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Bibliography of Publications on the Marine Ecology of Juvenile Pacific Salmon in North America, 2014-2015

by

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Abstract

In this document, we compile primary publications and NPAFC documents that pertain to the marine ecology of juvenile Pacific salmon (*Oncorhynchus* spp.). This document is an update to a previous bibliography that formed the basis of a review at the "Third International Workshop on Migration and Survival Mechanisms of Juvenile Salmon and Steelhead in Ocean Ecosystems" in Honolulu.

Introduction

The year-class strength of many Pacific salmon (*Oncorhynchus* spp.) stocks and species is believed to be influenced by their early marine ecology. As such, understanding early marine ecology of Pacific salmon may be critical to forecasting and fisheries management.

Previously, we reviewed research on the marine ecology of juvenile Pacific salmon in North America since the "Second NPAFC International Workshop on Factors Affecting Production of Juvenile Salmon" held in Sapporo, Japan, in 2006 (Trudel and Hertz 2013). From this review, we produced a bibliography of all relevant references that we could find that pertained to the marine ecology of juvenile Pacific salmon in North America up to April 2014 (Hertz and Trudel 2014). Here, we provide an updated bibliography of material that has been published up to April 2015. This compilation includes primary publications in peer-reviewed journals, as well as applicable NPAFC Bulletins and Documents that were available to the public. We did not include review papers, comments and responses, or papers that only considered methodological topics (e.g effects of acoustic tags). We thank the many authors who provided information for this bibliography.

Results and Discussion

The number of peer-reviewed publications in 2014 (n=61) was more than double the average from 2006-2013 (n=27). This pattern is inductive of the increasing trend in publications on the marine ecology of juvenile Pacific salmon in North America (Figure 1). To April in 2015, there were already 22 peer-reviewed papers published, suggesting that 2015 will likely end up with more publications than the long term average.

The majority of papers published in 2014-2015 were on the Washington/Oregon region (n=44) largely reflective of the considerable research on the Columbia River salmon populations (Figure 2). There were 26 papers on British Columbia salmon, 11 papers on each of California and Gulf of Alaska, and only 3 on Bering Sea salmon.

The primary species-of-interest was Chinook Salmon (n=45) which was studied in more than double the number of papers than other species. This is likely due to its low conservation status in many regions, coupled with high economic value. There were 19 publications concerning Coho Salmon, 17 on each of Sockeye and Steelhead Salmon, 8 on Pink Salmon and only 7 on Chum Salmon. Interestingly, there species that are most abundant (Pink and Chum) are the least studied in North America. Conversely, the least abundant species were the most studied, likely a result reflecting species distribution and conservation concerns.

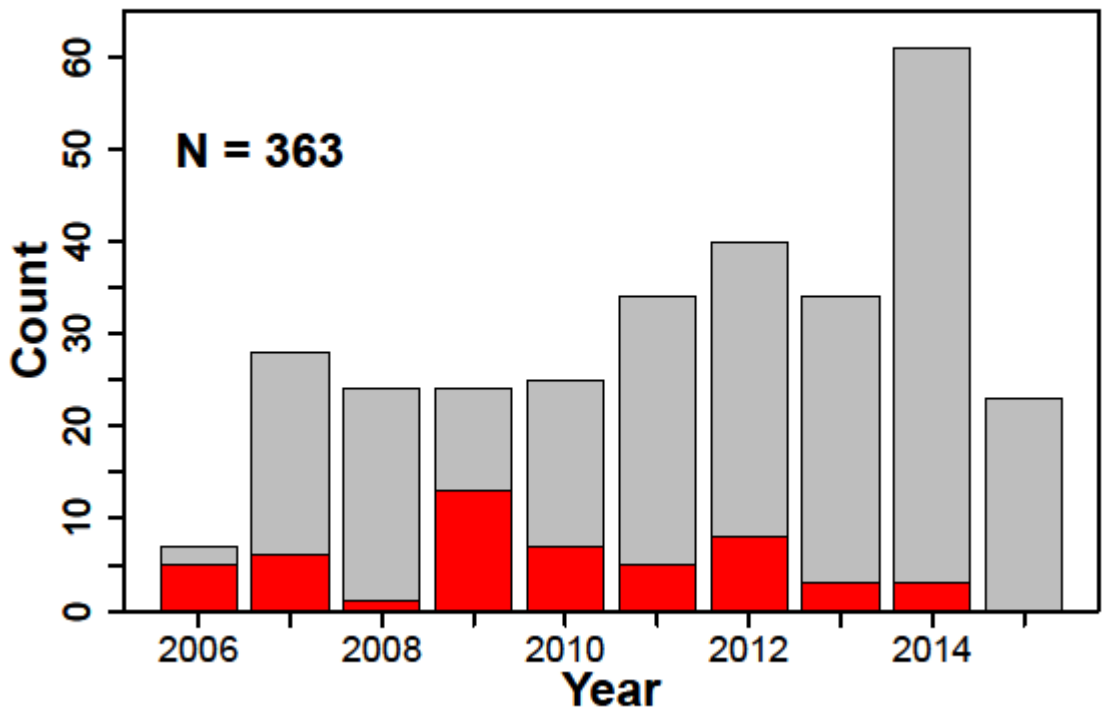

Figure 1: Peer-reviewed journal articles (grey bars) and NPAFC publications (red bars) published between 2006 and April 2015 on the marine ecology of juvenile Pacific salmon in North America.

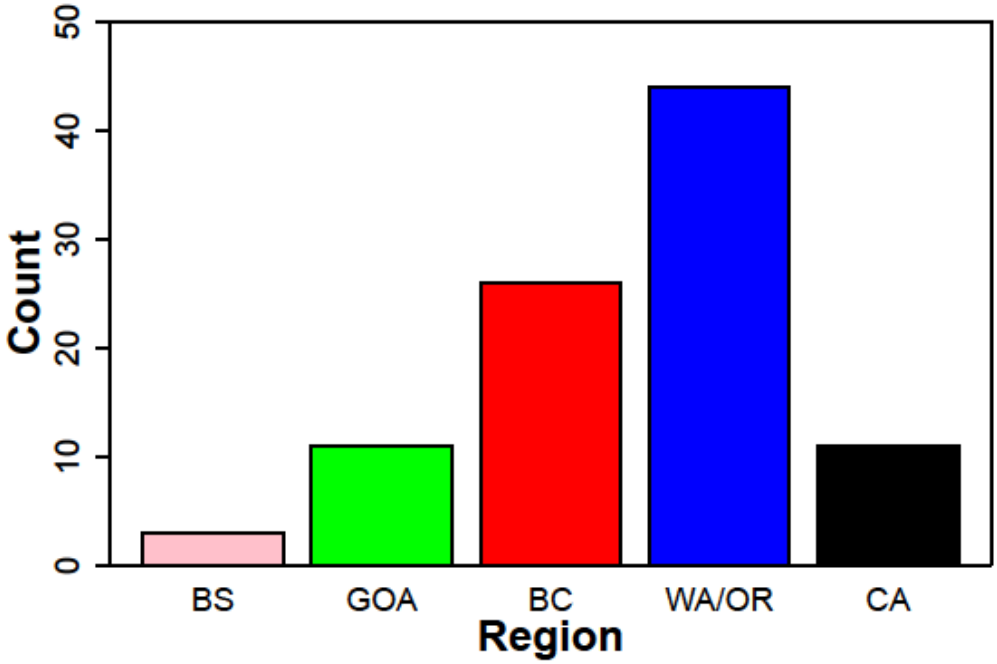

Figure 2: Region covered by publications on the marine ecology of juvenile Pacific salmon from 2014 to April 2015. BS is the Bering Sea, GOA is the Gulf of Alaska (including Alaska coastal waters), BC is British Columbia, WA/OR is Washington/Oregon, and CA is California.

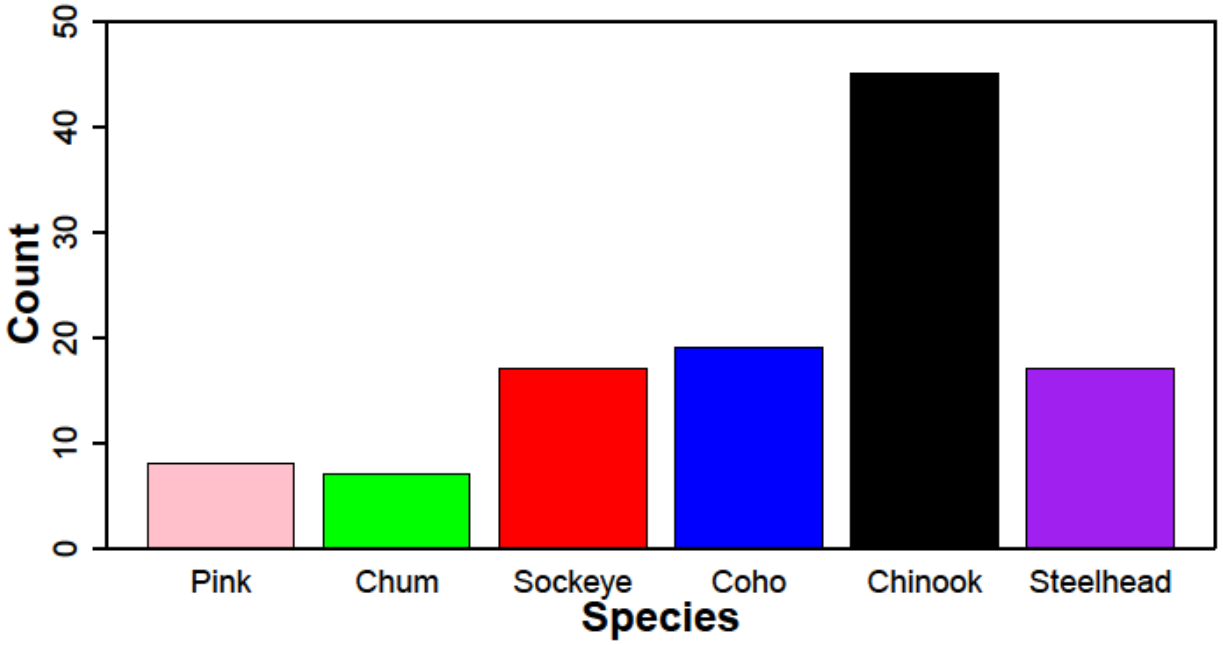

Figure 3: Species-of-concern in publications on the marine ecology of juvenile Pacific salmon from 2014 to April 2015.

References

Hertz, E. & M. Trudel. (2014). Bibliography of publications on the marine ecology of juvenile Pacific salmon in North America, 2006-2014. *North Pacific Anadromous Fish Commission Document,* 1520. 147 pp.

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.

Araujo, H. A., Candy, J. R., Beacham, T. D., White, B., & Wallace, C. (2014). Advantages and challenges of genetic stock identification in fish stocks with low genetic resolution. *Transactions of the American Fisheries Society*, *143*(2), 479–488. http://doi.org/10.1080/00028487.2013.855258

Genetic stock identification (GSI) is widely applied to mixed-stock fisheries for many commercially exploited species. However, the accuracy of GSI depends on the level of differentiation among stocks. To evaluate our ability to estimate contributions in mixed-stock fisheries of Pink Salmon *Oncorhynchus gorbuscha*, a species with limited population genetic differentiation, we analyzed 46 odd-year Pink Salmon stocks belonging to a baseline of genotypes from southern British Columbia, the Fraser River, and Puget Sound. Samples were obtained without replacement from the baseline (known mixtures), and 16 microsatellite loci were used for analysis with two software packages (cBayes and ONCOR) to evaluate the accuracy of using this marker set to identify the correct region, subregion, and spawning site. The correct subregion was identified for Pink Salmon from southern British Columbia and Puget Sound. However, incorrect assignments were observed for the Fraser River subregions and the stock-specific estimates. In addition, we used simulated baselines with the average genetic differentiation index F (ST) ranging from 0.0007 to 0.04 (the range of F (ST) values observed in Pink Salmon stocks) to identify biases in the GSI software programs. The results suggested that stock-level genetic identification is subject to significant biases (>15%) when the average F (ST) among baseline stocks is less than 0.01. ONCOR was more accurate than cBayes in identifying the correct stock at small mean F (ST) values (<0.01), but there was no significant difference between the software packages at larger F (ST) values. Our results can help to improve GSI methods and to identify their limitations, especially for stocks with low genetic separation.

Beacham, T. D., Beamish, R. J., Candy, J. R., Wallace, C., Tucker, S., Moss, J. H., & Trudel, M. (2014a). Stock-specific migration pathways of juvenile Sockeye Salmon in British Columbia waters and in the Gulf of Alaska. *Transactions of the American Fisheries Society*, *143*(6), 1386–1403. http://doi.org/10.1080/00028487.2014.935476

We outlined the route and relative timing of juvenile Sockeye Salmon *Oncorhynchus nerka* migration by analyzing stock composition and relative CPUE in marine sampling conducted in coastal British Columbia and the Gulf of Alaska. Variation at 14 microsatellites was analyzed for 10,500 juvenile Sockeye Salmon obtained from surveys conducted during 1996–2011. Using a 404-population baseline, we identified the sampled individuals to 47 populations or stocks of origin. Stock compositions of the mixtures increased in diversity in more northerly sampling locations, indicating a general northward movement of juveniles. The primary migration route of Columbia River and Washington stocks was northward along the west coast of Vancouver Island, with a majority of the juveniles subsequently migrating through Queen Charlotte Sound and Dixon Entrance. Fraser River stocks migrated principally through the Strait of Georgia and Johnstone Strait. Some Fraser River populations, such as the Cultus Lake population, appeared to spend little time rearing in the Strait of Georgia, as individuals from this population were primarily observed in July samples from Hecate Strait, Dixon Entrance, and Southeast Alaska. Other Fraser River populations, such as the Chilko Lake and Quesnel Lake populations, were widely distributed during July surveys, as they were observed from the Gulf of Alaska to the Strait of Georgia. For the British Columbia central coast and Owikeno Lake stocks, not all individuals migrated northward in the summer: some individuals were still present in local areas during the fall and winter after spring entry into the marine environment. Juvenile Fraser River

Sockeye Salmon dominated the catch of juveniles at the Yakutat, Prince William Sound, Kodiak Island, and Alaska Peninsula sampling locations. There was a wide divergence among stocks in dispersion among sampling locations.

Beacham, T. D., Beamish, R. J., Candy, J. R., Wallace, C., Tucker, S., Moss, J. H., & Trudel, M. (2014b). Stock-specific size of juvenile Sockeye Salmon in British Columbia waters and the Gulf of Alaska. *Transactions of the American Fisheries Society*, *143*(4), 876–889. http://doi.org/10.1080/00028487.2014.889751

The variation at 14 microsatellites was analyzed for 10,500 juvenile Sockeye Salmon *Oncorhynchus nerka* obtained from coastal British Columbia and Gulf of Alaska surveys during 1996–2011. A 404-population baseline was used to determine the individual identifications of the fish sampled, with individuals being identified to 47 populations or stocks of origin. Columbia River and Washington juveniles were consistently larger than those from British Columbia and Alaska. During July, larger individuals from the same Fraser River stock were observed in more northerly locations compared with those in the Strait of Georgia. There was a relationship between the timing of northward migration from the Strait of Georgia and juvenile body size, with individuals from larger populations or stocks migrating earlier than individuals from smaller stocks which remain resident for longer. There was a wide divergence among stocks in juvenile size and dispersion among sampling locations.

Beacham, T. D., Candy, J.C., Sato, S., & Urawa, S. (2014). Microsatellite identification of sockeye salmon rearing in the Bering Sea during 2009-2013. NPAFC Doc. 1511. 18 pp. (Available at http://www.npafc.org).

