Snake River Juvenile Salmon and Steelhead Transportation Synthesis Report

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APPENDIX:

References with abstracts and summaries

Anderson, B. T., D. J. S. Gianotti, J. C. Furtado and E. Di Lorenzo (2016). "A decadal precession of atmospheric pressures over the North Pacific." Geophysical Research Letters 43(8): 3921-3927.

Sustained droughts over the Northwestern U.S. can alter water availability to the region's agricultural, hydroelectric, and ecosystem service sectors. Here we analyze decadal variations in precipitation across this region and reveal their relation to the slow (similar to 10 year) progression of an atmospheric pressure pattern around the North Pacific, which we term the Pacific Decadal Precession (PDP). Observations corroborate that leading patterns of atmospheric pressure variability over the North Pacific evolve in a manner consistent with the PDP and manifest as different phases in its evolution. Further analysis of the data indicates that low-frequency fluctuations of the tropical Pacific Ocean state energize one phase of the PDP and possibly the other through coupling with the polar stratosphere. Evidence that many recent climate variations influencing the North Pacific/North American sector over the last few years are consistent with the current phase of the PDP confirms the need to enhance our predictive understanding of its behavior.

Anderson, J. J., K. D. Ham and J. L. Gosselin (2012). Snake River Basin Differential Delayed Mortality Synthesis. Richland, Washington, Prepared by Battelle, Pacific Northwest Division, Richland Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

The type of passage (barge vs. ROR) of juvenile salmon and steelhead through the Columbia River hydrosystem has a significant effect on their post-hydrosystem survivals. The effect has been viewed as a delayed mortality in that the hydrosystem passage experience affects the mortality of fish primarily in the estuary and ocean. The effect is important because the delayed mortality for barged and ROR passage types are significantly different and so when considering the benefits of each passage type, the associated delayed mortalities must also be considered. The direct survival in barging fish is on the order of 100% and after two decades of improvements to the hydrosystem, the direct survival of ROR fish within the hydrosystem is reaching an asymptote. Thus, further improvements in the overall fish survival are now focusing on reducing the delayed mortality associated with the passage types. In particular, further improvements to hydrosystem operations can be ascertained in terms of the relative delayed mortality of barged and ROR fish, which is designated differential delayed mortality. The focus of this report is to characterize the patterns and mechanisms of delayed mortality and identify potential future research that can resolve the uncertainties in the processes with the ultimate goal of reducing delayed mortality associated with both passage types.

To remove contributions of ocean survival common to fish from both passage types we focus on the differential delayed mortality (D) which is the ratio of the post-Bonneville Dam (BON) survival (S) of barged fish (B) divided by the post-BON survival of run-of-river fish (R), D = SB / SR . By convention, D is calculated using information about the survival of fish from the time

they pass Lower Granite Dam (LGR) as juveniles to the time they return to the hydrosystem as adults. The calculation is:
D = (SARB / (SARR) x (VR / VB)
where SARB and SARR are the smolt-to-adult return rates (SARs) from the juvenile barge-loading site to their return as adults at a point in the hydrosystem for barged and run-of-river (ROR) fish, respectively. To calculate D, the SARB and SARR are divided by the respective survival rates occurring between the barge-loading site and BON (VB and VR). D varies within a year (i.e., seasonally) and across years (i.e., inter-annually), and differs among species (Chinook salmon [Oncorhynchus tshawytscha] and steelhead [O. mykiss]), run-types (spring/summer and fall Chinook salmon), and rearing types (hatchery and wild).

Understanding and identifying the elements of delayed mortality is difficult because factors interact in ways that can obscure its true mechanisms. Individual hypotheses have been proposed for why D differs from 1, but the accumulated evidence indicates there is no one factor or theory that can adequately explain patterns observed in D.

The main goals of this synthesis were to accomplish the following:
• Compile a database of research studies related to D.
• Provide a conceptual framework to consider factors affecting D.
• Review past and current research related to D, and identify data gaps and key uncertainties.
• Conduct a regional workshop to discuss recent and ongoing research studies related to D, as well as prioritization of future research topics.
• Develop a roadmap of future research that would help better understand processes related to D and help determine ways of increasing the effectiveness of the Juvenile Fish Transportation Program, which transports fish downstream past most dams in barges or trucks in order to help improve salmonid adult returns.

