over eight summers in a juvenile marine ecology study conducted off the coasts of Washington and Oregon. Columbia River juveniles were caught at higher densities than coastal fish throughout the summer. Fish from Columbia River and coastal sources were captured both north and south of their points of sea entry in early summer and at higher densities than in late summer. September catch of Columbia River juveniles was correlated with adult abundance in the following year, indicating that year-class strength for this stock is largely set during the first summer in the ocean.

Volk, E. C., Bottom, D. L., Jones, K. K., & Simenstad, C. A. (2010). Reconstructing juvenile Chinook salmon life history in the Salmon River estuary, Oregon, using otolith microchemistry and microstructure. *Transactions of the American Fisheries Society*, *139*(2), 535–549. doi:10.1577/T08-163.1

We quantified the juvenile rearing and migratory patterns of individuals from a population of fall-spawning Chinook salmon *Oncorhynchus tshawytscha* in Oregon's Salmon River estuary using otolith microchemistry and microstructure. The study confirmed the daily periodicity of otolith growth increments in a natural fish population under field conditions and validated fundamental assumptions about increased otolith strontium: calcium values during entry into saline waters. The otolith results indicated that more than 75% of the subyearling Chinook salmon captured near the mouth of the Salmon River had entered the estuary during the summer and that two-thirds of these fish had spent more than a month in the estuary before capture. Unlike in other Oregon coastal estuaries, in which the fingerling-migrant portion of their life histories is dominant, approximately two-thirds of Salmon River Chinook salmon in upper-estuary marshes were early fry (<50-mm) migrants. A much smaller proportion at the river mouth suggests that many fry migrants did not survive to the lower estuary or passed undetected during ocean emigration. Nonetheless, the otolith results reveal a substantially greater contribution of estuarine-rearing fry to the out-migrant population at the Salmon River than has been reported in other Oregon coastal basins. A small component of fall-migrating fish with long freshwater residence times also occurred at the river mouth. Most of these individuals had migrated quickly through the estuary. Rather than revealing a series of discrete "types" defined by the predominant rearing patterns in the population, the individual otolith results depict a continuum of freshwater and estuarine life histories that is consistent with reports of considerable phenotypic plasticity in Chinook salmon. Otolith analysis offers the potential to quantify the relative contributions of different juvenile rearing patterns to adult returns.

Walker, R. V., Sviridov, V. V., Urawa, S., & Azumaya, T. (2007). Spatio-temporal variation in vertical distributions of Pacific salmon in the ocean. *North Pacific Anadromous Fish Commission Bulletin*, *4*, 193–201.

The vertical distribution of Pacific salmon (*Oncorhynchus* spp.) is of interest to biologists and the fishing industry. An understanding of the normal vertical distribution and movement of salmon facilitates better management of both directed and non-salmon fisheries and better evaluation of research data. Salmon vertical distribution can vary spatially in relation to distance from shore, depth of the water column, and by ocean region, and temporally by life-history stage, season, time of day, and ocean conditions. In coastal waters, juvenile salmon were usually less than 15 m from the surface. In offshore waters, salmon were usually within the top 40 to 60 m, above the thermocline, but occasionally were found from 80 to 120 m. They usually were near the surface at night, and moved vertically during the day. Sockeye salmon displayed the shallowest vertical distribution, followed by pink, coho, chum, and Chinook salmon. There are limited data for winter, but vertical distributions may not change substantially from summer in offshore waters, while it may shift in some species in coastal and shelf areas. There is a need for more long-term data, throughout the marine residency of individual fish.

Webster, S. J., Dill, L. M., & Butterworth, K. (2007). The effect of sea lice infestation on the salinity preference and energetic expenditure of juvenile pink salmon (*Oncorhynchus gorbuscha*). *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(4), 672–680. doi:10.1139/f07-043

Ocean-going juvenile salmonids heavily infected with salmon louse, *Lepeophtheirus salmonis*, have been observed prematurely returning to freshwater. This change in salinity preference may be an attempt either to regain osmotic balance or to remove the lice. For either hypothesis to be true, freshwater habitats must provide infected fish with a higher net fitness than saltwater habitats. The objectives of this study were to use behavioural titration to quantify the energetic cost of different salinities to infected and uninfected pink salmon (*Oncorhynchus gorbuscha*) and to determine if infection alters salinity preference. Results demonstrate that infection changes the salinity preference of fish from saltwater to freshwater. The cost paid by these freshwater-preferring infected fish foraging in saltwater increased with lice density during trials conducted between 13–33 days after infection. Other infection-induced behavioural changes include a 14-fold increase in the jumping frequency of infected versus control fish and a decrease inforaging between 13 and 33 days after infection.