Stock composition of sockeye salmon (*Oncorhynchus nerka*) caught in the southern central Bering Sea during Japanese research cruises in the summers of 2009, 2011, 2012, and 2013 was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for immature sockeye salmon, and a 404-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the stock composition of the fish sampled. Alaskan-origin sockeye salmon were the most abundant in the catch, comprising 86.1% of all sockeye salmon caught (United States total 86.1%), with the catch dominated by sockeye salmon of Bristol Bay origin. Russian-origin salmon accounted for an average of 10.6% of the annual catch, while Canadian-origin sockeye salmon accounted for 3.4% of the annual catch.

Beakes, M. P., Sharron, S., Charish, R., Moore, J. W., Satterthwaite, W. H., Sturm, E., Wells, B. K., Sogard, S. M. & Mangel, M. (2014). Using scale characteristics and water temperature to reconstruct growth rates of juvenile steelhead *Oncorhynchus mykiss*. *Journal of Fish Biology*, *84*(1), 58–72. http://doi.org/10.1111/jfb.12254

Juvenile steelhead *Oncorhynchus mykiss* from a northern California Central Valley population were reared in a controlled laboratory experiment. Significantly different rates of growth were observed among fish reared under two ration treatments and three temperature treatments (8, 14 and 20° C). Wider circulus spacing and faster deposition was associated with faster growth. For the same growth rate, however, circulus spacing was two-fold wider and deposited 36% less frequently in the cold compared to the hot temperature treatment. In a multiple linear regression, median circulus spacing and water temperature accounted for 68% of the variation in observed O. mykiss growth. These results corroborate previous research on scale characteristics and growth, while providing novel evidence that highlights the importance of water temperature in

these relationships. Thus, this study establishes the utility of using scale analysis as a relatively non-invasive method for inferring growth in salmonids.

Bennett, T. R., Roni, P., Denton, K., McHenry, M., & Moses, R. (2014). Nomads no more: early juvenile coho salmon migrants contribute to the adult return. *Ecology of Freshwater Fish*, 24: 264–275. http://doi.org/10.1111/eff.12144

The downstream movement of coho salmon fry and parr in the fall, as distinct from the spring migration of smolts, has been well documented across the range of the species. In many cases, these fish overwinter in freshwater, but they sometimes enter marine waters. It has long been assumed that these latter fish did not survive to return as adults and were "surplus" to the stream's carrying capacity. From 2004 to 2010, we passive integrated transponder tagged 25,981 juvenile coho salmon in three streams in Washington State to determine their movement, survival and the contribution of various juvenile life histories to the adult escapement. We detected 86 returning adults, of which 32 originated from fall/winter migrants. Half of these fall/winter migrants spent ~1 year in the marine environment, while the other half spent ~2 years. In addition, the median return date for fall/winter migrants was 16 days later than spring migrants. Our results indicated that traditional methods of spring-only smolt enumeration may underestimate juvenile survival and total smolt production, and also overestimate spring smolt-to-adult return (SAR). These are important considerations for coho salmon life cycle models that assume juvenile coho salmon have a fixed life history or use traditional parr-to-smolt and SAR rates.

Brodeur, R. D., Buchanan, J. C., Emmett, R. C. (2014). Pelagic and demersal fish predators on juvenile and adult forage fishes in the northern California Current: spatial and temporal variations. *CalCOFI Report, 55,* 96-116.

A requisite for reliable food web models and ecosystem-based management in regions such as the California Current is the availability of diet information on key predators. In upwelling ecosystems, much of the lower trophic level energy may be transferred through a relatively small set of very abundant pelagic forage fish taxa, such as anchovies, sardines, smelts, and herring. In addition the pelagic juvenile stages of some important midwater and demersal fishes (Pacific hake and rockfishes) may act as forage fishes during a more limited time period each year. In this paper, we review what is known about the utilization of these forage species by larger fish predators and elasmobranchs in the Northern California Current (NCC) from northern Washington to northern California (Cape Mendocino) to examine spatial and temporal variations in the kinds and sizes of forage fishes consumed. We found that predation on forage fishes was highly variable in space and time, and was often dependent on the size of the prey available as well as the predator. Pacific hake and spiny dogfish have the potential to be dominant forage fish predators due to their high biomass but other species such as arrowtooth flounder and Pacific halibut can be important due to their high proportion of forage fish in the diet. We also highlight where diet information is limited or lacking, and areas where regular fish diet monitoring could be useful for ecosystem-based management.

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. http://doi.org/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.

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. http://doi.org/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.

Campbell, L. A., Bottom, D. L., Volk, E. C., & Fleming, I. A. (2015). Correspondence between scale morphometrics and scale and otolith chemistry for interpreting juvenile salmon life histories. *Transactions of the American Fisheries Society*, *144*(1), 55–67. http://doi.org/10.1080/00028487.2014.963253

Fish scales have long been used to reconstruct fine-scale habitat transitions such as the movement of juvenile fish from freshwater, estuary, and ocean environments. Despite the importance of life history information to fisheries management and conservation, few studies have validated that scale morphology accurately describes fish movement between these habitats. Therefore, we tested the accuracy of using scale morphometric criteria to identify the movement of juvenile Chinook Salmon *Oncorhynchus tshawytscha* from freshwater to marine portions of the Columbia River estuary by comparing scale morphometric classification, scale chemistry, and otolith chemistry. Nearly one-half of all fish collected in the saline portion of the estuary and approximately one-quarter in the freshwater portion exhibited morphometric patterns (i.e., scale

checks and intermediate growth) often associated with periods of estuary rearing. Depending upon the criteria used to define scale checks, otolith chemical results indicated that 33–53% of fish would have been misclassified as estuary residents based solely on their scale patterns. Moreover, many individuals who had resided in strontium-rich estuary water did not form a visible check (37%) on their scales to coincide with estuary entry. We estimated from otolith chemistry that these fish had either entered at or near the size at which scale formation occurs (35–42 mm) or had recently migrated to the saline portion of the estuary (<30 d) before new scale material could be formed and calcified. Scale chemistry alone was a good indicator of entrance into the saline portion of the estuary. Scale chemistry responded to the strontium-enriched salt water, and explained 86% of the variation found in otolith chemistry. Scale morphometric classification did not provide the fine-scale resolution that scale and, even more so, otolith chemistry provided for describing the proportion of juvenile Chinook salmon using the saline portion of the Columbia River estuary.

Carr-Harris, C., Gottesfeld, A. S., & Moore, J. W. (2015). Juvenile salmon usage of the Skeena River estuary. *PLoS ONE, 10*(3), e0118988. http://doi.org/10.1371/journal.pone.0118988

Migratory salmon transit estuary habitats on their way out to the ocean but this phase of their life cycle is more poorly understood than other phases. The estuaries of large river systems in particular may support many populations and several species of salmon that originate from throughout the upstream river. The Skeena River of British Columbia, Canada, is a large river system with high salmon population- and species-level diversity. The estuary of the Skeena River is under pressure from industrial development, with two gas liquefaction terminals and a potash loading facility in various stages of environmental review processes, providing motivation for understanding the usage of the estuary by juvenile salmon. We conducted a juvenile salmonid sampling program throughout the Skeena River estuary in 2007 and 2013 to investigate the spatial and temporal distribution of different species and populations of salmon. We captured six species of juvenile anadromous salmonids throughout the estuary in both years, and found that areas proposed for development support some of the highest abundances of some species of salmon. Specifically, the highest abundances of sockeye (both years), Chinook in 2007, and coho salmon in 2013 were captured in areas proposed for development. For example, juvenile sockeye salmon were 2–8 times more abundant in the proposed development areas. Genetic stock assignment demonstrated that the Chinook salmon and most of the sockeye salmon that were captured originated from throughout the Skeena watershed, while some sockeye salmon came from the Nass, Stikine, Southeast Alaska, and coastal systems on the northern and central coasts of British Columbia. These fish support extensive commercial, recreational, and First Nations fisheries throughout the Skeena River and beyond. Our results demonstrate that estuary habitats integrate species and population diversity of salmon, and that if proposed development negatively affects the salmon populations that use the estuary, then numerous fisheries would also be negatively affected.

Celewycz, A. G., Fergusson, E. A. Moss, J. H. & Orsi, J. A. (2014). High seas salmonid coded-wire tag recovery data, 2013. NPAFC Doc. 1528. 37 p. (Available at http://www.npafc.org).

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 to the Regional Mark Processing Center

(RMPC, http://www.rmpc.org) of the Pacific States Marine Fisheries Commission (PSMFC) for inclusion into their Regional Mark Information System (RMIS) Database. This document lists recovery data for 324 CWT salmonids that will be reported to PSMFC/RMPC for the first time. These CWTs were recovered from 1) the U.S. groundfish trawl fishery in the Gulf of Alaska (GOA) as sampled by observers (10 Chinook salmon, *O.tshawytscha*) in 2012 and 2013, 2) the U.S. groundfish trawl fishery in the GOA as sampled in a CWT tunnel detector test conducted at a Kodiak processing plant (71 Chinook salmon) in 2012, 3) Salmon Excluder Device testing in the GOA (40 Chinook salmon) in 2013, 4) rockfish trawl fishery in the GOA (113 Chinook salmon) in 2013), 4) the U.S. groundfish trawl fishery in the eastern Bering Sea-Aleutian Islands (BSAI, 7 Chinook salmon) in 2012 and 2013, and 5) U.S. trawl research in the GOA (68 Chinook salmon and 15 coho salmon, *O. kisutch*) in 2012. No new CWT recoveries from either the at-sea Pacific hake (*Merluccius productus*) trawl fishery in the Northern Pacific Ocean off Washington/Oregon (WA/OR) or the West Coast trawl fishery off Washington/Oregon/California (WA/OR/CA) have been reported to the RMPC since 2011. No new CWT recoveries from foreign high seas research have been reported to the RMPC since 2010.

Chamberlin, J. W., & Quinn, T. P. (2014). Effects of natal origin on localized distributions of Chinook salmon, *Oncorhynchus tshawytscha,* in the marine waters of Puget Sound, Washington. *Fisheries Research, 153,* 113–122. http://doi.org/10.1016/j.fishres.2014.01.008

The inland marine waters of Puget Sound, Washington, and the Strait of Georgia and associated waters of British Columbia (the Salish Sea) have long been recognized as alternative rearing habitat to the continental shelf for Chinook and coho salmon. Recent analyses have indicated that these fish (termed residents) comprise a substantial fraction of the Chinook salmon populations originating from Puget Sound rivers. However, the extent to which these resident salmon remain within their natal region or move within Puget Sound has not been studied. Analysis of two decades of coded-wire tagging data revealed several clear patterns. First, the salmon showed spatial distributions that varied systematically with area of origin. In general, they were caught in the vicinity of their origin, indicating limited net movement during several years at large; however this pattern was not universal. Second, recovery distributions were highly influenced by marine age and showed region specific spatial patterns, with the largest differences between the youngest (marine age 1) and oldest (marine age 4) individuals.

Claiborne, A. M., Miller, J. A., Weitkamp, L. A., Teel, D. J., & Emmett, R. L. (2014). Evidence for selective mortality in marine environments: the role of fish migration size, timing, and production type. *Marine Ecology Progress Series, 515,* 187–202. http://doi.org/10.3354/meps10963

The underlying causes of mortality during critical life stages of fish are not well understood, nor is it clear if these causes are similar for naturally versus artificially propagated (i.e. hatchery) individuals. To assess the importance of selective mortality related to production type (hatchery vs. naturally produced) and size at and timing of marine entry, we compared attributes of juvenile Chinook salmon *Oncorhynchus tshawytscha* from the upper Columbia River summer- and fall-run genetic stock group captured in the Columbia River estuary with back-calculated attributes of survivors captured in marine waters. We used genetic stock identification, otolith chemistry and structure, and physical tags to determine stock of origin, size at and timing of marine entry, and production type. Fish emigrated from fresh water in May to September and the majority of fish collected in the estuary (87%) had arrived within 3 d of capture. In 1 of 2 yr,

timing of marine entry for both production types differed between the estuary and ocean: the ocean catch included a greater proportion of juveniles that emigrated in late July than the estuary catch. There was no evidence of selective mortality of smaller juveniles during early marine residence in hatchery or natural juveniles, but the mean percentage (±SE) of hatchery fish in ocean collections was 16 ± 5.8% less than in the estuary, which could indicate reduced survival compared to naturally produced fish. Results from this study highlight the need to understand the effects of hatchery rearing and how hatchery propagation may influence survival during later critical life-history transitions.

Copeland, T., Venditti, D. A., & Barnett, B. R. (2014). The importance of juvenile migration tactics to adult recruitment in stream-type Chinook Salmon populations. *Transactions of the American Fisheries Society*, *143*(6), 1460–1475. http://doi.org/10.1080/00028487.2014.949011

The existence of multiple migration tactics within a population has been observed for several fish species, and they may contribute differentially to adult recruitment. Relative contribution by juveniles using the same habitats on different schedules is variable; therefore, understanding and conserving this diversity should be important to fisheries managers. We investigated adult recruitment by two distinct juvenile migration tactics in several spawning populations of stream-type Chinook Salmon *Oncorhynchus tshawytscha* in Idaho: those leaving the spawning grounds as subyearlings during June through November (downstream rearing, or DSR, type) and those emigrating from natal areas 1 year after emergence (natal reach rearing, or NRR, type). The DSR type had greater juvenile abundance in all populations, although the NRR type exhibited better survival from the natal reach to the migratory corridor. The DSR type had greater survival from smoltification to adult return to freshwater compared with the NRR type. More DSR emigrants than NRR emigrants returned to freshwater as adults, although the difference was influenced by cohort and population. Adult recruits to stream-type Chinook Salmon populations in Idaho are comprised mostly of DSR emigrants, i.e., fish that dispersed from their natal habitats and reared in reaches downstream. This finding is ubiquitous, although the size of the effect depends on cohort and population. We demonstrated that juvenile Chinook Salmon in Idaho do indeed use downstream rearing habitats effectively, thereby increasing recruitment of adults back to the spawning gravels in these populations. This study illustrates how dispersive life histories are essential to achieve the full productive potential of migratory stream fish populations.

Craig, B. E., Simenstad, C. A., & Bottom, D. L. (2014). Rearing in natural and recovering tidal wetlands enhances growth and life-history diversity of Columbia Estuary tributary coho salmon *Oncorhynchus kisutch* population. *Journal of Fish Biology*, *85*(1), 31–51. http://doi.org/10.1111/jfb.12433

This study provides evidence of the importance of tributary tidal wetlands to local coho salmon *Oncorhynchus kisutch* populations and life-history diversity. Subyearling and, to a lesser extent, yearling *O. kisutch* life histories utilized various estuary habitats within the Grays River, a tidal freshwater tributary of the Columbia River estuary, including restoring emergent wetlands and natural forested wetlands. Migration timing data, size distributions, estuary residence and scale patterns suggest a predominance of subyearling migrant life histories, including several that involve extended periods of estuary rearing. Estuarine-rearing subyearling *O. kisutch* exhibited the greatest overall growth rates; the highest growth rates were seen in fish that utilized restoring emergent wetlands. These results contrast with studies conducted in the main-stem Columbia

River estuary, which captured few *O. kisutch*, of which nearly all were hatchery-origin yearling smolts. Restoration and preservation of peripheral and tributary wetland habitats, such as those in the Grays River, could play an important role in the recovery of natural *O. kisutch* populations in the Columbia River and elsewhere.