Database of Research Studies on D
We reviewed and developed a database of over 200 research studies related to D. References to these research studies are available in Appendix A with hyperlinks to abstracts and executive summaries within this report. The database includes papers published in peer-reviewed journals, technical memos, annual reports, and reviews.

Three Major Hypotheses
A main goal of this report is to synthesize factors that affect D. We first state overarching hypotheses and then consider the detailed factors contributing to these hypotheses later in the report. The patterns of D can generally be considered in terms of three hypotheses that are not mutually exclusive. The Fish Size Hypothesis attributes the D patterns primarily to the differential in the size of barged and ROR fish;

barged fish do not grow during their 2-d hydrosystem passage. The Arrival Time Hypothesis attributes the D patterns to the differential in arrival timing of barged fish and ROR fish; barged fish enter the estuary earlier than had they actively migrated and experience different

environmental conditions. The Fish Condition Hypothesis attributes the pattern in D to differential conditions of barged and ROR fish.

Conceptual Framework

We developed two frameworks in which to evaluate the effects of factors on D. The first approach, designated the Multivariate Regression Model, is a proportional hazards model. The second approach, designated the Culling Model, is based on a vitality model that characterizes the probability distribution of survival capacity, i.e., vitality.

In the Multivariate Regression Model, the log of the post-hydrosystem survival is defined in terms of the additive sum of explanatory variables as log S = log S0 +Σ Fi where Fi is the post-hydrosystem mortality rate that is attributed to explanatory variable i. Then D, which depends on the ratio of posthydrosystem survivals of fish from barged and ROR passage types, is defined by the passage typespecific differences in the explanatory variables giving D = exp(ΣΔFi). The important point here is that D depends on the difference of the factors between the ROR and barged fish passage through the hydrosystem, manifested as survival differences during migration after passing downstream of BON.

In the Culling Model, the distribution of survival capacity of fish entering the hydrosystem is adjusted first as they pass through the hydrosystem by barge and ROR passages and second as the fish pass through the estuary and ocean. The distribution of survival capacity (designated vitality) of fish entering the hydrosystem is equivalent for barged and ROR fish and may change over time and run composition.

As fish pass through the hydrosystem, the distribution of vitality changes by two processes. First, intrinsic processes associated with growth, pathogen loading, and other forms of stress can increase or decrease the distribution of vitality during passage. Second, extrinsic challenges, principally associated with predators and the physical effects of dam passage, selectively cull the individuals with lower vitality.

Thus, the distribution of vitality among fish exiting the hydrosystem depends on the intrinsic and extrinsic processes, which are different for each passage type. Post-hydrosystem survival then depends on these distributions and any additional changes in intrinsic vitality in conjunction with post-hydrosystem extrinsic challenges, which again selectively remove the weaker individuals. The rate of culling is driven by the magnitude and frequency of extrinsic challenges.

Review of Literature on D

Twelve factors hypothesized to contribute to D were identified and categorized by whether they are associated with the environment (open circled numbers) or with the state of the fish (closed circled numbers) (Figure S.1). Based on our literature review, we determined whether there was support for these hypothesized factors, or whether the results were inconclusive. We then categorized the 12 factors by degree of importance to D (low, moderate, high) and extent of data gaps and uncertainties (limited, extensive). Factors of high importance were those with

relatively strong and consistent effects on D with hypothesized mechanisms. Factors of moderate importance were those with some effect on D, but which showed inconsistent patterns possibly because they were overwhelmed by other factors. Factors of low importance were those with relatively little influence on D. The categorization of factors helps determine which of these provide the greatest insight for management (high and moderate importance; limited data gaps and uncertainty) and which are the most productive areas for future research (high and moderate importance; extensive data gaps and uncertainty). Overall, the research and published literature was most abundant for spring/summer Chinook salmon, and most deficient for fall Chinook salmon.

The 12 D factors hypothesized and evaluated are as follows:
0) Pre-hydrosystem conditions can affect the size, condition, disease susceptibility, and arrival timing of juvenile salmonids to the hydrosystem, and thus may indirectly affect D. Water temperature, population density, flow, velocity, turbulence, and hatchery conditions are some of the environmental and ecological conditions that are likely to affect the size, condition, and arrival timing of juvenile salmonids. Factor 0 was categorized as having moderate importance to D and extensive data gaps and uncertainty.