Weitkamp, L. A. (2008). Buoyancy regulation by hatchery and wild coho salmon during the transition from freshwater to marine environments. *Transactions of the American Fisheries Society*, *137*(3), 860–868. doi:10.1577/T07-081.1

One aspect of diadromy that has received little attention is buoyancy regulation in fish moving between freshwater and marine environments. Because of density differences between the two water types, fish must alter their whole-fish density (WFD) or they will become positively (float) or negatively (sink) buoyant as they change environments. This idea was first suggested over 80 year ago but has been largely overlooked by the scientific community. To explore how fish regulate buoyancy during this important transition, I measured WFD and lipid levels and estimated swim bladder volumes (SBVs) of juvenile coho salmon *Oncorhynchus kisutch* collected from freshwater and marine environments. These fish exhibited increased WFD with increasingly dense environments, suggesting active buoyancy regulation. Most of the WFD increase was

attributable to decreases in SBV, although hatchery coho salmon also exhibited decreased lipid levels with increasing WFD. Hatchery coho salmon had significantly higher lipid levels than wild coho salmon in both freshwater and marine environments. These high lipid levels may impede the ability of hatchery fish to regulate buoyancy and may increase their vulnerability to surface predators. Furthermore, lipid levels that vary with both environmental water density and fish origin clearly complicate the interpretation of this variable during the important transition from freshwater to the ocean.

Weitkamp, L. A., Bentley, P. J., & Litz, M. N. C. (2012). Seasonal and interannual variation in juvenile salmonids and associated fish assemblage in open waters of the lower Columbia River estuary. *Fishery Bulletin*, *110*(4), 426–450.

The transition between freshwater and marine environments is associated with high mortality for juvenile anadromous salmonids, yet little is known about this critica lperiod in many large rivers. To address this deficiency, we investigated the estuarine ecology of juvenile salmonids and their associated fish assemblage in open-water habitats of the lower Columbia River estuary during spring of 2007–10. For coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), chum (*O. keta*), and yearling (age 1.0) Chinook (*O. tshawytscha*) salmon, and steelhead (*O. mykiss*), we observed a consistent seasonal pattern characterized by extremely low abundances in mid-April, maximum abundances in May, and near absence by late June. Subyearling (age 0.0) Chinook salmon were most abundant in late June. Although we observed interannual variation in the presence, abundance, and size of juvenile salmonids, no single year was exceptional across all species-and-age classes. We estimated that >90% of juvenile Chinook and coho salmon and steelhead were of hatchery origin, a rate higher than previously reported. In contrast to juvenile salmonids, the abundance and composition of the greater estuarine fish assemblage, of which juvenile salmon were minor members, were extremely variable and likely responding to dynamic physical condition sin the estuary. Comparisons with studies conducted 3 decades earlier suggest striking changes in the estuarine fish assemblage—changes that have unknown but potentially important consequences for juvenile salmon in the Columbia River estuary.

Weitkamp, L. A., Orsi, J. A., Myers, K. W., & Francis, R. C. (2011). Contrasting early marine ecology of Chinook salmon and coho salmon in Southeast Alaska: Insight into factors affecting marine survival. *Marine and Coastal Fisheries*, *3*(1), 233–249. doi:10.1080/19425120.2011.588919

To identify processes potentially contributing to the differential marine survival rates of Chinook salmon *Oncorhynchus tshawytscha* and coho salmon *O. kisutch* originating from Southeast Alaska, we compared the early marine ecology of the two species during the critical first summer in marine waters. We predicted that the higher survival rates for coho salmon relative to Chinook salmon were related to the larger size, faster growth, or different habitat or species associations of coho salmon. Our size and growth expectations were largely substantiated: juvenile coho salmon were larger than juvenile Chinook salmon and had faster length-based growth, although weight-based growth rates were similar. The most obvious difference was in their distributions. Juvenile coho salmon overlapped spatially and temporally with abundant juvenile pink salmon *O. gorbuscha* and chum salmon *O. keta*, whereas juvenile Chinook salmon were

geographically separated from other salmonids. This suggests that coho salmon benefited from a predation buffer that did not extend to Chinook salmon. Our results indicate that factors influencing marine survival of juvenile Chinook salmon and coho salmon in Southeast Alaska are attributable to species-specific differences in their early marine distribution patterns and species interactions.