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, 6*(1), 62–80. http://doi.org/10.1080/19425120.2013.869284

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. Comparisons of 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 1–3 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.Received

David, A. T., Ellings, C. S., Woo, I., Simenstad, C. A., Takekawa, J. Y., Turner, K. L., Smith, A.L., & Takekawa, J. E. (2014). Foraging and growth potential of juvenile Chinook Salmon after tidal restoration of a large river delta. *Transactions of the American Fisheries Society, 143*(6), 1515–1529. http://doi.org/10.1080/00028487.2014.945663

We evaluated whether restoring tidal flow to previously diked estuarine wetlands also restores foraging and growth opportunities for juvenile Chinook Salmon *Oncorhynchus tshawytscha*. Several studies have assessed the value of restored tidal wetlands for juvenile Pacific salmon *Oncorhynchus* spp., but few have used integrative measures of salmon performance, such as habitat-specific growth potential, to evaluate restoration. Our study took place in the Nisqually River delta, Washington, where recent dike removals restored tidal flow to 364 ha of marsh—the largest tidal marsh restoration project in the northwestern contiguous United States. We sampled fish assemblages, water temperatures, and juvenile Chinook Salmon diet composition and consumption rates in two restored and two reference tidal channels during a 3-year period after restoration; these data were used as inputs to a bioenergetics model to compare Chinook Salmon

foraging performance and growth potential between the restored and reference channels. We found that foraging performance and growth potential of juvenile Chinook Salmon were similar between restored and reference tidal channels. However, Chinook Salmon densities were significantly lower in the restored channels than in the reference channels, and growth potential was more variable in the restored channels due to their more variable and warmer (2°C) water temperatures. These results indicate that some—but not all—ecosystem attributes that are important for juvenile Pacific salmon can recover rapidly after large-scale tidal marsh restoration.

Doubleday, A. J., & Hopcroft, R. R. (2014). Interannual patterns during spring and late summer of larvaceans and pteropods in the coastal Gulf of Alaska, and their relationship to pink salmon survival. *Journal of Plankton Research*, fbu092. http://doi.org/10.1093/plankt/fbu092

Larvacean (=appendicularian) and pteropod (*Limacina helicina*) composition and abundance were studied with physical variables each May and late summer across 11 years (2001–2011), along a transect that crosses the continental shelf of the sub-Arctic Gulf of Alaska (GoA) and five stations within Prince William Sound (PWS). Collection with 53-µm plankton nets allowed the identification of larvaceans to species: five occurred in the study area. Temperature was the driving variable in determining larvacean community composition, yielding pronounced differences between spring and late summer, while individual species were also affected differentially by salinity and chlorophyll-a concentration. During the spring *Oikopleura labradoriensis* and *Fritillaria borealis* were most abundant, being present at all stations. Late summer had highest abundances of *Oikopleura dioica* at nearshore stations, while *F. borealis* dominated numerically at outer stations. The 53-µm plankton nets collected higher abundances of *Oikopleura* spp., *Fritillaria* spp. and *L. helicina* than coarser 150- and 505-µm plankton nets. *Limacina helicina* abundance had a significant interaction effect among years, seasons and station location. *Limacina helicina* abundance in nearby PWS explained 30% of the variability in pink salmon survival; however, no significant correlations existed with larvacean or *L. helicina* abundances from the GoA stations.

Evans, A. F., Hostetter, N. J., Collis, K., Roby, D. D., & Loge, F. J. (2014). Relationship between juvenile fish condition and survival to adulthood in Steelhead. *Transactions of the American Fisheries Society*, *143*(4), 899–909. http://doi.org/10.1080/00028487.2014.901248

Understanding how individual characteristics are associated with survival is important to programs aimed at recovering fish populations of conservation concern. To evaluate whether individual fish characteristics observed during the juvenile life stage were associated with the probability of returning as an adult, juvenile steelhead *Oncorhynchus mykiss* from two distinct population segments (DPSs; Snake River and upper Columbia River) were captured, photographed to determine external condition (body injuries, descaling, signs of disease, fin damage, and ectoparasites), measured, classified by rearing type (hatchery, wild), marked with a PIT tag, and released to continue out-migration to the Pacific Ocean during 2007–2010. The PIT tags of returning adults were interrogated in fishways at hydroelectric dams on the lower Columbia River 1–3 years following release as juveniles. Juvenile-to-adult survival models were investigated independently for each DPS and indicated that similar individual fish characteristics were important predictors of survival to adulthood for both steelhead populations. The data analysis provided strong support for survival models that included explanatory variables for fish

length, rearing type, and external condition, in addition to out-migration year and timing. The probability of a juvenile surviving to adulthood was positively related to length and was higher for wild fish compared with hatchery fish. Survival was lower for juveniles with body injuries, fin damage, and external signs of disease. Models that included variables for descaling and ectoparasite infestation, however, had less support than those that incorporated measures of body injuries, fin damage, and disease. Overall, results indicated that individual fish characteristics recorded during the juvenile life stage can be used to predict adult survivorship in multiple steelhead populations.

Ferriss, B. E., Trudel, M., & Beckman, B. R. (2014). Regional and inter-annual trends in marine growth of juvenile salmon in coastal pelagic ecosystems of British Columbia, Canada. *Marine Ecology Progress Series, 503,* 247–261. http://doi.org/10.3354/meps10726

We measured insulin-like growth factor 1 (IGF1) concentrations (a proxy for growth) from juvenile coho *Oncorhynchus kisutch*, sockeye *O. nerka*, chum *O. keta*, and Chinook salmon *O. tshawytscha* collected in 8 regions of British Columbian coastal waters, in June of 2009, 2010, and 2011. We found annual differences in IGF1 for all 4 species, as well as species-specific regional differences in IGF1 concentrations in coho, chum, and sockeye salmon. Sockeye and chum salmon had consistently higher levels in the northern regions of the Dixon Entrance, Haida Gwaii, Hecate Strait, and lower levels in Queen Charlotte Strait. Regional differences in coho, chum, and sockeye salmon were highly correlated (R2 = 0.61–0.75). These results demonstrate that salmon growth responds to local environmental variability on a scale of several hundred kilometers. Thus, IGF1 measures should generate insight into fish production on relatively local regional and temporal scales, and these same measures may allow the assessment of how habitats vary on these same scales.

Fisher, J. P., Weitkamp, L. A., Teel, D. J., Hinton, S. A., Orsi, J. A., Farley, E. V., Morris, 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. http://doi.org/10.1080/00028487.2013.847862

Several evolutionarily significant units (ESUs) of Columbia River basin 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.

Freshwater, C., Trudel, M., Beacham, T. D., Neville, C.-E., Tucker, S., & Juanes, F. *In press.* Validation of daily increments and a marine entry check in the otoliths of Sockeye Salmon post-smolts. *Journal of Fish Biology.*

The formation of daily increments and a marine entry check in *Oncorhynchus nerka* otoliths were evaluated for 110 juvenile Sockeye Salmon smolted in controlled conditions and sacrificed over a 100-day period. Estimates of marine entry date from otolith microstructure techniques were secondarily validated using field-collected individuals with an inductively coupled plasma mass spectrometry analysis to assess visual bias. Our results indicate that in *O. nerka* post-smolts' otolith increments were formed daily and marine entry could be estimated from visible checks; however chemical estimates using Sr:Ca ratios consistently underestimated marine entry timing relative to visual marine entry estimates by several days.

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, 6*(1), 1–11. http://doi.org/10.1080/19425120.2013.860065

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.

Garza, J. C., Gilbert-Horvath, E. A., Spence, B. C., Williams, T. H., Fish, H., Gough, S. A., Anderson, J. H., Hamm, D., Anderson, E. C. (2014). Population structure of Steelhead in

coastal California. ***Transactions of the American Fisheries Society*****,** ***143*****(1), 134–152. http://doi.org/10.1080/00028487.2013.822420**

Steelhead *Oncorhynchus mykiss* are the most widespread of the Pacific salmonids *Oncorhynchus* spp. and are found in nearly all basins within their native range around the northern Pacific Rim. Here, we elucidate genetic population structure of steelhead in coastal basins from most of their coastal-California range using variation at 15 microsatellite loci. Juvenile fish from 60 streams in 40 river basins were sampled in a single year from a single cohort. As samples of juvenile salmonids often contain sibling groups, a method was implemented to identify and eliminate all but one member of larger sibships. This, in conjunction with a rigorous sampling protocol and hierarchical sampling design, provided substantially improved resolution for understanding patterns of migration and demography. A pattern of isolation by distance was evident, as indicated by both phylograms that were largely concordant with geography and a significant regression of genetic distance on geographic distance, indicating that population structure is largely determined by migration that is dependent upon geographic distance. Within-basin genetic distances tended to be smaller than those between basins, although there was substantial overlap between them. Using a Bayesian clustering method to evaluate signals of population structure above the level of a river basin, four geographic sites were identified where genetic composition shifted abruptly. These areas largely correspond to major geographic features of the coastline: San Francisco and Humboldt bays and two extended sections of coast (the so-called Lost Coast and Russian Gulch areas) with no streams reaching inland more than several kilometers. Only one of these boundaries is concordant with the current delineation of steelhead Distinct Population Segments designated under the U.S. Endangered Species Act. Finally, there was a strong correlation between latitude and genetic variation, with fewer alleles present in the south, a pattern consistent with generally smaller population sizes in the south.

Godwin, S. C., Dill, L. M., Reynolds, J. D., & Krkošek, M. (2015). Sea lice, sockeye salmon, and foraging competition: lousy fish are lousy competitors. ***Canadian Journal of Fisheries and Aquatic Sciences*****. http://doi.org/10.1139/cjfas-2014-0284**

Pathogens threaten wildlife globally, but these impacts are not restricted to direct mortality from disease. For fish, which experience periods of extremely high mortality during their early life history, infections may primarily influence population dynamics and conservation through indirect effects on ecological processes such as competition and predation. We conducted a competitive foraging experiment using out-migrating juvenile Fraser River sockeye salmon (*Oncorhynchus nerka*) to determine whether fish with high abundances of parasitic sea lice (*Caligus clemensi* and *Lepeophtheirus salmonis*) have reduced competitive abilities when foraging. Highly infected sockeye were 20% less successful at consuming food, on average, than lightly infected fish. Competitive ability also increased with fish body size. Our results provide the first evidence that parasite exposure may have negative indirect effects on fitness of juvenile sockeye salmon, and suggest that indirect effects of pathogens may be of key importance for the conservation of marine fish.

Goetz, F. A., Jeanes, E., Moore, M. E., & Quinn, T. P. (2015). Comparative migratory behavior and survival of wild and hatchery steelhead (*Oncorhynchus mykiss*) smolts in riverine, estuarine, and marine habitats of Puget Sound, Washington. ***Environmental Biology of Fishes*****,** ***98*****(1), 357–375. http://doi.org/10.1007/s10641-014-0266-3**

Declines in the survival of steelhead (*Oncorhynchus mykiss*) populations in protected waters of Washington and British Columbia have drawn attention to the need for more information on migratory patterns and losses in river, estuary, and nearshore habitats. Accordingly, acoustic telemetry was used to quantify movements by wild and hatchery steelhead smolts released from 2006 to 2009 in the Green River, and tracked through Puget Sound, Washington. Survival varied by release group and migration segment but overall survival rates from release to the Strait of Juan de Fuca were 9.7 % for wild and 3.6 % for hatchery fish. These rates are low relative to similar studies on steelhead. Survival was higher for wild fish along all migration segments than hatchery-origin fish; the greatest loss for both groups coincided with the slowest travel rates as fish first entered the estuary and as they exited Puget Sound. Wild fish travelled faster than hatchery fish in the river (15.1 vs. 4.4 km/d) with the fastest travel in the lower river (41 vs. 20.2 km/d) and slowest immediately after release (3.7 vs. 2.4 km/d). The travel rates of wild and hatchery fish became progressively more similar over time: 15.4 vs. 10.6 km/d in the estuary, and 10.3 vs. 9.3 km/d in nearshore areas. Movement was primarily nocturnal in the river, nearly equal between day and night in the upper estuary, and predominately diurnal in the lower estuary and nearshore waters, with no difference between wild and hatchery fish. The migration in marine water showed an early offshore movement and a strong northward and westward orientation, and all fish exited the Strait of Juan de Fuca rather than the Strait of Georgia. The findings support research suggesting that declines in wild and hatchery steelhead populations may be caused primarily by factors in the early marine period.

Greene, C., Kuehne, L., Rice, C., Fresh, K., & Penttila, D. (2015). Forty years of change in forage fish and jellyfish abundance across greater Puget Sound, Washington (USA): anthropogenic and climate associations. *Marine Ecology Progress Series, 525*, 153–170. http://doi.org/10.3354/meps11251

Coastal ecosystems face a variety of natural and anthropogenic influences, raising questions about mechanisms by which species abundance and composition change over time. We examined these questions by synthesizing 6 surface-trawling efforts in greater Puget Sound, Washington (USA), spanning 40 yr, and then determining changes in forage fish abundance and composition and jellyfish prevalence. We also assessed whether patterns were associated with potential anthropogenic pressures (human population density and commercial harvest) as well as large-scale climate signals. We found evidence for trends in abundance of all forage species in 4 sub-basins of Puget Sound. Cumulative distribution functions of catch per unit effort indicate that the historically dominant forage fishes (Pacific herring and surf smelt) have declined in surface waters in 2 sub-basins (Central and South Puget Sound) by up to 2 orders of magnitude. However, 2 other species (Pacific sand lance and three-spine stickleback) increased in all 4 sub-basins. Consequently, species composition diverged among sub-basins over the last 40 yr. In addition, jellyfish-dominated catches increased 3- to 9-fold in Central and South Puget Sound, and abundance positively tracked human population density across all basins. The strongest predictors of forage fish declines were human population density and commercial harvest. Climate signals offered additional explanatory power for forage fish but not jellyfish catch. These patterns suggest possible linkages between coastal anthropogenic activities (e.g. development, pollution) and the abundance of forage fish and jellyfish in pelagic waters. Our findings also provide a basis for improving indicators for assessment, monitoring, and spatial planning to rehabilitate pelagic ecosystems.

Harstad, D. L., Larsen, D. A., & Beckman, B. R. (2014). Variation in minijack rate among hatchery populations of Columbia River basin Chinook Salmon. *Transactions of the American Fisheries Society*, *143*(3), 768–778. http://doi.org/10.1080/00028487.2014.886621
In Columbia River spring and summer Chinook Salmon *Oncorhynchus tshawytscha*, age of male maturation ranges from age 1 (microjack), 2 (minijack), 3 (jack), to 4 or 5 (adult) years. The presence of minijacks has been noted in several experimental studies and documented for a few hatchery programs; but, a comprehensive survey of their occurrence in hatchery production programs has never been conducted. We measured the proportion of minijacks among males released from several spring- and summer-run Chinook Salmon hatchery programs throughout the Columbia River basin among brood years 1999–2010. The hatcheries surveyed included both segregated (uses only hatchery-origin spawners in broodstock) and integrated (includes some degree of natural-origin spawners in broodstock) programs. Minijacks were found in all programs monitored, and rates varied approximately 10-fold across release groups, ranging from 7.9% to 71.4% of males in spring Chinook Salmon programs and from 4.1% to 40.1% of males in summer Chinook Salmon programs. Cumulative growth (i.e., size at release) was found to be positively correlated with minijack rate, but for only the integrated Chinook Salmon programs. Domestication selection may have occurred in segregated spring Chinook Salmon programs, increasing the threshold size for maturation and lowering minijack rates. Elevated minijack rates in Chinook Salmon hatchery programs result in a direct reduction in both the number of male smolts released and potential adult males available for harvest and spawning.

Hill, A. D., Daly, E. A., & Brodeur, R. D. (2015). Diet variability of forage fishes in the Northern California Current System. *Journal of Marine Systems, 146,* 121-130. http://doi.org/10.1016/j.jmarsys.2014.08.006
As fisheries management shifts to an ecosystem-based approach, understanding energy pathways and trophic relationships in the Northern California Current (NCC) will become increasingly important for predictive modeling and understanding ecosystem response to changing ocean conditions. In the NCC, pelagic forage fishes are a critical link between seasonal and interannual variation in primary production and upper trophic groups. We compared diets among dominant forage fish (sardines, anchovies, herring, and smelts) in the NCC collected in May and June of 2011 and June 2012, and found high diet variability between and within species on seasonal and annual time scales, and also on decadal scales when compared to results of past studies conducted in the early 2000s. Copepoda were a large proportion by weight of several forage fish diets in 2011 and 2012, which differed from a preponderance of Euphausiidae found in previous studies, even though all years exhibited cool ocean conditions. We also examined diet overlap among these species and with co-occurring subyearling Chinook salmon and found that surf smelt diets overlapped more with subyearling Chinook diets than any other forage fish. Herring and sardine diets overlapped the most with each other in our interdecadal comparisons and some prey items were common to all forage fish diets. Forage fish that show plasticity in diet may be more adapted to ocean conditions of low productivity or anomalous prey fields. These findings highlight the variable and not well-understood connections between ocean conditions and energy pathways within the NCC.