1) Arrival time to the hydrosystem and travel time through the hydrosystem affect the timing of fish arrival at the lower river, estuary, and ocean, and thus influence the environmental conditions and predation risk that fish experience post-hydrosystem. Although hydrosystem arrival time and travel time are not mechanistic factors, post-hydrosystem arrival timing is important because seasonal patterns in survival have been relatively strong across years of data. D is generally below 1 in the early season, increases throughout the season, and sometimes drops quickly at the end of the season. Seasonal patterns in survival rates in the lower river and estuary (LRE) are also apparent for spring/summer and fall Chinook salmon. Further investigations of the mechanisms producing these seasonal trends in D are needed. These include fish length, physiological condition, and estuarine and ocean conditions. These factors are further considered below. Factor 1 was considered to be of high importance to D and have limited data gaps and uncertainty.

2) Fish length is generally correlated with SAR, therefore factors that differentially affect the length distributions of fish, such as the lost opportunity to grow during barge transportation and differential entrainment into the bypass system, will affect D. The seasonal increase in fish size upon arriving at the hydrosystem and its resulting effect on transport collection efficiency and post-hydrosystem survival is a potentially important mechanism for the seasonal changes in D. The differences in sizes of barged and ROR fish that carry forward into the coastal ocean environment may affect survival through size-selective predation and through physiological processes (critical size hypotheses). Factor 2 was considered to be of high importance to D and have extensive data gaps and uncertainty.

3) Fish physiology includes processes such as smoltification, depletion of energetic reserves, and stress that may influence migration readiness and the overall health of the fish. Lower levels of smoltification in barged fish upon arrival downstream of BON are hypothesized to

increase their travel time in the LRE, and consequently increase their post-hydrosystem predation risk relative to ROR fish. However, decreased energetic reserves in ROR fish and negligible loss of energetic reserves in barged fish during passage through the hydrosystem may counteract the differential effects of smoltification. Other indices of physiological condition such as stress hormones may be detected in barged juveniles, but do not necessarily translate into reduced SARs. The diversity of responses shows that complex interactions can occur between environmental conditions, physiological responses, and survival rates. There will be a need to decipher which combinations of physiological indices can help decide when, where, and which to fish collect for an effective Juvenile Fish Transportation Program to help improve adult returns. Factor 3 by and large was considered to be of moderate importance to D and have extensive data gaps and uncertainty.

4) Fish diseases may affect fish survival directly or indirectly through increased predation risk. Pathogen prevalence and load together can be indicators of the overall health of a group of fish. Contrasting patterns in the barge vs. ROR survival in disease-related experiments across several studies suggest that the pre-hydrosystem conditions of these fish are important. It is important to understand that fish constantly move back and forth along a continuum of healthy to pathogenic states depending on the environmental conditions they experience, and thus may exhibit complex patterns in pathogen prevalence and survival. Techniques, now available to sample pathogens non-lethally and assess both pathogen prevalence and pathogen load, would help in determining whether disease is a major driver of D patterns. If it is, the conditions that minimize pathogen transmission, such as those that have recently been identified for barging, can be implemented. Factor 4 was considered to be of moderate importance to D and have extensive data gaps and uncertainty.

5) Dam operations are hypothesized to affect D via changes in passage conditions that alter cumulative stress effects. Although compelling evidence has been found to suggest that undetected fish experience better ROR passage conditions than those detected in the bypass system and returned to the river, the exact causes are elusive. Percent spill may also affect the proportion of fish transported, the survival of ROR migrants, and hence D. Model simulations have shown that hatchery spring/summer Chinook salmon are more sensitive to spill, while steelhead are more sensitive to flow. The mixed spilltransport strategy implemented since 2006 will provide more data on how dam operations under various conditions of flow affect SARs and D. Factor 5 was categorized as having high importance to D with extensive data gaps and uncertainty.

6) Barging conditions that have been hypothesized in the literature to affect D include 1) cumulative stress during dam passage as suggested by increased delayed mortality in fish that migrated in the river part-way and then were barged from dams downstream of Lower Granite Dam, 2) disruption of homeostasis and auditory sensitivity by dissolved metals and noise within barges, 3) diminished fish condition from high surface-water temperatures circulating in barges, particularly in fall Chinook salmon, and 4) decreased predation risk but increased straying from the alternative barging strategy near Astoria. Subhypotheses 1 and 3 were considered to be of moderate importance and have extensive data gaps and uncertainties. Subhypotheses 2 was

considered not to be of importance and subhypothesis 4 was not considered not to be important because it is not a standard barging operation.