Weitkamp, L. A., & Sturdevant, M. V. (2008). Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of Southeast Alaska. *Fisheries Oceanography*, *17*(5), 380–395. doi:10.1111/j.1365-2419.2008.00485.x

Little is known about the food habits of juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon in marine environments of Alaska, or whether their diets may have contributed to extremely high marine survival rates for coho salmon from Southeast Alaska and much more modest survival rates for Southeast Alaskan Chinook salmon. To address these issues, we documented the spatial and temporal variability of diets of both species collected from marine waters of Southeast Alaska during summers of 1997–2000. Food habits were similar: major prey items of both species included fishes, crab larvae, hyperiid amphipods, insects, and euphausiids. Multivariate analyses of diet composition indicated that the most distinct groups were formed at the smallest spatial and temporal scales (the haul), although groups also formed at larger scales, such as by month or habitat type. Our expectations for how food habits would influence survival were only partially supported. As predicted, Southeast Alaskan coho salmon had more prey in their stomachs overall [1.8% of body weight (BW)] and proportionally far fewer empty stomachs (0.7%) than either Alaskan Chinook (1.4% BW, 5.1% empty) or coho salmon from other regions. However, contrary to our expectations, coho salmon diets contained surprisingly few fish (49% by weight). Apparently, Alaskan coho salmon achieved extremely high marine survival rates despite a diet consisting largely of small, less energetically-efficient crustacean prey. Our results suggest that diet quantity (how much is eaten) rather than diet quality (what is eaten) is important to marine survival.

Welch, D. W., Melnychuk, M. C., Payne, J. C., Rechisky, E. L., Porter, A. D., Jackson, G. D., Ward, B. R., Vincent, S. P., Wood, C. C., & Semmens, J. (2011). In situ measurement of coastal ocean movements and survival of juvenile Pacific salmon. *Proceedings of the National Academy of Sciences*, *108*(21), 8708–8713. doi:10.1073/pnas.1014044108

Many salmon populations in both the Pacific and Atlantic Oceans have experienced sharply decreasing returns and high ocean mortality in the past two decades, with some populations facing extirpation if current marine survival trends continue. Our inability to monitor the movements of marine fish or to directly measure their survival precludes experimental tests of theories concerning the factors regulating fish populations, and thus limits scientific advance in many aspects of fisheries management and conservation. Here we report a large-scale synthesis of survival and movement rates of free-ranging juvenile salmon across four species, 13 river watersheds, and 44 release groups of salmon smolts (>3,500 fish tagged in total) in rivers and coastal ocean waters, including an assessment of where mortality predominantly occurs during the juvenile migration. Of particular importance, our data indicate that, over the size range of smolts tagged, (i) smolt survival

was not strongly related to size at release, (ii) tag burden did not appear to strongly reduce the survival of smaller animals, and (iii) for at least some populations, substantial mortality occurred much later in the migration and more distant from the river of origin than generally expected. Our findings thus have implications for determining where effort should be invested to improve the accuracy of salmon forecasting, to understand the mechanisms driving salmon declines, and to predict the impact of climate change on salmon stocks.

Welch, D. W., Melnychuk, M. C., Rechisky, E. R., Porter, A. D., Jacobs, M. C., Ladouceur, A., McKinley, R. S., & Jackson, G. D. (2009). Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. *Canadian Journal of Fisheries and Aquatic Sciences*, *66*(5), 736–750. doi:10.1139/F09-032

Freshwater and early marine migration and survival of endangered Cultus Lake sockeye (*Oncorhynchus nerka*) salmon were studied using the Pacific Ocean Shelf Tracking (POST) array. Smolts were acoustically tagged in 2004–2007, and their migration was recorded within the lower Fraser River and coastal southern British Columbia waters. Most smolts showed rapid directional movement (swimming speeds of ~15–30 km·day^{-1}). Average exit time from the Fraser River was 4.0–5.6 days after release, and average residence time within the Strait of Georgia was 25.6–34.1 days. Most individuals migrated northward, generally close to the mainland coast. Survival rates, assessed using standard mark–recapture methods, were generally high during the downstream migration (50%–70%), except in 2005 when survival was <20%, possibly because of a late release. Marine survival rates were stable among years, between 10%–30% at a subarray sited 500 km away from the release site. Movement rates were similar to those of previously published work, but the POST array provided direct measurements of movement and estimates of survival and demonstrated the feasibility of establishing continental-scale acoustic arrays for management and conservation of marine species.

Welch, D. W., Rechisky, E. L., Melnychuk, M. C., Porter, A. D., Walters, C. J., Clements, S., Clemens, B. J., McKinley, R. S., & Schreck, C. (2008). Survival of migrating salmon smolts in large rivers with and without dams. *PLoS Biol*, *6*(10), e265. doi:10.1371/journal.pbio.0060265

The mortality of salmon smolts during their migration out of freshwater and into the ocean has been difficult to measure. In the Columbia River, which has an extensive network of hydroelectric dams, the decline in abundance of adult salmon returning from the ocean since the late 1970s has been ascribed in large measure to the presence of the dams, although the completion of the hydropower system occurred at the same time as large-scale shifts in ocean climate, as measured by climate indices such as the Pacific Decadal Oscillation. We measured the survival of salmon smolts during their migration to sea using elements of the large-scale acoustic telemetry system, the Pacific Ocean Shelf Tracking (POST) array. Survival measurements using acoustic tags were comparable to those obtained independently using the Passive Integrated Transponder (PIT) tag system, which is operational at Columbia and Snake River dams. Because the technology underlying the POST array works in both freshwater and the ocean, it is therefore possible to extend the measurement of survival to large rivers lacking dams,