Hostetter, N. J., Evans, A. F., Cramer, B. M., Collis, K., Lyons, D. E., & Roby, D. D. (2015). Quantifying avian predation on fish populations: integrating predator-specific deposition

probabilities in tag recovery studies. ***Transactions of the American Fisheries Society, 144*****(2), 410–422. http://doi.org/10.1080/00028487.2014.988882**

Accurate assessment of specific mortality factors is vital to prioritize recovery actions for threatened and endangered species. For decades, tag recovery methods have been used to estimate fish mortality due to avian predation. Predation probabilities derived from fish tag recoveries on piscivorous waterbird colonies typically reflect minimum estimates of predation due to an unknown and unaccounted-for fraction of tags that are consumed but not deposited on-colony (i.e., deposition probability). We applied an integrated tag recovery modeling approach in a Bayesian context to estimate predation probabilities that accounted for predator-specific tag detection and deposition probabilities in a multiple-predator system. Studies of PIT tag deposition were conducted across three bird species nesting at seven different colonies in the Columbia River basin, USA. Tag deposition probabilities differed significantly among predator species (Caspian terns *Hydroprogne caspia*: deposition probability = 0.71, 95% credible interval [CRI] = 0.51–0.89; double-crested cormorants *Phalacrocorax auritus*: 0.51, 95% CRI = 0.34–0.70; California gulls *Larus californicus*: 0.15, 95% CRI = 0.11–0.21) but showed little variation across trials within a species or across years. Data from a 6-year study (2008–2013) of PIT-tagged juvenile Snake River steelhead *Oncorhynchus mykiss* (listed as threatened under the Endangered Species Act) indicated that colony-specific predation probabilities ranged from less than 0.01 to 0.17 and varied by predator species, colony location, and year. Integrating the predator-specific deposition probabilities increased the predation probabilities by a factor of approximately 1.4 for Caspian terns, 2.0 for double-crested cormorants, and 6.7 for California gulls compared with traditional minimum predation rate methods, which do not account for deposition probabilities. Results supported previous findings on the high predation impacts from strictly piscivorous waterbirds nesting in the Columbia River estuary (i.e., terns and cormorants), but our findings also revealed greater impacts of a generalist predator species (i.e., California gulls) than were previously documented. Approaches used in this study allow for direct comparisons among multiple fish mortality factors and considerably improve the reliability of tag recovery models for estimating predation probabilities in multiple-predator systems.

Irvine, J. R., Michielsens, C. J. G., O'Brien, M., White, B. A., & Folkes, M. (2014). Increasing dominance of odd-year returning Pink Salmon. ***Transactions of the American Fisheries Society, 143*****(4), 939–956. http://doi.org/10.1080/00028487.2014.889747**

The hypothesis that abundance patterns differ between even- and odd-year returning Pink Salmon *Oncorhynchus gorbuscha* was examined using data from the eastern and western North Pacific Ocean, northern and southern British Columbia, and biologically based conservation units, which are Canadian groupings of salmon that are genetically and/or ecologically distinct from each other. Detailed data from (mostly) southern British Columbia were examined to test hypotheses that the differences between even- and odd-year broodlines were due to fishing, broodline interactions, limitations in freshwater or the ocean, and/or density dependence. The odd-year broodline has become increasingly predominate over the genetically distinct even-year broodline on both sides of the Pacific and in five of six British Columbia regions. Five analytical approaches revealed abundances were generally increasing for odd-year conservation units and declining or stable for even-year conservation units. Recent increases in odd-year spawner abundance in southern British Columbia were correlated with decreased fishery exploitation, but exploitation was higher for odd-year than for even-year salmon, refuting the hypothesis that differential exploitation is responsible for the changing dominance. Significant negative

interactions between even- and odd-year broodlines were found in several of the British Columbia regions tested, but there was little evidence of competition between broodlines in the marine environment. Odd-year populations in the Fraser River increased despite density-dependent reductions in freshwater production, while there was no indication of changes in marine productivity. Our results, combined with literature findings indicating a more southerly glacial refugium for odd-year than for even-year Pink Salmon and temperature-related survival differences between these broodlines, suggest that recent climate conditions are benefiting odd-year returning Pink Salmon more than even-year salmon, especially in the southern part of their range.

Johnson, G. E., Ploskey, G. R., Sather, N. K., & Teel, D. J. (2015). Residence times of juvenile salmon and steelhead in off-channel tidal freshwater habitats, Columbia River, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, http://doi.org/10.1139/cjfas-2014-0085

We documented two life history strategies for juvenile salmonids as expressed in off-channel tidal freshwater habitats of the Columbia River: (*i*) active migrations by upper river Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) during the primary spring and summer migration periods and (*ii*) overwinter rearing in tidal freshwater habitats by coho salmon (*Oncorhynchus kisutch*) and naturally produced Chinook salmon mostly from lower river sources. During spring–summer 2007–2008, acoustic-tagged fish originating above Bonneville Dam (rkm 234) had short residence times in off-channel areas (rkm 192–203): median 2.5 and 2.6 h for yearling (mean lengths 134 and 158 mm) and 3.0 and 3.4 h for subyearling (104 and 116 mm) Chinook salmon and 2.5 h for yearling steelhead (215 mm). The percentage of fish in off-channel areas out of the total in the main- and off-channels areas was highest for yearling Chinook salmon (8.1% and 9.3% for 2007 and 2008, respectively) and lowest for steelhead (4.0% for 2008) and subyearling Chinook salmon (3.6% and 6.1% for 2007 and 2008, respectively). In late January and early February 2010, 2011, and 2012, we captured and tagged yearling Chinook and coho salmon occupying off-channel tidal freshwater habitats. Median residence times in off-channel areas were 11.6–25.5 days for juvenile Chinook (106, 115, and 118 mm, respectively by year) and 11.2 days for coho salmon (116 mm). This study is the first to estimate residence times for juvenile salmonids specifically in off-channel areas of tidal fresh water and, most importantly, residence times for Chinook salmon expressing a life history of overwintering in tidal fresh water. The findings support restoration of shallow off-channel habitats in tidal freshwater portions of the Columbia River.

Johnson, G. E., Sather, N. K., Skalski, J. R. & Teel, D. J. (2014). Application of diversity indices to quantify early life-history diversity for Chinook salmon. *Ecological Indicators*, 38, 170-180. http://doi.org/10.1016/j.ecolind.2013.11.005

We developed an approach to quantify early life history diversity for Chinook salmon (*Oncorhynchus tshawytscha*). Early life history diversity (ELHD) is the variation in morphological and behavioral traits expressed within and among populations by individual juvenile salmon during downstream migration. A standard quantitative method does not exist for this prominent concept in salmon biology. For Chinook salmon, ELHD reflects the multitude of possible strategies undertaken during the juvenile (fry through smolt) phases of their life cycle, where a life history strategy (or pattern) describes the combination of traits exhibited by an organism throughout its life cycle. Increasing life history diversity to improve resilience and aid recovery of diminished salmon and steelhead populations is a common objective in fish

population recovery efforts. In this paper, we characterized early life history traits and prioritize timing and fish size as two appropriate, measurable dimensions for an ELHD index. We studied diversity index literature, identified an indexing approach based on the effective number of time-size trait combinations, and tested several candidate indices for performance and usefulness in case studies using juvenile salmon catch data from the lower Columbia River and estuary. The recommended ELHD index is diversity expressed as the effective number of time-size trait combinations for the Shannon Index, modified to include an adjustment for missing time-size trait combinations and a sample coverage factor. This index applies to multiple life history strategies of juvenile salmonids; incorporates fish abundance, richness, and evenness; and produces readily interpretable values. The ELHD index can support comparisons across like locales and examinations of trends through time at a given locale. It has application as a high-level indicator to track trends in the status of the recovery of salmon and steelhead populations in the Columbia River basin and elsewhere where salmon recovery efforts are under way.

Jones, K. K., Cornwell, T. J., Bottom, D. L., Campbell, L. A., & Stein, S. (2014). The contribution of estuary-resident life histories to the return of adult *Oncorhynchus kisutch*. *Journal of Fish Biology*, *85*(1), 52–80. http://doi.org/10.1111/jfb.12380

This study evaluated estuarine habitat use, life-history composition, growth and survival of four successive broods of coho salmon *Oncoryhnchus kisutch* in Salmon River, Oregon, U.S.A. Subyearling and yearling *O. kisutch* used restored and natural estuarine wetlands, particularly in the spring and winter. Stream-reared yearling smolts spent an average of 2 weeks in the estuary growing rapidly before entering the ocean. Emergent fry also entered the estuary in the spring, and some resided in a tidal marsh throughout the summer, even as salinities increased to > 20. A significant portion of the summer stream-resident population of juvenile *O. kisutch* migrated out of the catchment in the autumn and winter and used estuary wetlands and adjacent streams as alternative winter-rearing habitats until the spring when they entered the ocean as yearling smolts. Passive integrated transponder (PIT) tag returns and juvenile life-history reconstructions from otoliths of returning adults revealed that four juvenile life-history types contributed to the adult population. Estuarine-associated life-history strategies accounted for 20–35% of the adults returning to spawn in the four brood years, indicating that a sizable proportion of the total *O. kisutch* production is ignored by conventional estimates based on stream habitat capacity. Juvenile *O. kisutch* responses to the reconnection of previously unavailable estuarine habitats have led to greater life-history diversity in the population and reflect greater phenotypic plasticity of the species in the U.S. Pacific Northwest than previously recognized.

Kilduff, D. P., Botsford, L. W., & Teo, S. L. H. (2014). Spatial and temporal covariability in early ocean survival of Chinook salmon (*Oncorhynchus tshawytscha*) along the west coast of North America. *ICES Journal of Marine Science: Journal Du Conseil*, fsu031. http://doi.org/10.1093/icesjms/fsu031

Knowledge of the spatial and temporal extent of covariation in survival during the critical ocean entry stage will improve our understanding of how changing ocean conditions influence salmon productivity and management. We used data from the Pacific coastwide coded-wire tagging program to investigate local and regional patterns of ocean survival of Chinook salmon (*Oncorhynchus tshawytscha*) from the Central Valley of California to southeastern Alaska from 1980–2006. Ocean survival of fish migrating as subyearlings covaried strongly from Vancouver Island to California. Short-term correlations between adjacent regions indicated this covariability

increased, beginning in the early 1990s. Chinook salmon survivals exhibited a larger spatial scale of variability (50% correlation scale: 706 km) than those reported for other northeast Pacific Ocean salmon. This scale is similar to that of environmental variables related to ecosystem productivity, such as summer upwelling (50% correlation scale: 746 km) and sea surface temperature (50% correlation scale: 500–600 km). Chinook salmon ocean survival rates from southeastern Alaska and south of Vancouver Island were not inversely correlated, in contrast to earlier observations based on catch data, but note that our data differ in temporal and spatial coverage from those studies. The increased covariability in Chinook salmon ocean survival suggests that the marine phase contributes little to the reduction in risk across populations attributable to the portfolio effect. In addition, survival of fish migrating as yearlings from the Columbia River covaried with Chinook salmon survival from the northernmost regions, consistent with our understanding of their migration patterns.

Kondzela, C. M., Guthrie III, C. M., Marvin, C. T., Whittle, J. A., Nguyen, H. T., Ramsower, C. & Guyon, J.R. (2014). Stock composition analysis of juvenile chum and Chinook salmon captured on the 2012 Bering Sea and Chukchi Sea research surveys. NPAFC Doc. 1521. 13 pp. (Available at http://www.npafc.org).

Juvenile chum (*Oncorhynchus keta*) and Chinook salmon (*O. tshawytscha*) were collected in the Bering and Chukchi seas as part of the 2012 U.S. BASIS/Arctic Ecosystem Integrated Survey (Arctic EIS) cruises. Juvenile chum salmon were more commonly encountered on the survey and 1,222 juveniles were genotyped for 11 microsatellite markers to determine their stock of origin. The most northern sample set was relatively small; juvenile chum salmon collected in the Chukchi Sea were predominantly from the Kotzebue Sound stock group. Juvenile chum salmon collected in the northern Bering Sea near Norton Sound were predominantly of Norton Sound origin. Yukon River chum salmon were present in both survey areas of the Bering Sea, but were more prevalent between lat. 60-63°N. Juvenile Chinook salmon were not encountered in the Chukchi Sea, but a small sample of 81 juveniles from the Bering Sea was genotyped for 43 single nucleotide polymorphism (SNP) markers. Most of the Chinook salmon were from the Upper Yukon, Coastal Western Alaska, and Middle Yukon stock groups. This study determined the freshwater origin of juvenile chum and Chinook salmon from the northern Bering and Chukchi seas during late-summer/fall based on genetic data and may be used to help guide future surveys of juvenile salmon abundance in western Alaska.

Li, L., Pitcher, T. J., & Devlin, R. H. (2014). Potential risks of trophic impacts by escaped transgenic salmon in marine environments. *Environmental Conservation, FirstView,* 1–10. http://doi.org/10.1017/S0376892914000319

There is significant concern about potential ecological effects of introduced organisms, including non-indigenous species and those created by genetic modification. This paper presents an Ecopath with Ecosim modelling approach, designed to examine long-term trophic effects of growth hormone (GH) transgenic coho salmon should they ever escape to a coastal salmonid ecosystem, namely the Strait of Georgia in British Columbia (Canada). The model showed that the effects of introduced GH transgenic coho salmon varied with their biomass, diet, structure of the invaded ecosystem, and environmental conditions. Occasional escapes of non-reproductive salmon did not have a significant impact on the example ecosystem. However, effects of GH coho salmon varied with their diet when large numbers of these fish were present in the simulated ecosystem (for example, when they constituted 20% of total current aquaculture production in the area). Further, climate-driven changes in the biomass of low trophic levels

(bottom-up effects) could have a greater impact on the ecosystem than the introduction of large numbers of GH coho salmon. A new version of Ecopath with Ecosim's Monte Carlo approach showed that the model predictions were robust to GH coho salmon's Ecopath parameters, but more sensitive to vulnerabilities of prey to GH coho salmon. Modelling ecosystem effects of genetically modified organisms provides a complementary approach for risk assessments when data from nature are not readily obtainable.