7) Lower Columbia River (BON to rkm 56) conditions and predation have been hypothesized to affect the differential survival between barged fish and ROR migrants. Mechanisms include sizeselective predation and the seasonal pattern of fish migration rate through the lower river. The literature shows that survival through this reach is relatively high for barged and ROR spring/summer Chinook salmon and steelhead. However, differences exist between barged and ROR fall Chinook salmon. Also, seasonal declines in survival have been observed across these species and runs. Factor ⑦ was deemed to be of low importance and have limited uncertainty for spring/summer Chinook salmon, but to be of moderate importance and have extensive uncertainty for fall Chinook salmon.

8) Estuarine conditions (downstream of rkm 56) and bird predation may affect smolt survival at the freshwater-saltwater interface where susceptibility depends on the species, level of smoltification, and fish condition. The degree of smoltification, stress, and diseases in fish and the seasonal pattern of bird predation rates may contribute to the seasonal variations in D. Most of the research on avian predation is focused on run-at-large fish and few, if any, have formally tested differences in the susceptibility of barged and ROR fish. Striking and consistent patterns of decreased fish survival occur within the freshwater-seawater interfaces (rkm 0 to 32), but these were tested in run-at-large spring/summer and fall Chinook and steelhead. Factor 8 was considered to be of high importance to D and have extensive uncertainty.

9) Oceanic conditions can affect the seasonal and year-to-year variations in D. Mechanisms may involve the timing and intensity of upwelling, spring productivity, and the arrival of ocean predators, alternative prey, and competitors. The differential arrival timing to the estuary between barged and ROR fish together with the seasonal variations in ocean conditions appear to have a significant impact on the variations in D. Factor ⑨ was deemed to be of high importance to D and have extensive uncertainty.

10) Straying increases with rates of barging, possibly due to the impairment of the homing ability of the fish. Differences in straying rates between barged and ROR fish are an example of a late-acting effect of barging on D, but their significance to D is likely minimal, especially in spring/summer Chinook salmon. Factor 10 was deemed to be of low importance to D and have limited uncertainty.

11) The estimation of survival by tagged fish can also be influenced by passage type and hence affect estimates of D. Estimates of the transport-to-in-river ratio (T:I) can be biased high because they are based on passive integrated transponder-tagged fish that are detected only when they pass through the bypass system and consequently experience lower survival than fish that pass through the spill route. An alternative standard for T:I has been recently developed to compensate for the bias related to reduced survival of bypassed fish. No estimates of an alternative D have been developed. The estimation of survival as well as tagging effects were both considered to be of low importance to D but have extensive uncertainty.

Differential Delayed Mortality Workshop

The 1.5-day workshop was held 10–11 May 2011 in Portland, Oregon, and was attended by at least 42 participants. Please see Appendix D for the agenda. On the first day, presentations generally covered the topics of fish disease, physiology, and survival including the following:

- a synopsis of this report
- a culling model based on individual heterogeneity and degree of selection
- general research approaches to investigate fish pathogens
- differential physiological indices and gene expression
- two potential issues with estimations of D
- an adjusted standard for Transport:Migrant (T:M; also T:I) ratios to reflect higher survival of neverdetected fish relative to bypassed fish.

On the second day, presentations covered the lower river, estuary, and ocean, including the following:

- a comprehensive model to identify significant factors of D
- within-barge survival rates
- survival, travel time, and migration pathways in the LRE
- annual and seasonal ocean conditions
- the possibility of equivalent hydrosystem and coastal ocean survival rates.

Many of the discussions about data gaps and key uncertainties were related to fish length, health, environmental conditions, and dam operations. The effect of fish lengths, physiological condition, and pathogens on the differential survival of barged fish and ROR migrants was of general interest. Whether fish condition caused bias in their entrainment into the juvenile bypass system was also discussed. It was suggested that low D may be expressed in small-sized fish and not larger-sized fish.

Roadmap for Future Research

We discuss areas of research in relation to when to barge, how many to barge, which fish to barge, where to begin barging, and how to barge. Finally, we present the roadmap for future research, which addresses some key questions, their relevance to a juvenile fish transportation program with the goal of improving adult returns, some potential research approaches, the approximate durations of study, and potential challenges that can be addressed. The categorization of hypothesized factors by the degree of importance to D and by the extent of data gaps and uncertainty were used to determine areas of future research with the greatest potential to inform the management of the Juvenile Fish Transportation Program and help improve SARs.