such as the Fraser, and to also extend the measurement of survival to the lower Columbia River and estuary, where there are no dams. Of particular note, survival during the downstream migration of at least some endangered Columbia and Snake River Chinook and steelhead stocks appears to be as high or higher than that of the same species migrating out of the Fraser River in Canada, which lacks dams. Equally surprising, smolt survival during migration through the hydrosystem, when scaled by either the time or distance migrated, is higher than in the lower Columbia River and estuary where dams are absent. Our results raise important questions regarding the factors that are preventing the recovery of salmon stocks in the Columbia and the future health of stocks in the Fraser River.

Wells, B. K., Grimes, C. B., Sneva, J. G., McPherson, S., & Waldvogel, J. B. (2008). Relationships between oceanic conditions and growth of Chinook salmon (*Oncorhynchus tshawytscha*) from California, Washington, and Alaska, USA. *Fisheries Oceanography*, *17*(2), 101–125. doi:10.1111/j.1365-2419.2008.00467.x
We model age-specific growth rates of Chinook salmon (*Oncorhynchus tshawytscha*) with two life-history behaviors from Alaska (i. Situk and ii.Taku Rivers), Puget Sound, Washington (iii., iv. Skagit River), and California (v. Smith River) relative to oceanic conditions in those regions. By analyzing over 20 yr of biological and physical data from the NE Pacific downwelling, upwelling, and transition zones, we are able to determine the factors affecting growth across much of the species' range and between life-history behaviors. With scale increment data from returning fish, we use path analysis and partial least squares regression to quantify the relationships between growth and regional- and large-scale oceanic conditions (e.g., sea level height, sea surface temperature, upwelling). Alaskan fish with both ocean- and stream-type behaviors were fit best by the environmental data from the winter in Alaska waters. Specifically, coastal and gyre factors such as sea surface temperature, river flow, and Ekman pumping positively correlated to growth, indicating a productive and strong Alaska Current promoted growth. Growth of fish from California was fit by local factors such as increased upwelling, lower coastal sea surface temperature, and wind stresses during summer and spring, indicating a productive and strong California Current promoted growth. For Puget Sound, Washington, growth of fish that migrate to sea in their first year was generally negatively correlated to a strong California Current. Puget Sound fish that spend a year in freshwater before migrating to sea were modeled well with environmental data from their source region for the first 2 yr at sea and by data from Alaska waters in their third year at sea. Results suggest that conditions in which the transition zone is dominated by neither the Alaska nor California Currents are best for increased growth of Puget Sound fish.

Wells, B. K., Grimes, C. B., & Waldvogel, J. B. (2007). Quantifying the effects of wind, upwelling, curl, sea surface temperature and sea level height on growth and maturation of a California Chinook salmon (*Oncorhynchus tshawytscha*) population. *Fisheries Oceanography*, *16*(4), 363–382. doi:10.1111/j.1365-2419.2007.00437.x
We used retrospective scale growth chronologies and return size and age of female Chinook salmon (*Oncorhynchus tshawytscha*) from a northern California, USA, population collected over 22 run years and encompassing 18 complete cohorts to model the effects of oceanographic conditions on growth during ocean residence. Using path

analyses and partial least squares regressive approaches, we related growth rate and maturation to seven environmental variables (sea level height, sea surface temperature, upwelling, curl, scalar wind, northerly pseudo-wind stress and easterly pseudo-wind stress). During the first year of life, growth was negatively related to summer sea surface temperature, curl and scalar winds, and was positively related to summer upwelling. During the second, third and fourth growth years growth rate was negatively related to sea level height and sea surface temperature, and was positively related to upwelling and curl. The age at maturation and the fork length at which three ocean-winter fish returned were related to the environment experienced during the spring before the third winter at sea (the year prior return). Faster growth during the year before return led to earlier maturation and larger return size.

Wells, B. K., Santora, J. A., Field, J. C., MacFarlane, R. B., Marinovic, B. B., & Sydeman, W. J. (2012). Population dynamics of Chinook salmon *Oncorhynchus tshawytscha* relative to prey availability in the central California coastal region. *Marine Ecology Progress Series*, *457*, 125–137. doi:10.3354/meps09727

Mortality during the first period at sea is thought to be a primary determinant of salmon productivity and return rates. Here, we test this hypothesis by linking variation in prey resources during the initial phase at sea with measurements of central California Chinook salmon *Oncorhynchus tshawytscha* diet, condition, and later adult abundance. Specifically, we investigate linkages between the distribution and abundance of krill and other prey with juvenile Chinook salmon diet and body condition. Hydrographic features of the Gulf of the Farallones during May and June were related to the abundance and spatial organization of Chinook salmon prey. When upwelling was reduced, there were fewer krill on the inner Gulf of the Farallones shelf, thereby less available to outgoing juvenile Chinook salmon smolts. Notably, we found a 1 yr lag in the relationship between the abundance of adult *Thysanoessa spinifera* and the volume of krill in the diet of juvenile Chinook salmon. Body condition of juvenile Chinook salmon was positively related to the abundance of adult krill the year before and specifically to the proportion of *T. spinifera* in the diet. In turn, the condition of juvenile Chinook salmon was correlated to the abundance of mature Chinook salmon returning from the same cohort the next year. This information may be useful for fisheries management by improving sibling-based forecasting models as well as informing escapement goals.