Liberoff, A. L., Miller, J. A., Riva-Rossi, C. M., Hidalgo, F. J., Fogel, M. L., & Pascual, M. A. (2014). Transgenerational effects of anadromy on juvenile growth traits in an introduced population of rainbow trout (*Oncorhynchus mykiss*). *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(3), 398–407. http://doi.org/10.1139/cjfas-2013-0466

We determined whether the propensity for anadromy was related to maternal phenotype in a population of partially anadromous rainbow trout (*Oncorhynchus mykiss*). We identified the maternal phenotype (anadromous versus resident) of wild juveniles from two successive cohorts using stable isotope analysis ($\delta^{15}N$) of muscle tissue and (or) strontium to calcium ratios in the otolith core. We also tested the hypothesis that juvenile size and growth are related to maternal migratory history. For both cohorts, juvenile size at capture and growth, as determined using otolith and scale structural analyses, were strongly related to maternal migratory history. Offspring of anadromous mothers were larger and grew faster than resident offspring. Back-calculated length at age 1 of anadromous and resident adults provided support for a positive association between body size and anadromy, indicating that larger offspring are more prone to displaying anadromy. We conclude that maternal anadromy, which influences adult size and egg quality, affects the propensity of progeny to migrate, thus perpetuating the anadromous tactic across generations and influencing the establishment and persistence of anadromy

Litz, M. N. C., Emmett, R. L., Bentley, P. J., Claiborne, A. M., & Barcelo, C. (2014). Biotic and abiotic factors influencing forage fish and pelagic nekton community in the Columbia River plume (USA) throughout the upwelling season 1999-2009. *Ices Journal of Marine Science*, *71*(1), 5–18. http://doi.org/10.1093/icesjms/fst082

Large river plumes modify coastal environments and can impact production across multiple trophic levels. From 1999 to 2009, the assemblages of forage fish, predator fish, and other pelagic nekton were monitored in coastal waters associated with the Columbia River plume. Surveys were conducted at night to target vertically migrating species, and community structure evaluated to better understand ecological interactions. Distinct inshore and offshore communities were identified during spring and summer that were correlated with ocean temperature, salinity, plume volume, and upwelling intensity. Resident euryhaline forage fish species, such as smelts, anchovy, herring, market squid, juvenile salmon, and spiny dogfish, showed a high affinity for inshore habitat and the lower salinity plume during spring. Highly migratory species, such as sardine, piscivorous hake, sharks, and mackerels, were associated with warmer, saltier waters offshore, during strong upwelling periods in summer. Overall, our study of pelagic nekton revealed that temporal dynamics in abundance and community composition were associated with seasonal abiotic phenomenon, but not interannual, large-scale oceanographic processes. Forage fish assemblages differed seasonally and spatially from the assemblages of major piscivorous predators. This finding suggests a potential role of the plume as refuge for forage fish from predation by piscivorous fish in the northern California Current.

Losee, J. P., Fisher, J., Teel, D. J., Baldwin, R. E., Marcogliese, D. J., & Jacobson, K. C. (2014). Growth and condition of juvenile coho salmon *Oncorhynchus kisutch* relate positively to species richness of trophically transmitted parasites. *Journal of Fish Biology*, *85*(5), 1665–1681. http://doi.org/10.1111/jfb.12525

The aims of this study were first, to test the hypothesis that metrics of fish growth and condition relate positively to parasite species richness (SR) in a salmonid host; second, to identify whether SR differs as a function of host origin; third, to identify whether acquisition of parasites through marine v. freshwater trophic interactions was related to growth and condition of juvenile salmonids. To evaluate these questions, species diversity of trophically transmitted parasites in juvenile coho salmon *Oncorhynchus kisutch* collected off the coast of the Oregon and Washington states, U.S.A. in June 2002 and 2004 were analysed. Fish infected with three or more parasite species scored highest in metrics of growth and condition. Fish originating from the Columbia River basin had lower SR than those from the Oregon coast, Washington coast and Puget Sound, WA. Parasites obtained through freshwater or marine trophic interactions were equally important in the relationship between SR and ocean growth and condition of juvenile *O. kisutch* salmon.

Losee, J. P., Miller, J. A., Peterson, W. T., Teel, D. J., & Jacobson, K. C. (2014). Influence of ocean ecosystem variation on trophic interactions and survival of juvenile coho and Chinook salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(11), 1747–1757. http://doi.org/10.1139/cjfas-2014-0043

The community of trophically transmitted marine parasites of juvenile coho (*Oncorhynchus kisutch*) and Chinook (*Oncorhynchus tshawytscha*) salmon across 8 years (2002–2009) was related to indices of physical and biological ocean conditions and adult returns. When the biomass of lipid-poor, southern origin copepods in the coastal ocean was high during juvenile salmon outmigration from fresh water (April–June), yearling coho and Chinook salmon harbored a different trophically transmitted parasite fauna and exhibited lower survival compared with years when the southern copepod biomass was low. As copepods are key intermediate hosts in many marine parasite life cycles, these results support a trophic linkage between the copepod community and salmon prey. Interannual variation in the parasite community was correlated with survival of coho salmon ($r = -0.67$) measured 1 year later and adult returns of Upper Columbia River summer and fall Chinook salmon ($r = -0.94$) 3 years from the time of ocean entry.

Malick, M. J., Cox, S. P., Mueter, F. J., & Peterman, R. M. (2015). Linking phytoplankton phenology to salmon productivity along a north/south gradient in the Northeast Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences*. http://doi.org/10.1139/cjfas-2014-0298

We investigated spatial and temporal components of phytoplankton dynamics in the Northeast Pacific Ocean to better understand the mechanisms linking biological oceanographic conditions to productivity of 27 pink salmon (*Oncorhynchus gorbuscha*) stocks. Specifically, we used spatial covariance functions in combination with multi-stock spawner-recruit analyses to model relationships among satellite-derived chlorophyll a concentrations, initiation date of the spring phytoplankton bloom, and salmon productivity. For all variables, positive spatial covariation was strongest at the regional scale (0-800 km) with no covariation beyond 1500 km. Spring bloom timing was significantly correlated with salmon productivity for both northern (Alaska) and

southern (British Columbia) populations, although the correlations were opposite in sign. An early spring bloom was associated with higher productivity for northern populations and lower productivity for southern populations. Furthermore, the spring bloom initiation date... Furthermore, the spring bloom initiation date was always a better predictor of salmon productivity than mean chlorophyll-a concentration. Our results suggest that changes in spring bloom timing resulting from natural climate variability or anthropogenic climate change could potentially cause latitudinal shifts in salmon productivity.

McKinnell, S., Curchitser, E., Groot, K., Kaeriyama, M., & Trudel, M. (2014). Oceanic and atmospheric extremes motivate a new hypothesis for variable marine survival of Fraser River sockeye salmon. *Fisheries Oceanography, 23*(4), 322–341. http://doi.org/10.1111/fog.12063

In spite of a relatively optimistic pre-season forecast, the total return of adult sockeye salmon (*Oncorhynchus nerka*) to the Fraser River (British Columbia, Canada) in 2009 was the lowest recorded since quantitative records began in the late 1940s. A plausible mechanism is proposed that links a sequence of extreme oceanic and climatic events to poor marine survival. It began with record-setting snow packs in the coastal mountain range during the winter of 2007 that led to the development of unprecedented oceanographic conditions in the spring of 2007 from Queen Charlotte Strait in central British Columbia to Southeast Alaska. When combined with equally extreme atmospheric anomalies in the region in the spring of 2007, with a winter wind regime persisting through July, a coastal surface ocean with characteristics that are known to be associated with lower marine survival was established. Most of the sockeye salmon that were expected to return to the Fraser River as adults in 2009 passed through this atypical ocean as juveniles on their migration to the open ocean in 2007. A trophic gauntlet hypothesis is proposed as a new paradigm to describe the oceanic environment faced by sockeye salmon after they emigrate northward from the Strait of Georgia. The hypothesis identifies a new type of high nutrient low chlorophyll region that can explain how oceanographic extremes at critical locations along the migration route beyond the Strait of Georgia can reduce marine survival in some years.

Melnychuk, M. C., Korman, J., Hausch, 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, 71*(6), 831–846. http://doi.org/10.1139/cjfas-2013-0165

We observed large survival differences between wild and hatchery-reared steelhead trout (*Oncorhynchus mykiss*) 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. We used acoustic telemetry and mark–recapture models to estimate survival of wild and (or) hatchery-reared steelhead during 4 years of the smolt migration, with both groups released in 2008. After adjusting for estimated freshwater residualization, 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 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.

Miller, K. M., Teffer, A., Tucker, S., Li, S., Schulze, A. D., Trudel, M., Juanes, F., Tabata, A., Kaukinen, K. H., Ginther, N. G., Ming, T. J., Cooke, S. J., Hipfner, J. M., Patterson, D. A. & Hinch, S. G. (2014). Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. *Evolutionary Applications, 7*(7), 812–855. http://doi.org/10.1111/eva.12164

Emerging diseases are impacting animals under high-density culture, yet few studies assess their importance to wild populations. Microparasites selected for enhanced virulence in culture settings should be less successful maintaining infectivity in wild populations, as once the host dies, there are limited opportunities to infect new individuals. Instead, moderately virulent microparasites persisting for long periods across multiple environments are of greatest concern. Evolved resistance to endemic microparasites may reduce susceptibilities, but as barriers to microparasite distributions are weakened, and environments become more stressful, unexposed populations may be impacted and pathogenicity enhanced. We provide an overview of the evolutionary and ecological impacts of infectious diseases in wild salmon and suggest ways in which modern technologies can elucidate the microparasites of greatest potential import. We present four case studies that resolve microparasite impacts on adult salmon migration success, impact of river warming on microparasite replication, and infection status on susceptibility to predation. Future health of wild salmon must be considered in a holistic context that includes the cumulative or synergistic impacts of multiple stressors. These approaches will identify populations at greatest risk, critically needed to manage and potentially ameliorate the shifts in current or future trajectories of wild populations.

Miller, J. A., Teel, D. J., Peterson, W. T., & Baptista, A. M. (2014). Assessing the relative importance of local and regional processes on the survival of a threatened salmon population. *PLoS ONE*, *9*(6), e99814. http://doi.org/10.1371/journal.pone.0099814

Research on regulatory mechanisms in biological populations often focuses on environmental covariates. An integrated approach that combines environmental indices with organismal-level information can provide additional insight on regulatory mechanisms. Survival of spring/summer Snake River Chinook salmon (*Oncorhynchus tshawytscha*) is consistently low whereas some adjacent populations with similar life histories experience greater survival. It is not known if populations with differential survival respond similarly during early marine residence, a critical period in the life history. Ocean collections, genetic stock identification, and otolith analyses were combined to evaluate the growth-mortality and match-mismatch hypotheses during early marine residence of spring/summer Snake River Chinook salmon. Interannual variation in juvenile attributes, including size at marine entry and marine growth rate, was compared with estimates of survival and physical and biological metrics. Multiple linear regression and multi-model inference were used to evaluate the relative importance of biological and physical metrics in explaining interannual variation in survival. There was relatively weak support for the match-mismatch hypothesis and stronger evidence for the growth-mortality hypothesis. Marine growth and size at capture were strongly, positively related to survival, a finding similar to spring Chinook salmon from the Mid-Upper Columbia River. In hindcast models, basin-scale indices (Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO)) and biological indices (juvenile salmon catch-per-unit-effort (CPUE) and a copepod community

index (CCI)) accounted for substantial and similar portions of variation in survival for juvenile emigration years 1998–2008 (R^2>0.70). However, in forecast models for emigration years 2009–2011, there was an increasing discrepancy between predictions based on the PDO (50–448% of observed value) compared with those based on the NPGO (68–212%) or biological indices (CPUE and CCI: 83–172%). Overall, the PDO index was remarkably informative in earlier years but other basin-scale and biological indices provided more accurate indications of survival in recent years.

Munsch, S. H., Cordell, J. R., Toft, J. D., & Morgan, E. E. (2014). Effects of seawalls and piers on fish assemblages and juvenile salmon feeding behavior. *North American Journal of Fisheries Management, 34*(4), 814–827. http://doi.org/10.1080/02755947.2014.910579

Shoreline modifications, such as seawall armoring and piers, are ubiquitous along developed waterfronts worldwide, and recent research suggests that their ecological effects are primarily negative. We utilized snorkel surveys to quantify the effects of seawalls and piers on fish in nearshore habitats of an urbanized estuary in Puget Sound, Washington. We observed 17 species of fish and 4 species of crab during April–August 2012 at sites modified by seawalls and piers and at reference beach sites with minimal anthropogenic structures. Species assemblages at modified sites were significantly different from those at reference beaches. At modified sites, fish distribution and assemblage structure varied with proximity to the shade cast by piers; overall fish abundances were reduced under piers, and the greatest abundances were observed at high tides in areas directly adjacent to piers. Juvenile Pacific salmon *Oncorhynchus* spp. were the dominant fish species, and piers reduced their presence and feeding, indicating that areas under piers provide less-valuable habitat to salmon species. Piers may interrupt movements of juvenile salmon when they use shallow waters along shorelines to migrate from freshwater to marine habitats, as juvenile salmon tend to avoid shade under piers, especially at high tides. Our results show that shoreline modifications can alter species assemblage structure, thus potentially creating novel combinations and abundances of species, and can reduce habitat function for species that utilize these and similar habitats elsewhere.

Neher, T. D. H., Rosenberger, A. E., Zimmerman, C. E., Walker, C. M., & Baird, S. J. (2014). Use of glacier river-fed estuary channels by juvenile Coho Salmon: transitional or rearing habitats? *Environmental Biology of Fishes, 97*(7), 839–850. http://doi.org/10.1007/s10641-013-0183-x

Estuaries are among the most productive ecosystems in the world and provide important rearing environments for a variety of fish species. Though generally considered important transitional habitats for smolting salmon, little is known about the role that estuaries serve for rearing and the environmental conditions important for salmon. We illustrate how juvenile coho salmon *Oncorhynchus kisutch* use a glacial river-fed estuary based on examination of spatial and seasonal variability in patterns of abundance, fish size, age structure, condition, and local habitat use. Fish abundance was greater in deeper channels with cooler and less variable temperatures, and these habitats were consistently occupied throughout the season. Variability in channel depth and water temperature was negatively associated with fish abundance. Fish size was negatively related to site distance from the upper extent of the tidal influence, while fish condition did not relate to channel location within the estuary ecotone. Our work demonstrates the potential this glacially-fed estuary serves as both transitional and rearing habitat for juvenile coho salmon

during smolt emigration to the ocean, and patterns of fish distribution within the estuary correspond to environmental conditions.

Neville, C. M., Beamish, R. J., & Chittenden, C. M. (2015). Poor survival of acoustically-tagged juvenile Chinook Salmon in the Strait of Georgia, British Columbia, Canada. *Transactions of the American Fisheries Society*, *144*(1), 25–33. http://doi.org/10.1080/00028487.2014.954053

The collapse of the commercial fishery and the major decline in catches in the recreational fishery for Chinook Salmon *Oncorhynchus tshawytscha* in the Strait of Georgia since the mid-1990s represents a major economic loss to British Columbia. Early marine residence is critical for survival of Chinook Salmon, but measuring the amount of mortality has been difficult. Acoustic tags can be used to measure marine mortality and study migratory behavior. We surgically implanted 278 juvenile Chinook Salmon with acoustic tags to monitor when and how many tagged fish moved out of the Strait of Georgia. Only eight tagged fish were detected leaving the Strait of Georgia, indicating that there could have been substantial mortality of the tagged juvenile Chinook Salmon within the strait. Tagging mortality was minimal, and the detection of tags was shown not to be a major source of error in this study. A major change in population structure between the spring and fall tagging periods meant that it was unlikely that most of the fish tagged in June and July remained within the Strait of Georgia. The decline in abundance of juvenile Chinook Salmon in November 2008 also indicates that the lack of detections of all tagged fish is unlikely a consequence of fish remaining in the Strait of Georgia. This information and the low catches in winter surveys indicated that most juvenile Chinook salmon were no longer in the strait in the late fall and winter. If the tagged fish were representative of the untagged fish, the current brood-year strength probably is largely determined within the Strait of Georgia.

Osterback, A.-M. K., Frechette, D. M., Hayes, S. A., Bond, M. H., Shaffer, S. A., & Moore, J. W. (2014). Linking individual size and wild and hatchery ancestry to survival and predation risk of threatened steelhead (*Oncorhynchus mykiss). Canadian Journal of Fisheries and Aquatic Sciences*, *71*(12), 1877–1887. http://doi.org/10.1139/cjfas-2014-0097

We examined the role of individual size and origin (wild versus hatchery) to predation risk and marine survival for threatened juvenile steelhead (*Oncorhynchus mykiss*) in a coastal California watershed. In this study, we found that individual size and origin were strongly associated with increased predation risk of steelhead by a generalist avian predator (western gull, Larus occidentalis) and associated with survival to reproduction by tracking the fate of juvenile steelhead tagged with passive integrated transponder (PIT) tags. Across six cohorts (2005–2010), larger steelhead (>170 mm fork length (FL)) experienced marine survival rates at least 60 times higher than the smallest individuals. Predation risk by western gulls was highest for intermediate-sized fish (145–190 mm FL), which was at least ten times higher than the predation risk of the smallest individuals and four times higher than the predation risk of the largest individuals. Wild steelhead experienced both higher predation risk and higher survival rates than hatchery fish of the same size. Although gulls disproportionately remove intermediate-sized wild steelhead from the population, they also remove large wild individuals that may otherwise experience the highest adult return rates. Instead of focusing on population size alone, conservation measures could also be guided towards the recovery of larger and wild individuals, whose survival is paramount for population recovery

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 of London B: Biological Sciences, 281*****(1776), 20132913. http://doi.org/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.