The proposed future research opportunities generally fall into three major categories that focus on fish condition, fish behavior and environmental conditions, with some interaction between these categories. Research topics of interest in the fish condition category relate to the effects of fish size, physiological condition, and pathogen load on D. One key research question is whether smaller fish experience lower survival than larger fish within and across species, runs,

and rearing types to produce the patterns of D observed. Fish condition could also affect their swimming behavior and probability of entrainment into the bypass system, thus possibly causing selection of "weaker" fish for transportation. But much uncertainty remains. Research topics of interest in the ecological and environmental conditions category include the correlative effects of proportion of spill and proportion of fish transported on D across a range of flow rates, and determination of indices of estuary and ocean conditions associated with D. Possible approaches to investigating these topics include adventitious analyses of current data and model simulations; surveys or monitoring programs of fish conditions with fish collections by a mobile Separation by Code system in the LRE; challenge experiments of fish collected that were entering and exiting the hydrosystem by ROR and barge passage types; and continued investigation of survival in the estuary using acoustic tags.

Hypotheses related to D have been and continue to be refined. As data collection and improvements in technology continue, the region is gaining a better understanding of this complex issue that spans large spatial and temporal scales and that involves many interacting factors. As we gain a better understanding of the processes affecting D, we are working toward the possibility of a real-time monitoring program in which the indices collected and modeled with historical data help predict D and SARs. When that possibility is realized, web-based real-time monitoring and predictions could help inform transport decision-making.

Anderson, J. J., R. A. Hinrichsen, C. Van Holmes and K. D. Ham (2005). Historical Analysis of PIT Tag Data for Transportation of Fish at Lower Granite, Little Goose, Lower Monumental and McNary Dams. Task 1: Analysis of In-River Environmental Conditions. Prepared for the U.S. Army Corps of Engineers, Walla Walla Disctrict, Walla Walla, Washington, by Battelle, Pacific Northwest Division Richland, Washington.

The U.S. Army Corps of Engineers (Corps) intercepts migratory juvenile salmonids at up to four dams and transports them downstream in an attempt to increase their survival rate to the ocean. Previous studies have shown that transport does not always increase smolt to adult returns (SAR). Therefore, it is important to understand if, and when, the transportation of fish is likely to improve survivals. The purpose of this study was to examine the available information to identify factors that influence the survival of juvenile salmonids migrating out of the Snake River and how these factors affect the performance of the transportation system. PIT tag data regarding transportation and bypass processes and their effects on juvenile salmonids, have been collected since 1995 in the Lower Snake River. In addition, environmental data have been collected throughout the basin, including water temperature, total dissolved gas, river discharge, and spill proportion. These data were analyzed to identify:
1) Year-to-year variation in SAR
2) Within-year statistical correlations among specific transportation operations and SAR
3) Environmental factors that would allow prediction of when the SAR of transported fish exceed the SAR of in-river passing fish (T:I > 1)

Results indicated that SAR varied widely among years for all passage history types and for all stocks. An increasing trend in SAR began about 1998 for spring/summer Chinook salmon and steelhead. SARs increased after 1998 for fish tagged above Lower Granite (LGR) Dam and for those tagged at LGR Dam. For fall Chinook salmon, SAR varied among years, but no clear trend was evident from 1995 to 2000.

In spite of large variation in SAR among years, regression analyses revealed consistent trends among groups with differing passage histories. Our analysis of passage routes, using yearly averaged SARs across years, indicated that hatchery spring/summer Chinook salmon transported from LGR and Little Goose (LGO) Dams had higher SARs than from all other passage history types. Transported hatchery spring/summer Chinook salmon returned at rates 30% higher than nondetected fish and at nearly twice the rate of once-detected fish and fish transported from Lower Monumental (LMN) and McNary (MCN) Dams. Wild spring/summer Chinook salmon transported from LGR returned at higher rates than those returned to migrate in the river, but LGR/LGO transported fish returned at rates equal to only 80% of the in-river fish detected only once. Wild and hatchery steelhead transportation at LGR and LGO appeared to be beneficial or at least not deleterious relative to nondetected and once-detected fish passage. For fall Chinook salmon, the limited evidence suggests that nondetected fish return at higher rates than transported fish, but there were too few fish to make the more important comparisons of transported versus detected. For all fish, in-river passage SAR was higher for nondetected fish than detected fish; multiple-detected fish had the lowest SARs among groups.