Wertheimer, A. C., Orsi, J. A., Fergusson, E. A. & M. V. Sturdevant. (2010). Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters: 2009 harvest and 2010 forecast. *North Pacific Andaromous Fish Comission Document, 1278*, 19 pp.

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated environmental parameters in northern Southeast Alaska (SEAK) annually since 1997 to better understand effects of environmental change on salmon production. A pragmatic application of this sampling effort is to forecast the abundance of adult salmon returns in subsequent years. Since 2004, juvenile peak salmon catch per unit effort (CPUE) from SECM, modified by other environmental parameters as appropriate, has been used to forecast harvest of adult pink salmon (*O. gorbuscha*) in SEAK. The 2009 return of 38.0 million fish was 17% below

the forecast of 44.4 million. This represents the fifth forecast over the period 2004-2009 which was within 0-17% of the actual harvest. Conversely, the forecast for 2006 did not follow this pattern and was 200% higher than the actual harvest; however, the simple CPUE forecast model did indicate a downturn in harvest that year. These results show that the CPUE information has great utility for forecasting year class strength of SEAK pink salmon, but additional environmental data are needed to avoid "misses" such as the forecast of the 2006 return. Beginning with the forecast for the 2007 return, the simple CPUE forecast model was enhanced to include stepwise multiple regression, jackknife hindcast analysis, and bootstrap confidence intervals. For 2010, a three-parameter model was selected as the "best" forecast model. Juvenile pink salmon CPUE in northern SEAK accounted for 82% of the variability in annual harvest of SEAK pink salmon over the period 1997-2009. The amount of variability explained was improved to 94% when the May 20-m integrated sea water temperatures and an index of the El Niño Southern Oscillation (ENSO) were included in the model. The forecast for the 2010 harvest was 26.8 million fish, with an 80% bootstrap confidence interval of 18-35 million fish. Preliminary end of the season pink salmon harvests for 2010 are currently 23.4 million (17 Sept 2010, Alaska Department of Fish and Game) and are within 15% of the SECM 2010 harvest forecast.

Wertheimer, A. C., Orsi, J. A., Fergusson, E. A. & M. V. Sturdevant. (2011). Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters: 2010 harvest and 2011 forecast. ***North Pacific Andaromous Fish Comission Document, 1343*****, 20 pp.**

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated environmental parameters in northern Southeast Alaska (SEAK) annually since 1997 to better understand effects of environmental change on salmon production. A pragmatic application of the annual sampling effort is to forecast the abundance of adult salmon returns in subsequent years. Since 2004, juvenile peak salmon catch per unit effort (CPUE) from SECM, adjusted for highly-correlated environmental parameters, has been used to forecast harvest of adult pink salmon (*O. gorbuscha*) in SEAK. The 2010 forecast of 26.8 M fish was 15% higher than the actual harvest of 23.4 M fish. Six forecasts produced over the period 2004-2010 have been within 0-17% of the actual harvest, with an average forecast deviation of 7.9%. However, the forecast for 2006 did not follow this pattern. The simple CPUE forecast model indicated a downturn in the harvest, but the prediction was 209% higher than the actual harvest. These results show that the CPUE information has great utility for forecasting year class strength of SEAK pink salmon, but additional information may be needed to avoid "misses" such as the forecast for the 2006 return. For the 2011 forecast, model selection included a review of ecosystem indicator variables and considered additional environmental parameters to improve the simple single-parameter CPUE forecast model. The single parameter model was selected as the "best" forecast model for 2011. Juvenile pink salmon CPUE in northern SEAK accounted for 82% of the variability in annual harvest of SEAK pink salmon over the period 1997-2010. The 2011 forecast from this model, using juvenile salmon data collected in 2010, was 56.2 M fish, with an 80% bootstrap confidence interval of 47-62 M fish. Over the past seven years, the

use of the SECM time series of CPUE data and associated environmental parameters has largely been successful in forecasting year-class strength of pink salmon in SEAK.