Perry, R. W., Brandes, P. L., Burau, J. R., Sandstrom, P. T., & Skalski, J. R. (2015). Effect of tides, river flow, and gate operations on entrainment of juvenile salmon into the interior Sacramento–San Joaquin River delta. ***Transactions of the American Fisheries Society, 144*****(3), 445–455. http://doi.org/10.1080/00028487.2014.1001038**

Juvenile Chinook Salmon *Oncorhynchus tshawytscha* emigrating from natal tributaries of the Sacramento River, California, must negotiate the Sacramento–San Joaquin River Delta (hereafter, the Delta), a complex network of natural and man-made channels linking the Sacramento River with San Francisco Bay. Fish that enter the interior and southern Delta—the region to the south of the Sacramento River where water pumping stations are located—survive at a lower rate than fish that use alternative migration routes. Consequently, total survival decreases as the fraction of the population entering the interior Delta increases, thus spurring management actions to reduce the proportion of fish that are entrained into the interior Delta. To better inform management actions, we modeled entrainment probability as a function of hydrodynamic variables. We fitted alternative entrainment models to telemetry data that identified when tagged fish in the Sacramento River entered two river channels leading to the interior Delta (Georgiana Slough and the gated Delta Cross Channel). We found that the probability of entrainment into the interior Delta through both channels depended strongly on the river flow and tidal stage at the time of fish arrival at the river junction. Fish that arrived during ebb tides had a low entrainment probability, whereas fish that arrived during flood tides (i.e., when the river's flow was reversed) had a high probability of entering the interior Delta. We coupled our entrainment model with a flow simulation model to evaluate the effect of nighttime closures of the Delta Cross Channel gates on the daily probability of fish entrainment into the interior Delta. Relative to 24-h gate closures, nighttime closures increased daily entrainment probability by 3 percentage points on average if fish arrived at the river junction uniformly throughout the day and by only 1.3 percentage points if 85% of fish arrived at night. We

illustrate how our model can be used to evaluate the effects of alternative water management actions on fish entrainment into the interior Delta.

Perry, R. W., Plumb, J. M., & Huntington, C. W. (2015). Using a laboratory-based growth model to estimate mass- and temperature-dependent growth parameters across populations of juvenile Chinook Salmon. *Transactions of the American Fisheries Society*, *144*(2), 331–336. http://doi.org/10.1080/00028487.2014.996667

To estimate the parameters that govern mass- and temperature-dependent growth, we conducted a meta-analysis of existing growth data from juvenile Chinook Salmon *Oncorhynchus tshawytscha* that were fed an ad libitum ration of a pelleted diet. Although the growth of juvenile Chinook Salmon has been well studied, research has focused on a single population, a narrow range of fish sizes, or a narrow range of temperatures. Therefore, we incorporated the Ratkowsky model for temperature-dependent growth into an allometric growth model; this model was then fitted to growth data from 11 data sources representing nine populations of juvenile Chinook Salmon. The model fit the growth data well, explaining 98% of the variation in final mass. The estimated allometric mass exponent (b) was 0.338 (SE = 0.025), similar to estimates reported for other salmonids. This estimate of b will be particularly useful for estimating mass-standardized growth rates of juvenile Chinook Salmon. In addition, the lower thermal limit, optimal temperature, and upper thermal limit for growth were estimated to be 1.8°C (SE = 0.63°C), 19.0°C (SE = 0.27°C), and 24.9°C (SE = 0.02°C), respectively. By taking a meta-analytical approach, we were able to provide a growth model that is applicable across populations of juvenile Chinook Salmon receiving an ad libitum ration of a pelleted diet.

Peterson, W. T., Fisher, J. L., Peterson, J. O., Morgan, C. A., Burke, B. J., & Fresh, K. L. (2014). Applied fisheries oceanography: Ecosystem indicators of ocean conditions inform fisheries management in the California Current. *Oceanography, 27*(4), 80–89. http://dx.doi.org/10.5670/oceanog.2014.88

Fisheries oceanography is the study of ecological relationships between fishes and the dynamics of their marine environments and aims to characterize the physical, chemical, and biological factors that affect the recruitment and abundance of harvested species. A recent push within the fisheries management community is toward ecosystem-based management. Here, we show how physical and biological oceanography data can be used to generate indicators of ocean conditions in an ecosystem context, and how these indicators relate to the recruitment of salmonids, sablefish, sardines, and rockfish in the California Current.

Plumb, J. M., & Moffitt, C. M. (2015). Re-estimating temperature-dependent consumption parameters in bioenergetics models for juvenile Chinook Salmon. *Transactions of the American Fisheries Society*, *144*(2), 323–330. http://doi.org/10.1080/00028487.2014.986336

Researchers have cautioned against the borrowing of consumption and growth parameters from other species and life stages in bioenergetics growth models. In particular, the function that dictates temperature dependence in maximum consumption (Cmax) within the Wisconsin bioenergetics model for Chinook Salmon *Oncorhynchus tshawytscha* produces estimates that are lower than those measured in published laboratory feeding trials. We used published and unpublished data from laboratory feeding trials with subyearling Chinook Salmon from three stocks (Snake, Nechako, and Big Qualicum rivers) to estimate and adjust the model parameters for temperature dependence in Cmax. The data included growth measures in fish ranging from

1.5 to 7.2 g that were held at temperatures from 14°C to 26°C. Parameters for temperature dependence in Cmax were estimated based on relative differences in food consumption, and bootstrapping techniques were then used to estimate the error about the parameters. We found that at temperatures between 17°C and 25°C, the current parameter values did not match the observed data, indicating that Cmax should be shifted by about 4°C relative to the current implementation under the bioenergetics model. We conclude that the adjusted parameters for Cmax should produce more accurate predictions from the bioenergetics model for subyearling Chinook Salmon.

Price, M. H. H., & Connors, B. M. (2014). Evaluating relationships between wild Skeena River Sockeye Salmon productivity and the abundance of spawning channel enhanced Sockeye smolts. *PLoS ONE, 9*(4). http://doi.org/10.1371/journal.pone.0095718

The enhancement of salmon populations has long been used to increase the abundance of salmon returning to spawn and/or to be captured in fisheries. However, in some instances enhancement can have adverse impacts on adjacent non-enhanced populations. In Canada's Skeena watershed, smolt-to-adult survival of Babine Lake sockeye from 1962–2002 was inversely related to the abundance of sockeye smolts leaving Babine Lake. This relationship has led to the concern that Babine Lake smolt production, which is primarily enhanced by spawning channels, may depress wild Skeena (Babine and non-Babine) sockeye populations as a result of increased competition between wild and enhanced sockeye smolts as they leave their natal lakes and co-migrate to sea. To test this hypothesis we used data on Skeena sockeye populations and oceanographic conditions to statistically examine the relationship between Skeena sockeye productivity (adult salmon produced per spawner) and an index of Babine Lake enhanced smolt abundance while accounting for the potential influence of early marine conditions. While we had relatively high power to detect large effects, we did not find support for the hypothesis that the productivity of wild Skeena sockeye is inversely related to the abundance of enhanced sockeye smolts leaving Babine Lake in a given year. Importantly, life-time productivity of Skeena sockeye is only partially explained by marine survival, and likely is an unreliable measure of the influence of smolt abundance. Limitations to our analyses, which include: (1) the reliance upon adult salmon produced per spawner (rather than per smolt) as an index of marine survival, and (2) incomplete age structure for most of the populations considered, highlight uncertainties that should be addressed if understanding relationships between wild and enhanced sockeye is a priority in the Skeena.

Putman, N. F., Meinke, A. M., & Noakes, D. L. G. (2014). Rearing in a distorted magnetic field disrupts the "map sense" of juvenile steelhead trout. *Biology Letters, 10*(6), 20140169. http://doi.org/10.1098/rsbl.2014.0169

We used simulated magnetic displacements to test orientation preferences of juvenile steelhead trout (*Oncorhynchus mykiss*) exposed to magnetic fields existing at the northernmost and southernmost boundaries of their oceanic range. Fish reared in natural magnetic conditions distinguished between these two fields by orienting in opposite directions, with headings that would lead fish towards marine foraging grounds. However, fish reared in a spatially distorted magnetic field failed to distinguish between the experimental fields and were randomly oriented. The non-uniform field in which fish were reared is probably typical of fields that many hatchery fish encounter due to magnetic distortions associated with the infrastructure of aquaculture. Given that the reduced navigational abilities we observed could negatively influence marine

survival, homing ability and hatchery efficiency, we recommend further study on the implications of rearing salmonids in unnatural magnetic fields.

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, 24*(4), 446–450. http://doi.org/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 [1–3]. 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 [1–7]. Although adults reproducing in the vicinity of favorable ocean currents can facilitate transport of their offspring to these habitats [7–9], variation in ocean circulation makes passive transport unreliable, and young animals probably take an active role in controlling their migratory trajectories [10–13]. 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 [12–21], imply that magnetic maps are phylogenetically widespread and likely explain the extraordinary navigational abilities evident in many long-distance underwater migrants.

Quinn, T. P., Bond, M., & Slater, S. (2014). Use of stable isotopes and otolith micro-chemistry to evaluate migration in male Chinook Salmon, *Oncorhynchus tshawytscha*, from an Alaskan river. *Northwest Science, 88*(4), 360–366. http://doi.org/10.3955/046.088.0409

In salmonid fishes, males display much more variation in age and size at maturity than females, including a greater proportion of non-anadromous individuals, and those spending fewer years at sea than females. The life history of Chinook salmon is especially variable among Pacific salmon species, including non-anadromous (precocious parr) and early maturing anadromous males (jacks) but these have been studied primarily in populations towards the central and southern part of their range. In this study we investigated reports of small and putatively non-anadromous male Chinook salmon in Lake Creek, Alaska, using otolith microchemistry and stable isotopes. Small males (ca. 300–350 mm fork length) displayed otolith Sr:Ca ratios and $\delta^{15}N$ values consistent with anadromy; indeed, the $\delta^{15}N$ values of these "mini-jacks" that had spent a year at sea and larger jacks (ca. 500 mm) were more enriched than those of the larger, older conspecifics. Thus the multiple alternative anadromous male life history patterns reported in southern populations (and often associated with rapid pre-smolt growth in hatcheries) are present in more northerly wild populations of Chinook salmon as well. Moreover, variation in stable isotopes indicated differences in marine distribution related to age (with younger fish closer to the coast), and otolith microchemistry suggested that some of the young males may have moved to low salinity water during their period of marine residence.

Quinn, T. P., Shaffer, J. A., Brown, J., Harris, N., Byrnes, C., & Crain, P. (2014). Juvenile Chinook salmon, *Oncorhynchus tshawytscha*, use of the Elwha river estuary prior to dam

removal. ***Environmental Biology of Fishes*****,** ***97*****(6), 731–740. http://doi.org/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.

Quiñones, R. M., Holyoak, M., Johnson, M. L., & Moyle, P. B. (2014). Potential factors affecting survival differ by run-timing and location: linear mixed-effects models of Pacific Salmonids (*Oncorhynchus* spp.) in the Klamath River, California. ***PLoS ONE*****,** ***9*****(5). http://doi.org/10.1371/journal.pone.0098392**

Understanding factors influencing survival of Pacific salmonids (*Oncorhynchus* spp.) is essential to species conservation, because drivers of mortality can vary over multiple spatial and temporal scales. Although recent studies have evaluated the effects of climate, habitat quality, or resource management (e.g., hatchery operations) on salmonid recruitment and survival, a failure to look at multiple factors simultaneously leaves open questions about the relative importance of different factors. We analyzed the relationship between ten factors and survival (1980–2007) of four populations of salmonids with distinct life histories from two adjacent watersheds (Salmon and Scott rivers) in the Klamath River basin, California. The factors were ocean abundance, ocean harvest, hatchery releases, hatchery returns, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, El Niño Southern Oscillation, snow depth, flow, and watershed disturbance. Permutation tests and linear mixed-effects models tested effects of factors on survival of each taxon. Potential factors affecting survival differed among taxa and between locations. Fall Chinook salmon *O. tshawytscha* survival trends appeared to be driven partially or entirely by hatchery practices. Trends in three taxa (Salmon River spring Chinook salmon, Scott River fall Chinook salmon; Salmon River summer steelhead trout *O. mykiss*) were also likely driven by factors subject to climatic forcing (ocean abundance, summer flow). Our findings underscore the importance of multiple factors in simultaneously driving population trends in widespread species

such as anadromous salmonids. They also show that the suite of factors may differ among different taxa in the same location as well as among populations of the same taxa in different watersheds. In the Klamath basin, hatchery practices need to be reevaluated to protect wild salmonids.

Rebenack, J. J., Ricker, S., Anderson, C., Wallace, M., & Ward, D. M. (2015). Early emigration of juvenile Coho Salmon: Implications for population monitoring. *Transactions of the American Fisheries Society*, *144*(1), 163–172. http://doi.org/10.1080/00028487.2014.982258

Salmon monitoring programs often measure juvenile production by operating migrant traps downstream of spawning and rearing areas during smolt migration. However, this approach does not account for individuals that move downstream of trapping locations prior to smolt sampling. We used a mark-recapture study with passive integrated transponder tagging to estimate the proportion of Coho Salmon *Oncorhynchus kisutch* juveniles, tagged in the fall in a Northern California stream, that migrated to rearing habitat downstream of a seasonally operated trap before spring smolt sampling. Emigrants were detected by using the migrant trap, located near the upstream limit of tidal influence, and continuously operated antennas located in tidal wetlands downstream of the trap. For all three cohorts sampled (2010, 2011, 2012), we identified two distinct emigration periods (not including fry emigrants that emigrated in spring at a size too small to tag): a fall-winter period, when early emigrant parr moved into a restored tidal wetland (early emigrants); and a spring period, when smolts emigrated (smolt emigrants). There was little movement in the intervening period. Emigration timing varied depending on the location in the basin where fish were tagged; locations in the lower main stem generally produced more early emigrants, while locations in the upper basin produced more smolt emigrants. Across locations, early emigrants accounted for 2-25% of the fall-marked juveniles from 2010, 8-29% from 2011, and 7-13% in 2012. Smolt emigrants accounted for 15-49% of the fall-marked juveniles from 2010, 13-14% from 2011, and 3-35% from 2012. The consistent occurrence of early emigration in this and other recent studies brings into question estimates of smolt abundance and demographic rates (e.g., overwinter and marine survival) that do not account for this life history variant.

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. http://doi.org/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.

Reese, D. C., & Brodeur, R. D. (2015). Species associations and redundancy in relation to biological hotspots within the northern California Current ecosystem. *Journal of Marine Systems, 146,* 3-16. http://doi.org/10.1016/j.jmarsys.2014.10.009

The dynamic nature of biological hotspots, while well recognized, is not well understood. We hypothesize that the persistence of hotspots in the northern California Current System (CCS), despite seasonal and annual changes in the nekton community species composition, is related to associations among species and their functional redundancy. To address this hypothesis, sampling was conducted during June and August of 2000 and 2002 within two hotspots occurring between Newport, Oregon and Crescent City, California in the coastal CCS. Associations were examined to identify potentially complementary and redundant species. The strongest negative associations were between jellyfish and fish species, with strong positive associations evident among several fish species. Dominant species varied seasonally and annually, although evidence indicated replacement of dominant species by other similar species with respect to functional group and preferred habitat. This finding suggests that the persistence of these biological hotspots is related to species redundancy and is an important attribute contributing to stability within this highly variable system.

Reum, J. C. P., Hovel, R. A., & Greene, C. M. (2015). Estimating continuous body size-based shifts in delta N-15-delta C-13 space using multivariate hierarchical models. *Marine Biology, 162*(2), 469–478. http://doi.org/10.1007/s00227-014-2574-8

Stable isotopes (delta N-15 and delta C-13) offer one representation of an individual's trophic niche and are important tools for elucidating ecological patterns and testing a diversity of hypotheses. Because delta N-15 and delta C-13 values are often obtained from the same sample, they compose a bivariate response that researchers commonly analyze using multivariate statistical methods. However, stable isotope data sets often exhibit hierarchical structure whereby samples may be clustered or grouped at multiple levels either as an artifact of sampling design or due to structure inherent in the sampled population (e.g., samples from individuals grouped according to life history stages, social groups, ages, or sizes classes). Ignoring such structure can result in overly optimistic confidence intervals and heighten the risk of observing significant differences where none exist. To address these issues, we suggest researchers utilize multivariate hierarchical models, which are a simple extension of univariate hierarchical methods. The models account for potential dependencies between delta N-15 and delta C-13 values, permit valid predictions of shifts in delta N-15-delta C-13 space related to predictor variables, provide more accurate estimates of parameter uncertainty, and improved inferences on coefficients that correspond to groups with small to moderate quantities of data. We demonstrate advantages of multivariate hierarchical models by examining size-dependent shifts in delta N-15-delta C-13 space in outmigrating post-smolt Chinook salmon sampled from an estuarine habitat. Given the

prevalence of complex structure in ecological stable isotope data sets, multivariate hierarchical models should hold considerable value to food web and stable isotope ecologists.

Roegner, G. C., & Teel, D. J. (2014). Density and condition of subyearling Chinook Salmon in the lower Columbia River and estuary in relation to water temperature and genetic stock of origin. ***Transactions of the American Fisheries Society, 143*****(5), 1161–1176. http://doi.org/10.1080/00028487.2014.918055**

We examined the hypotheses that density and morphometric condition of subyearling juvenile Chinook Salmon *Oncorhynchus tshawytscha* would decline during periods of high water temperature in the lower Columbia River and estuary. The hypotheses were tested using salmon density measurements and a condition anomaly calculated from residuals of the length–weight linear regression based on 5,536 subyearlings collected from brackish estuarine and tidal freshwater (TFW) habitats. We captured Chinook Salmon at all temperatures encountered (4.2–23.5°C). In the TFW zone, densities were highest at optimal temperatures and lowest at suboptimal and supraoptimal temperatures; in the estuary, density did not differ among temperature regimes. Fish condition was lowest in winter, when temperatures were suboptimal, and highest in summer, when temperatures were supraoptimal. Pairwise comparisons of fish condition between periods of optimal temperature (spring) and supraoptimal or stressful temperature (summer) showed little change in the estuary but a large, positive increase with temperature in the TFW zone. Similarly, we examined seasonal differences in the condition of 50–60-mm fry and again found condition to be lowest in winter and highest in summer. Finally, using genetic information, we identified stock-specific differences in migration timing and concluded that most large yearlings and many subyearlings migrated in late winter or spring and therefore were never exposed to high temperatures. Other prevalent stocks persisted in the estuary during periods of elevated temperature; however, the condition of those fish also tended to be higher or neutral in summer than in spring. High temperatures appeared to influence migration timing, as evidenced by reduced density in TFW reaches during summer. However, we found little support for the hypothesis that condition of juvenile Chinook Salmon is reduced during periods of high water temperature in the lower Columbia River and estuary.

Rohde, J., Fresh, K. L., & Quinn, T. P. (2014). Factors affecting partial migration in Puget Sound Coho Salmon. ***North American Journal of Fisheries Management, 34*****(3), 559–570. http://doi.org/10.1080/02755947.2014.892548**

Partial migration, the behavior pattern in which a portion of a population migrates while others do not, is a widespread phenomenon with ecological and evolutionary consequences. Most Coho Salmon *Oncorhynchus kisutch* from Puget Sound, Washington, migrate to feed over the continental shelf or offshore in the North Pacific Ocean, but some remain in the semiestuarine waters of Puget Sound and are termed residents. The objective of this study was to determine which of several factors influenced residency in Puget Sound Coho Salmon. Coded wire tag recovery data showed that resident Coho Salmon were smaller than their migratory counterparts, and we used this size difference and the relative catch patterns along the coast and in Puget Sound to classify Coho Salmon caught in Puget Sound between November and August as residents. We then analyzed the effects of location of origin, day of release, weight at release, hatchery or wild rearing, and year on the proportion of fish caught as residents. Based on 268 release groups between 1975 and 1992, we classified 3.4% of fish recovered as residents, 61.3% as migrants, and 35.3% as ambiguous because they were recovered in Puget Sound in September

and October, when residents and migrants were mixed. The proportion of residents varied as a function of year, basin, and day of the year. Releases into south Puget Sound produced the highest proportion of residents, and resident fish tended to be recovered in the basin where they entered Puget Sound. While other factors may influence residency in Coho Salmon, the effects of day of release and location of origin may be useful for management of these populations, as the tendency to remain in Puget Sound or migrate to the coast affects the fisheries in which the fish are taken and their growth rate, their uptake of contaminants, and their role in food webs.

Ruggerone, G. T., & Connors, B. M. (2015). Productivity and life history of sockeye salmon in relation to competition with pink and sockeye salmon in the North Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences*. http://doi.org/10.1139/cjfas-2014-0134

Sockeye salmon populations from Southeast Alaska through British Columbia to Washington State have experienced similar declines in productivity over the past two decades, leading to economic and ecosystem concerns. Because the declines have spanned a wide geographic area, the primary mechanisms driving them likely operate at a large, multi-regional scale at sea. However, identification of such mechanisms has remained elusive. Using hierarchical models of stock-recruitment dynamics, we tested the hypothesis that competition between pink and sockeye salmon for prey has led to reduced growth and productivity and delayed maturation of up to 36 sockeye populations spanning the region during the past 55 years. Our findings indicate the abundance of North Pacific pink salmon in the second year of sockeye life at sea is a key factor contributing to the decline of sockeye salmon productivity, including sockeye in the Fraser River where an increase from 200 to 400 million pink salmon is predicted to reduce sockeye recruitment by 39%. Additionally, length-at-age of Fraser River sockeye salmon declined with greater sockeye and pink salmon abundance, and age-at-maturity increased with greater pink salmon abundance. Our analyses provide evidence that interspecific competition for prey can affect growth, age and survival of sockeye salmon at sea.

Sandell, T. A., Teel, D. J., Fisher, J., Beckman, B., & Jacobson, K. C. (2015). Infections by *Renibacterium salmoninarum* and *Nanophyetus salmincola* Chapin are associated with reduced growth of juvenile Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Northeast Pacific Ocean. *Journal of Fish Diseases*, 38(4), 365-378. http://doi.org/10.1111/jfd.12243

We examined 1454 juvenile Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), captured in nearshore waters off the coasts of Washington and Oregon (USA) from 1999 to 2004 for infection by *Renibacterium salmoninarum, Nanophyetus salmincola* Chapin and skin metacercariae. The prevalence and intensities for each of these infections were established for both yearling and subyearling Chinook salmon. Two metrics of salmon growth, weight residuals and plasma levels of insulin-like growth factor-1, were determined for salmon infected with these pathogens/parasites, both individually and in combination, with uninfected fish used for comparison. Yearling Chinook salmon infected with *R. salmoninarum* had significantly reduced weight residuals. Chinook salmon infected with skin metacercariae alone did not have significantly reduced growth metrics. Dual infections were not associated with significantly more severe effects on the growth metrics than single infections; the number of triple infections was very low and precluded statistical comparison. Overall, these data suggest that infections by these organisms can be associated with reduced juvenile Chinook salmon growth. Because growth in the first year at sea has been linked to survival for some stocks of Chinook salmon, the

infections may therefore play a role in regulating these populations in the Northeast Pacific Ocean.

Satterthwaite, W. H., Carlson, S. M., Allen-Moran, S. D., Vincenzi, S., Bograd, S. J., & Wells, B. K. (2014). Match-mismatch dynamics and the relationship between ocean-entry timing and relative ocean recoveries of Central Valley fall run Chinook salmon. *Marine Ecology Progress Series, 511*, 237–248. http://doi.org/10.3354/meps10934

The match-mismatch hypothesis suggests there is an optimal window for organisms to undergo key life cycle events. Here, we test the importance of match-mismatch dynamics in the timing of salmon arrival to the ocean, relative to ecosystem phenology, for the ocean survival rates of hatchery-origin fall run Chinook salmon originating from California's Central Valley. Specifically, we considered tag recovery data for releases of coded-wire tagged fish released into the San Francisco Estuary during the years 1978 to 2010. We determined a time lag for each release relative to the local spring transition date (initiation of net upwelling). Additionally, we obtained information on fish condition and size at release, the number of fish released corresponding to distinct tag codes, and yearly stock-specific harvest rate estimates. We used generalized linear models, generalized additive models, and cross-validation to identify the best-supported models for the effects of release timing and other covariates on age-3 ocean fishery recovery rates, a proxy of ocean survival rates. Release time is a useful predictor of within-year variation in survival rates, above and beyond the effects of size at release, presence of disease, and the use of net pens, and the lag relative to spring transition was a slightly better predictor than year-day. The optimal release timing appeared to occur around the end of May, and the optimal time lag appeared to be approximately 70 to 115 d after the spring transition date. However, timing is only one of many factors that affected within- and among-year variation in survival.

Schaller, H. A., Petrosky, C. E., & Tinus, E. S. (2014). Evaluating river management during seaward migration to recover Columbia River stream-type Chinook salmon considering the variation in marine conditions. *Canadian Journal of Fisheries and Aquatic Sciences, 71*(2), 259–271. http://doi.org/10.1139/cjfas-2013-0226

Evidence suggests Snake River stream-type Chinook salmon (*Oncorhynchus tshawytscha*) experience substantial delayed mortality in the marine environment as a result of their outmigration experience through the Federal Columbia River Power System (FCRPS). We analyzed mortality patterns using methods that incorporated downriver reference populations passing fewer dams, and temporal approaches that were independent of reference populations. Our results from the alternative spatial and temporal methods consistently corroborated with spawner–recruit residuals and smolt-to-adult survival rate data sets, indicating that Snake River salmon survived about one quarter as well as the reference populations. Temporal analysis indicated that a high percentage (76%) of Snake River juvenile salmon that survived the FCRPS subsequently died in the marine environment as a result of their outmigration experience. Through this and previous studies, it is evident that delayed hydrosystem mortality increases with the number of powerhouse passages and decreases with the speed of outmigration. Therefore, a promising conservation approach would be to explore management experiments that evaluate these relationships by increasing managed spill levels at the dams during the spring migration period.

Spangenberg, D., Larsen, D. A., Gerstenberger, R., Brun, C., & Beckman, B. R. (2014). The effects of variation in rearing conditions on growth, smolt development, and minijack rate in yearling Chinook Salmon: a hatchery scale experiment. *Transactions of the American Fisheries Society*, *143*(5), 1220–1230. http://doi.org/10.1080/00028487.2014.931304

In this investigation a single genetic stock of Hood River, Oregon, Chinook Salmon *Oncorhynchus tshawytscha* was reared at three different hatchery facilities over three brood years (2008–2010) and monitored for size, growth rate, gill Na+,K+-ATPase activity, condition factor, whole body energetics, and precocious male maturation (age-2 minijack rate). This experimental design provided a unique opportunity to isolate environmental from genetic effects on salmonid life history. Differences in the seasonal thermal regimes and associated growth profiles among the three facilities resulted in modest differences in smolt development but significant variation in size at release (range = 18 g body weight, 118 mm FL to 31 g body weight, 142 mm FL) and minijack rates (range = 4.8–57.1%) among groups. Previous studies have found a positive relationship between body size at release and minijack rates. However, in this investigation the release group with the largest mean body size consistently had the lowest minijack rates. This unique result may be due to the more natural thermal regime and feeding profile experienced by fish at this facility compared with that of the other two facilities and highlights the importance and potential benefits of adhering to a more "wildlike" growth profile in hatchery supplementation programs.

Stocks, A. P., Pakhomov, E. A., & Hunt, B. P. V. (2014). A simple method to assess the marine environment residence duration of juvenile sockeye salmon (*Oncorhynchus nerka*) using laser ablation. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(10), 1437–1446. http://doi.org/10.1139/cjfas-2014-0073

Monitoring habitat utilization and early marine growth of sockeye salmon juveniles (*Oncorhynchus nerka*) in fjords of the Pacific Northwest is currently hampered by difficulties in estimating residence times, limiting scientific advances in certain aspects of this species' fisheries management and conservation. Combining otolith microchemistry and conventional daily ring counts, we were able to obtain the date of first entry and the residence time of sockeye juveniles in Rivers Inlet, British Columbia. This operationally inexpensive method builds upon variable microelement concentrations in fresh- and saltwater environments: barium (Ba) and strontium (Sr) concentrations within the sockeye otoliths differed between the freshwater and seawater growth zones; Ba concentrations in the freshwater growth zone were significantly higher than those in the seawater growth zone, while Sr concentrations in the former were significantly lower than in the latter. The concentrations of these elements within otoliths were determined quantitatively at high spatial resolution using in situ laser ablation inductively coupled with a plasma mass spectrometer (ICPMS) providing a record of the ambient environmental conditions experienced by individual fish. Exploratory analysis of a 3-year data set showed that the mean residence time of sockeye juveniles in Rivers Inlet varied between 3 and 6 weeks between years.

Sutherland, B. J., Koczka, K. W., Yasuike, M., Jantzen, S. G., Yazawa, R., Koop, B. F., & Jones, S. R. (2014). Comparative transcriptomics of Atlantic *Salmo salar*, chum *Oncorhynchus keta* and pink salmon *O. gorbuscha* during infections with salmon lice *Lepeophtheirus salmonis*. *BMC Genomics*, *15*(1), 200. http://doi.org/10.1186/1471-2164-15-200

Salmon species vary in susceptibility to infections with the salmon louse (*Lepeophtheirus salmonis*). Comparing mechanisms underlying responses in susceptible and resistant species is important for estimating impacts of infections on wild salmon, selective breeding of farmed salmon, and expanding our knowledge of fish immune responses to ectoparasites. Herein we report three *L. salmonis* experimental infection trials of co-habited Atlantic *Salmo salar*, chum *Oncorhynchus keta* and pink salmon *O. gorbuscha*, profiling hematocrit, blood cortisol concentrations, and transcriptomic responses of the anterior kidney and skin to the infection.

Tanasichuk, R. W., Grayson, J., Yakimishyn, J., Taylor, S., & Dagley, G. D. (2014). The Early Marine Biology of the Hatchery/Wild Juvenile Salmonid (*Oncorhynchus* sp.) Community in Barkley Sound, Canada. *The Open Fish Science Journal*, *7*(1), 8–22.

We conducted 11 purse seine/beachseine surveys over the summers of 2000 and 2001 to learn about the migration timing, distribution, and diet of hatchery chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*), and wild chinook, coho, sockeye (*O. nerka*) and chum (*O. keta*) juvenile salmon, in Barkley Sound, West Coast Vancouver Island. Juvenile salmon partitioned Barkley Sound by time and space, and by diet except for hatchery and wild coho. The analysis of migration timing included historic data for 1987-89, and results showed that timing differed between species and was consistent over years. Sockeye and chum dominated the juvenile salmon community until mid-June and hatchery and wild chinook dominated subsequently. Fish tended to be dispersed contagiously. Results of correlation analyses of catch suggested that fish of different origins and species did not co-occur. The euphausiid *Thysanoessa spinifera* was an important prey item but different fish species selected different sizes of *T. spinifera* at different times. The diet overlap between hatchery and wild coho did not affect return. Migration timing for sockeye and wild coho seems to reflect a strategy to enter the ocean when the biomass of the size fraction of *T. spinifera* that each species selects is likely to be maximal. Descriptions of migration timing, fish interactions, and diet provide information which appears to be useful for learning about the biological basis of salmon return variability.