Wertheimer, A. C., Orsi, J. A., Fergusson, E. A. & M. V. Sturdevant. (2012). Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters: 2011 harvest and 2012 forecast. ***North Pacific Andaromous Fish Comission Document, 1414*****, 20 pp.**

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated biophysical parameters in northern Southeast Alaska (SEAK) annually since 1997 to better understand the effects of environmental change on salmon production. A pragmatic application of the annual sampling effort is to forecast the abundance of adult salmon returns in subsequent years. Since 2004, juvenile peak salmon catch per unit effort (CPUE) from SECM, adjusted for highly-correlated biophysical parameters, has been used to forecast harvest of adult pink salmon (*O. gorbuscha*) in SEAK. The 2011 forecast of 56.2 M fish was 5% lower than the actual harvest of 59.0 M fish. Seven of eight forecasts produced over the period 2004-2011 have been within 0-17% of the actual harvest, with an average forecast deviation of 7%. The forecast for 2006 was the exception; while the simple CPUE model indicated a downturn in harvest, the prediction still overestimated the harvest by 209%. These results show that the CPUE information has great utility for forecasting year-class strength of SEAK pink salmon, but additional information may be needed to avoid "misses" such as the forecast for the 2006 return. For the 2012 forecast, model selection included a review of ecosystem indicator variables and considered additional biophysical parameters to improve the simple single-parameter CPUE forecast model. A two-parameter model, including May temperature data as well as juvenile CPUE, was selected as the "best" forecast model for 2012. The 2012 forecast from this model, using juvenile salmon data collected in 2011, was for 18.8 M fish, with an 80% bootstrap confidence interval of 13-25 M fish.

Wertheimer, A. C., Orsi, J. A., Fergusson, E. A. & M. V. Sturdevant. (2013). Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters: 2012 harvest and 2013 forecast. ***North Pacific Andaromous Fish Comission Document, 1486*****, 24 pp.**

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated biophysical parameters in northern Southeast Alaska (SEAK) annually since 1997 to better understand the effects of environmental change on salmon production. A pragmatic application of the annual sampling effort is to forecast the abundance of adult salmon returns in subsequent years. Since 2004, juvenile peak salmon catch per unit effort (CPUE) from SECM, adjusted for highly-correlated biophysical parameters, has been used to forecast harvest of adult pink salmon (*O. gorbuscha*) in SEAK. The 2012 forecast of 18.8 M fish was 12 % lower than the actual harvest of 21.3 M fish. Eight of nine forecasts produced over the period 2004-2012 have been within 17% of the actual harvest, with an average forecast deviation of 7%. The forecast for 2006 was the exception; while the simple CPUE model indicated a downturn in harvest, the prediction substantially overestimated the harvest. These results show that the CPUE information has great utility for forecasting year class strength of SEAK pink

salmon, but additional information may be needed to avoid forecast "misses." For the 2013 forecast, model selection included a review of ecosystem indicator variables and considered additional biophysical parameters to improve the simple single-parameter juvenile CPUE forecast model. The "best" forecast model for 2013 included two parameters, the Icy Strait Temperature Index (ISTI) and juvenile CPUE. The 2013 forecast of 53.8 M fish from this model, using juvenile salmon data collected in 2012, had an 80% bootstrap confidence interval of 48-60 M fish.

Wertheimer, A. C., & Thrower, F. P. (2007). Mortality rates of chum salmon during their early marine residency. *American Fisheries Society Symposium, 57,* 233-247.
Interannual variability in chum salmon *Oncorhynchus keta* mortality during early marine life is thought to have a major influence on recruitment. However, few estimates of daily mortality are available for chum salmon during this period, and average values reported in the literature are unrealistically high when used in a simple life-history model. We analyzed survival to adult of seven groups of chum salmon, marked as juveniles, and released at different times and sizes at Little Port Walter, Alaska to estimate average daily mortality during early marine residency for an early emigration group and a late emigration group. We assumed that differences in proportions of groups surviving to adult between the initial releases of unfed fry and subsequent releases of fed fry for each group were due to natural mortality during the time interval between releases. For both groups, mortality was highest during the period immediately after release, declining rapidly thereafter. Average daily mortality was 8 % for the early release during their first 2 d in the ocean and 3.9% for the late release during the first 32 d in the ocean. After May 4 (54 d and 33 d postrelease, respectively, for the early and late groups), average daily mortality was less than 0.6% for both groups. These results support the paradigm that most of the mortality of chum salmon in the ocean occurs early in their marine residency, and the results provide realistic rates for demographic modeling of the abundance of chum salmon in marine habitats.