Teel, D. J., Bottom, D. L., Hinton, S. A., Kuligowski, D. R., McCabe, G. T., McNatt, R., Roegner, G. C., Stamatiou, L. A., & Simenstad, C. A. (2014). Genetic identification of Chinook Salmon in the Columbia River estuary: stock-specific distributions of juveniles in shallow tidal freshwater habitats. *North American Journal of Fisheries Management*, *34*(3), 621–641. http://doi.org/10.1080/02755947.2014.901258

Extensive efforts are underway to restore and conserve nearshore shallow water habitats in the Columbia River estuary with the intent of increasing the estuary's capacity to provide food, refuge, and other crucial ecosystem functions for juvenile salmon. Juvenile Chinook Salmon *Oncorhynchus tshawytscha*, including those from the five Evolutionarily Significant Units listed as threatened or endangered under the U.S. Endangered Species Act, are particularly expected to benefit from the habitat improvements. However, information on the temporal and spatial estuarine distributions of juveniles from specific populations or stocks is lacking and impedes restoration planning for at-risk salmon. We conducted a series of surveys to sample juvenile Chinook Salmon occupying shallow-water habitats with sandy beaches in six hydrogeomorphic reaches across the tidal freshwater portion of the estuary and also at one long-term reference site near the estuary mouth. Sites were sampled bimonthly over 26 months during 2010–2012 to capture seasonal patterns of stock-specific habitat use. Genetic stock identification analyses were conducted on the samples using microsatellite DNA loci and genotypic data representing

spawning populations from throughout the Columbia River basin. We identified three tidal freshwater areas that could be distinguished by genetic stock composition. Lower tidal freshwater reaches were dominated by fall-run juveniles from West Cascade tributaries (>70%), upper reaches had a large proportion of fish from the upper Columbia River summer–fall stock (>60%), and middle reaches were characterized by greater stock diversity with no single stock contributing more than 30% in each reach. Stock-specific juvenile habitat use differed by season, life history type, and between natural and hatchery-produced fish. Data from this study provide improved descriptions of the near-shore estuary habitat use of several Columbia River genetic stocks of Chinook Salmon that can assist managers in the design and selection of estuary restoration projects.

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–U561. http://doi.org/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, J. N., & Beauchamp, D. A. (2014). Size-selective mortality of Steelhead during freshwater and marine life stages related to freshwater growth in the Skagit River, Washington. *Transactions of the American Fisheries Society, 143*(4), 910–925. http://doi.org/10.1080/00028487.2014.901253

We evaluated freshwater growth and survival from juvenile (ages 0–3) to smolt (ages 1–5) and adult stages in wild steelhead *Oncorhynchus mykiss* sampled in different precipitation zones of the Skagit River basin, Washington. Our objectives were to determine whether significant size-selective mortality (SSM) in steelhead could be detected between early and later freshwater stages and between each of these freshwater stages and returning adults and, if so, how SSM varied between these life stages and mixed and snow precipitation zones. Scale-based size-at-annulus comparisons indicated that steelhead in the snow zone were significantly larger at annulus 1 than those in the mixed rain–snow zone. Size at annuli 2 and 3 did not differ between

precipitation zones, and we found no precipitation zone × life stage interaction effect on size at annulus. Significant freshwater and marine SSM was evident between the juvenile and adult samples at annulus 1 and between each life stage at annuli 2 and 3. Rapid growth between the final freshwater annulus and the smolt migration did not improve survival to adulthood; rather, it appears that survival in the marine environment may be driven by an overall higher growth rate set earlier in life, which results in a larger size at smolt migration. Efforts for recovery of threatened Puget Sound steelhead could benefit by considering that SSM between freshwater and marine life stages can be partially attributed to growth attained in freshwater habitats and by identifying those factors that limit growth during early life stages.

Thorson, J. T., Scheuerell, M. D., Buhle, E. R., & Copeland, T. (2014). Spatial variation buffers temporal fluctuations in early juvenile survival for an endangered Pacific salmon. *Journal of Animal Ecology, 83*(1), 157–167. http://doi.org/10.1111/1365-2656.12117

Spatial, phenotypic and genetic diversity at relatively small scales can buffer species against large-scale processes such as climate change that tend to synchronize populations and increase temporal variability in overall abundance or production. This portfolio effect generally results in improved biological and economic outcomes for managed species. Previous evidence for the portfolio effect in salmonids has arisen from examinations of time series of adult abundance, but we lack evidence of spatial buffering of temporal variability in demographic rates such as survival of juveniles during their first year of life. We therefore use density-dependent population models with multiple random effects to represent synchronous (similar among populations) and asynchronous (different among populations) temporal variability as well as spatial variability in survival. These are fitted to 25 years of survey data for breeding adults and surviving juveniles from 15 demographically distinct populations of Chinook salmon (*Oncorhynchus tshawytscha*) within a single metapopulation in the Snake River in Idaho, USA. Model selection identifies the most support for the model that included both synchronous and asynchronous temporal variability, in addition to spatial variability. Asynchronous variability (log-SD = 0·55) is approximately equal in magnitude to synchronous temporal variability (log-SD = 0·67), but much lower than spatial variability (log-SD = 1·11). We also show that the pairwise correlation coefficient, a common measure of population synchrony, is approximated by the estimated ratio of shared and total variance, where both approaches yield a synchrony estimate of 0·59. We therefore find evidence for spatial buffering of temporal variability in early juvenile survival, although between-population variability that persists over time is also large. * We conclude that spatial variation decreases interannual changes in overall juvenile production, which suggests that conservation and restoration of spatial diversity will improve population persistence for this metapopulation. However, the exact magnitude of spatial buffering depends upon demographic parameters such as adult survival that may vary among populations and is proposed as an area of future research using hierarchical life cycle models. We recommend that future sampling of this metapopulation employ a repeated-measure sampling design to improve estimation of early juvenile carrying capacity.

Tucker, S., Thiess, M. E., Morris, J. F. T., Mackas, D., Peterson, W. T., Candy, J. R., Beacham, T. D., Iwamoto, E. M., Teel, D. J., Peterson, M. & Trudel, M. (2015). Coastal distribution and consequent factors influencing production of endangered Snake River Sockeye Salmon. *Transactions of the American Fisheries Society*, *144*(1), 107–123. http://doi.org/10.1080/00028487.2014.968292

Snake River Sockeye Salmon *Oncorhynchus nerka* were declared endangered in 1991 after several years of decreasing abundance. Several factors, including poor marine survival, likely contributed to the decline of Snake River Sockeye Salmon. Little is known about their migration and ocean distribution and the factors influencing their production. We sampled (1) coastal waters from southern British Columbia (BC) to southeast Alaska during June–July, October–November, and February–March 1998–2011; and (2) Oregon and Washington coastal waters during May–June and September 2007–2010. In total, 8,227 juvenile Sockeye Salmon were captured. Despite their extremely low abundance relative to other stocks, 15 coded-wire-tagged juveniles from Redfish Lake were recovered since 2007, primarily in spring and summer surveys off the BC coast. Genetic analyses revealed that an additional eight Redfish Lake juveniles were also present in this area during summer. Snake River smolts undertook a rapid northward migration that brought them well beyond the Columbia River estuary and plume, exposing them to ocean conditions prevailing off BC. Through a multimodel inference approach, we characterized associations between the number of returning adults and a suite of ocean and river variables. Seven ocean variables and five river variables were chosen for the model selection analysis (e.g., copepod biomass anomalies, coastal upwelling indices, date of the spring transition, river discharge, river temperature, and the proportion of smolts transported through the hydropower system). Although adult returns were highly correlated with smolt abundance, our analyses suggest that ocean conditions encountered during the first growing season (as indexed by copepod anomalies) contribute to the variability in total adult returns. There was also evidence for a negative effect of transporting smolts through the hydropower system, with the caveat that we used transportation data for steelhead *O. mykiss* as a proxy.

Van Doornik, D. M., Hess, M. A., Johnson, M. A., Teel, D. J., Friesen, T. A., & Myers, J. M. (2015). Genetic population structure of Willamette River Steelhead and the influence of introduced Stocks. *Transactions of the American Fisheries Society*, *144*(1), 150–162. http://doi.org/10.1080/00028487.2014.982178

Conservation genetics studies are frequently conducted on Pacific salmon *Oncorhynchus* spp. to delineate their population structure and to quantify their genetic diversity, especially for populations that have experienced declines in abundance and are subject to anthropogenic activities. One such group of salmonids is steelhead *O. mykiss* (anadromous Rainbow Trout) from the Willamette River, a tributary of the Columbia River. Within the Willamette River there are multiple steelhead life history and run-timing types, some of which originated from nonnative populations. Late winter-run steelhead and Rainbow Trout are native to the Willamette River, whereas early winter-run and summer-run steelhead have been introduced into the system via releases from artificial propagation efforts. We conducted genetic analyses of Willamette River steelhead to determine the effect that nonnative steelhead released into the Willamette River basin have had on the genetic population structure of native steelhead. We found genetic differentiation among the samples that separated steelhead into four population groups that corresponded to run type. Possibly due to local adaptation, the native run type has retained its genetic distinctiveness from the introduced types, despite there being opportunities for gene flow among all types. Introduced early winter-run steelhead appear to be the origin of steelhead inhabiting certain Willamette River tributaries where native steelhead did not historically spawn.

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, 23*(3), 210–224. http://doi.org/10.1111/fog.12056
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 R2 = 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.

Winship, A. J., O'Farrell, M. R., & Mohr, M. S. (2014). Fishery and hatchery effects on an endangered salmon population with low productivity. *Transactions of the American Fisheries Society, 143*(4), 957–971. http://doi.org/10.1080/00028487.2014.892532
We estimated the natural spawner–fry stock–recruitment relationship and juvenile survival rates for Sacramento River winter Chinook Salmon *Oncorhynchus tshawytscha* in California and used these estimates to examine the expected numbers of spawners and fishing mortality under different fishing mortality rates and levels of hatchery supplementation. A stochastic, age-structured population dynamics model was fit to fry and female spawner abundance data for the years 1996–2010. Estimated survival rates of fry through the end of the first year in the ocean were generally <0.5%. Estimated survival rates of hatchery-origin fish from egg to the end of the first year in the ocean were on average about four times greater than the estimated maximum rate for natural-origin fish. The hatchery program was estimated to increase the number of spawners returning to natural spawning areas and thereby increase the fishing mortality rate that could be sustained. Assessing the past or future net effect of the hatchery on the size of the natural population would require quantifying any potential reduction in the productivity of the natural population as a result of reduced fitness of hatchery-origin fish spawning in natural spawning areas.

Winship, A. J., O'Farrell, M. R., Satterthwaite, W. H., Wells, B. K., & Mohr, M. S. (2015). Expected future performance of salmon abundance forecast models with varying complexity. *Canadian Journal of Fisheries and Aquatic Sciences, 72*(4), 557–569. http://doi.org/10.1139/cjfas-2014-0247
We evaluated the scope for improving abundance forecasts for fishery management using Sacramento River fall Chinook salmon (*Oncorhynchus tshawytscha*) as a case study. A range of forecast models that related the Sacramento Index (SI; an index of adult ocean abundance) to

jack (estimated age 2) spawning escapement the previous year were considered. Alternative models incorporated effects of density dependence, local environmental conditions, the abundance of the previous cohort, and trends or autocorrelation in the jack-to-SI relationship. Forecast performance was assessed in terms of bias, accuracy, ability to track trends in the SI, and management objectives. Several models achieved higher accuracy than the model used for management, but no single model performed best across all criteria, and substantial forecast error remained across all approaches considered. Environmental models generally performed better than the management model, but there were differences in the relative importance of individual environmental variables over time and among model formulations. Accounting for model selection uncertainty in environmental models decreased their forecast performance. Simpler models often had similar or better performance than environmental models. In particular, the model incorporating temporally autocorrelated errors demonstrated potential for modest forecast improvement with relatively little additional model complexity.

Ye, H., Beamish, R. J., Glaser, S. M., Grant, S. C. H., Hsieh, C., Richards, L. J., Schnute, J. T. & Sugihara, G. (2015). Equation-free mechanistic ecosystem forecasting using empirical dynamic modeling. ***Proceedings of the National Academy of Sciences, 112*****(13), E1569–E1576. http://doi.org/10.1073/pnas.1417063112**

It is well known that current equilibrium-based models fall short as predictive descriptions of natural ecosystems, and particularly of fisheries systems that exhibit nonlinear dynamics. For example, model parameters assumed to be fixed constants may actually vary in time, models may fit well to existing data but lack out-of-sample predictive skill, and key driving variables may be misidentified due to transient (mirage) correlations that are common in nonlinear systems. With these frailties, it is somewhat surprising that static equilibrium models continue to be widely used. Here, we examine empirical dynamic modeling (EDM) as an alternative to imposed model equations and that accommodates both nonequilibrium dynamics and nonlinearity. Using time series from nine stocks of sockeye salmon (*Oncorhynchus nerka*) from the Fraser River system in British Columbia, Canada, we perform, for the the first time to our knowledge, real-data comparison of contemporary fisheries models with equivalent EDM formulations that explicitly use spawning stock and environmental variables to forecast recruitment. We find that EDM models produce more accurate and precise forecasts, and unlike extensions of the classic Ricker spawner–recruit equation, they show significant improvements when environmental factors are included. Our analysis demonstrates the strategic utility of EDM for incorporating environmental influences into fisheries forecasts and, more generally, for providing insight into how environmental factors can operate in forecast models, thus paving the way for equation-free mechanistic forecasting to be applied in management contexts.

Zimmerman, M. S., Irvine, J. R., O'Neill, M. Anderson, J. H., Greene, C. M., Weinheimer, J., Trudel, M., & Rawson, K. ***In press.*** **Spatial and temporal patterns in smolt survival of wild and hatchery coho salmon (*Oncorhynchus kisutch*) in the Salish Sea.** ***Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science.***

Understanding the factors contributing to declining smolt-to-adult survival (hereafter “smolt survival”) of Coho Salmon *Oncorhynchus kisutch* originating in the Salish Sea of southwestern British Columbia and Washington State is a high priority for fish management agencies. Uncertainty regarding the relative importance of mortality operating at different spatial scales hinders the prioritization of science and management activities. We therefore examined spatial

and temporal coherence in smolt survival rates for Coho Salmon based on a decision tree framework organized by spatial hierarchy. Smolt survival patterns of populations that entered marine waters within the Salish Sea were analyzed and compared with Pacific coast reference populations at similar latitudes. Coherence in Coho Salmon smolt survival occurred at multiple spatial scales during ocean entry years 1977–2010. The primary pattern within the Salish Sea was a declining smolt survival trend over this period. In comparison, smolt survival of Pacific coast reference populations was low in the 1990s but subsequently increased. Within the Salish Sea, smolt survival in the Strait of Georgia declined faster than it did in Puget Sound. Spatial synchrony was stronger among neighboring Salish Sea populations and occurred at a broader spatial scale immediately following the 1989 ecosystem regime shift in the North Pacific Ocean than before or after. Smolt survival of Coho Salmon was synchronized at a more local scale than reported by other researchers for Chinook Salman *O. tshawytscha*, Pink Salmon *O. gorbuscha*, Chum Salmon *O. keta*, and Sockeye Salmon *O. nerka*, suggesting that early marine conditions are especially important for Coho Salmon in the Salish Sea. Further exploration of ecosystem variables at multiple spatial scales is needed to effectively address linkages between the marine ecosystem and Coho Salmon smolt survival within the Salish Sea. Since the relative importance of particular variables may have changed during our period of record, researchers will need to carefully match spatial and temporal scales to their questions of interest.