Williams, J. G., Smith, S. G., Fryer, J. K., Scheuerell, M. D., Muir, W. D., Flagg, T. A., Zabel, R. W., Ferguson, J. W., & Casillas, E. (2014). Influence of ocean and freshwater conditions on Columbia River sockeye salmon *Oncorhynchus nerka* adult return rates. *Fisheries Oceanography*, *In press*
In recent years, returns of adult sockeye salmon *Oncorhynchus nerka* to the Columbia River Basin have reached numbers not observed since the 1950s. To understand factors related to these increased returns, we first looked for changes in freshwater production and survival of juvenile migrants. We then evaluated productivity changes by estimating smolt-to-adult return rates (SAR) for juvenile migration years 1985–2010. We found SAR varied between 0.2 and 23.5%, with the highest values coinciding with recent large adult returns. However, the largest adult return, in 2012, resulted not from increased survival, but from increased smolt production. We evaluated 19 different variables that could influence SARs, representing different facets of freshwater and ocean conditions. We used model selection criteria based on small-sample corrected AIC to evaluate the relative performance of all two- and three-variable models. The model with April upwelling, Pacific Northwest Index (PNI) in the migration year, and PNI in the year before migration had 10 times the AICc weight as the second-best-supported model, and

R^2 = 0.82. The variables of April ocean upwelling and PNI in the migration year had high weights of 0.996 and 0.927, respectively, indicating they were by far the best of the candidate variables to explain variations in SAR. While our analyses were primarily correlative and limited by the type and amount of data currently available, changes in ocean conditions in the northern California Current system, as captured by April upwelling and PNI, appeared to play a large role in the variability of SAR.

Wood, C. C., Welch, D. W., Godbout, L., & Cameron, J. (2011). Marine migratory behavior of hatchery-reared anadromous and wild non-anadromous sockeye salmon revealed by acoustic tags. *American Fisheries Society Symposium, 76, 289-311.*
We investigated the marine migratory behavior and survival of Sakinaw Lake sockeye salmon *Oncorhynchus nerka* during their outbound migration as juveniles and return migration as adults two or more years later by tracking individuals that had been implanted with Vemco acoustic tags programmed to have two periods of active transmission. We tracked both hatchery-reared anadromous sockeye salmon ("hatchery sockeye") and wild nonanadromous "kokanee," two genetically-distinct, sympatric ecotypes inhabiting Sakinaw Lake, British Columbia. Tagged kokanee were distinguished from wild sockeye by haplotype frequencies at two mitochondrial DNA genes. Migrations were inferred from detections by the Pacific Ocean Shelf Tracking (POST) receivers, and supplemental tracking near the release site and in Sakinaw Lake. We found no significant differences between the ecotypes in the proportion of "migratory" fish (those detected migrating seaward by POST telemetry in the year of release, 42% of all 254 fish released) or in the proportion of ocean-going fish (those detected at receivers near the open ocean, 20% of all fish released). Seaward migration in both ecotypes was primarily northward through Johnstone Strait in 2 of the 3 years studied (92% of migratory fish in 2004 and 84% in 2006). A significantly higher proportion of fish moved southward in 2005 (45% of migratory fish) than in 2004 or 2006, but this difference could not be attributed to ecotype, body size, or release date. One significant difference observed between the ecotypes was that 6 kokanee but no sockeye migrated back into Sakinaw Lake within 2 weeks of release in 2006. The number of tagged fish detected as returning adults with operational tags was low (3 sockeye at the release site and 2 kokanee at Sakinaw Creek), but none of these fish had been detected crossing seaward POST lines as juveniles and thus appeared to be nonmigratory. The adult return rate of these non migratory tagged fish (3.4% in sockeye, 4.3% in kokanee) was higher than for migratory tagged fish (0% for both ecotypes). This discrepancy suggests that factors outside the Strait of Georgia have caused the poor marine survival that is preventing recovery of the endangered Sakinaw sockeye population (mean <0.2% since 2003).

Woodson, L. E., Wells, B. K., Weber, P. K., MacFarlane, R. B., Whitman, G. E., & Johnson, R. C. (2013). Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. *Marine Ecology Progress Series*, *487*, 163–175. doi:10.3354/meps10353
Selective mortality during early life history stages can have significant population-level consequences, yet critical periods when selective mortality occurs, the strength of selection, and under what environmental conditions can be difficult to identify. Here, we

used otolith microstructure and chemistry to examine the factors potentially linked to selective mortality of juvenile fall-run Chinook salmon *Oncorhynchus tshawytscha* from California's Central Valley during early ocean residence. Back-calculated size and growth rates of the population were compared across 3 sample periods: as juveniles exited the San Francisco Bay estuary (estuary-exit), after their first month at sea (summer-ocean) and 5 mo after ocean entry (fall-ocean). We compared mortality dynamics during years of exceptional recruitment (addition of individuals to harvestable population; 2000 and 2001) to a year of poor recruitment (2005). Otoliths from 2005 were also analyzed for sulfur isotopes to discern hatchery from naturally spawned stock. Significant size and growth-rate selective mortality were detected during the first month at sea in the low recruitment year of 2005, but not in 2000 and 2001. Individuals that were larger and growing faster during freshwater and estuarine rearing were more likely to survive to summer and fall in the low recruitment year. There was a slight, but insignificant, increase in the proportion of hatchery to naturally spawned individuals from estuary-exit to fall-ocean, suggesting that fish from neither origin were overwhelmingly favored. Our results suggest that Central Valley Chinook salmon can be subject to significant size and growth-rate selective mortality resulting in low adult abundance, and this mortality appears independent of origin.

Yu, H., Bi, H., Burke, B., Lamb, J., & Peterson, W. (2012). Spatial variations in the distribution of yearling spring Chinook salmon off Washington and Oregon using COZIGAM analysis. *Marine Ecology Progress Series*, *465*, 253–265. doi:10.3354/meps09909

Yearling Chinook salmon *Oncorhynchus tshawytscha* were sampled off Washington and Oregon, USA, along with environmental factors, every June from 1998 to 2010. The abundance of yearling Chinook salmon varied over space with a high proportion of zero catches. Positive catches were more numerous north of the Columbia River, likely because most yearling Chinook salmon turn north after leaving the Columbia River. Using the latitude of the Columbia River mouth as a geographical border, the survey area was divided into 2 regions: north and south of the Columbia River. We hypothesized that (1) the spatial distribution pattern within each region was related to local environmental factors and (2) the difference between north and south was related to large-scale ocean processes. A constrained zero-inflated generalized additive model (COZIGAM) was applied to examine the non-linear relationships between juvenile salmon abundance and environmental factors. Results from the COZIGAM suggested that water temperature, chlorophyll *a* (chl *a*) concentration, copepod biomass and spatial factors were significantly correlated with the density of salmon in the northern region, and only chl a concentration was correlated significantly with yearling Chinook density in the southern region. The difference between the abundances north and south of the Columbia River was significantly correlated with alongshore ocean currents, with weaker alongshore currents leading to greater difference between north and south. Results suggest that salmon distribution is determined not only by standard habitat parameters (local biotic and abiotic factors) but by ocean conditions such as the strength of alongshore coastal currents.

Zabel, R. W., Scheuerell, M. D., McClure, M. M., & Williams, J. G. (2006). The Interplay

between Climate Variability and Density Dependence in the Population Viability of Chinook Salmon. ***Conservation Biology*****,** ***20*****(1), 190–200. doi:10.1111/j.1523-1739.2005.00300.x**

The viability of populations is influenced by driving forces such as density dependence and climate variability, but most population viability analyses (PVAs) ignore these factors because of data limitations. Additionally, simplified PVAs produce limited measures of population viability such as annual population growth rate (λ) or extinction risk. Here we developed a "mechanistic" PVA of threatened Chinook salmon (*Oncorhynchus tshawytscha*) in which, based on 40 years of detailed data, we related freshwater recruitment of juveniles to density of spawners, and third-year survival in the ocean to monthly indices of broad-scale ocean and climate conditions. Including climate variability in the model produced important effects: estimated population viability was very sensitive to assumptions of future climate conditions and the autocorrelation contained in the climate signal increased mean population abundance while increasing probability of quasi extinction. Because of the presence of density dependence in the model, however, we could not distinguish among alternative climate scenarios through mean λ values, emphasizing the importance of considering multiple measures to elucidate population viability. Our sensitivity analyses demonstrated that the importance of particular parameters varied across models and depended on which viability measure was the response variable. The density-dependent parameter associated with freshwater recruitment was consistently the most important, regardless of viability measure, suggesting that increasing juvenile carrying capacity is important for recovery.

Zeug, S. C., & Cavallo, B. J. (2013). Influence of estuary conditions on the recovery rate of coded-wire-tagged Chinook salmon (*Oncorhynchus tshawytscha*) in an ocean fishery. ***Ecology of Freshwater Fish*****,** ***22*****(1), 157–168. doi:10.1111/eff.12013**

Chinook salmon (*Oncorhynchus tschawytscha*) populations within the highly modified San Francisco Estuary, California, have seen precipitous declines in recent years. To better understand this decline, a decade of coded-wire tag release and recovery data for juvenile salmon was combined with physicochemical data to construct models that represented alternative hypotheses of estuarine conditions that influence tag recovery rate in the ocean. An information theoretic approach was used to evaluate the weight of evidence for each hypothesis and model averaging was performed to determine the level of support for variables that represented individual hypotheses. A single best model was identified for salmon released into the Sacramento River side of the estuary, whereas two competitive models were selected for salmon released into the San Joaquin River side of the estuary. Model averaging found that recovery rates were greatest for San Joaquin River releases when estuary water temperatures were lower, and salmon were released at larger sizes. Recovery rate of Sacramento releases was greatest during years with better water quality. There was little evidence that large-scale water exports or inflows influenced recovery rates in the ocean during this time period. These results suggest that conceptual models of salmon ecology in estuaries should be quantitatively evaluated prior to implementation of recovery actions to maximise the effectiveness of management and facilitate the recovery of depressed Chinook populations.