A number of environmental covariates were examined for correlations with SAR. Two independent methods, covariate analysis and running averages, showed that SAR was strongly correlated with LGR passage day, temperature and, to a lesser extent, flow. In particular, for spring/summer Chinook salmon and steelhead the SAR of fish that passed in river decreased with increasing temperature and LGR passage day. These two covariates were highly correlated so the significance of each could not be separated. Additionally, transported fish SARs did not vary significantly with flow, temperature or LGR passage day. Estimates of the impact of temperature on smolt passage survival from relationships proposed in other studies was sufficient to explain half the decline of in-river fish SARs. Furthermore, indirect evidence from challenge experiments conducted by NOAA in 2002 indicated it was possible that higher migration temperature could have weakened the in-river migrants ability to survive as they entered the ocean.

From the exponential relationships of SAR and covariates it was possible to obtain equations relating for T:I to temperature, and T:I to LGR passage day. The T:I ratio increased with both temperature and passage day. However, our analysis of the impacts of temperature on in-river fish suggested an increasing T:I ratio resulted from degrading conditions for in-river passing fish, not improved survival of transported fish.

When all stocks were taken together, the resulting equations predicted that when day > 112 or temperature > 9.3°C, transported fish would return at higher rates than in-river fish. Flow was also correlated with T:I in some years, but the seasonal dynamics of flow made it a poor

predictor of SAR. A retrospective analysis on spring/summer Chinook salmon indicated that temperature may be the better predictor of optimal transportation conditions.

Ashley, M. V., M. F. Willson, O. R. W. Pergams, D. J. O'Dowd, S. M. Gende and J. S. Brown (2003). "Evolutionarily enlightened management." Biological Conservation 111(2): 115-123.

Here we review growing evidence that microevolutionary changes may often be rapid and, in many cases, occur on time frames comparable to human disturbance and anthropogenic change. Contemporary evolutionary change has been documented in relatively pristine habitats, in disturbed populations, under captive management, and in association with both intentional and inadvertent introductions. We argue that evolutionary thinking is thus relevant to conservation biology and resource management but has received insufficient consideration. Ignoring evolution may have a variety of consequences, including unpredicted evolutionary responses to disturbance and naive or inappropriate management decisions. Philosophically, we must also grapple with the issue of whether the evolution of adaptations to disturbance and degraded habitats is sometimes beneficial or something to be rigorously avoided. We advocate promoting evolutionarily enlightened management [Lecture Notes in Biomathematics 99 (1994) 248], in which both the ecological and evolutionary consequences of resource management decisions are considered.

Auth, T. D. (2011). "Analysis of the Spring-Fall epipelagic ichthyoplankton community in the Northern California Current in 2004-2009 and its relation to environmental factors." California Cooperative Oceanic Fisheries Investigations Reports 52: 148-167.

The taxonomic composition, distribution, concentration, and community structure of ichthyoplankton off the Oregon and Washington coasts were examined in 2004–2009 to investigate annual, seasonal, latitudinal, and cross-shelf variability. Larval concentrations and community structure were also analyzed in relation to several local and larger-scale environmental variables. The dominant taxa, comprising 94% of the total larvae collected, were Engraulis mordax, Sebastes spp., Stenobrachius leucopsarus, Tarletonbeania crenularis, and Lyopsetta exilis. Larval concentrations and diversity generally varied across the temporal and spatial scales. Several seasonal and crossshelf assemblages were identified, and annual, seasonal, latitudinal, and cross-shelf gradients of taxonomic associations with significant indicator taxa were found. Distance from shore, salinity, and temperature were the local environmental factors that explained the most variability in larval fish concentrations, while Columbia River outflow and sea-surface temperature were the larger-scale factors that explained the most variability in 2–4 month lagged larval fish concentrations and diversity.

Auth, T. D. and R. D. Brodeur (2013). "An overview of ichthyoplankton research in the Northern California Current region: contributions to ecosystem assessments and management." California Cooperative Oceanic Fisheries Investigations Reports 54: 107-126.

We review the scientific literature based on ichthyoplankton research conducted in the northern California Current (NCC) north of Cape Mendocino, California to northern Washington. A total of 69 papers have been written on ichthyoplankton research in the NCC region from 1940 to 2012, with several more currently in the process of publication. Although there were some extended California Cooperative Fisheries Investigation (CalCOFI) cruises in the 1950s conducted as far north as northern California, the first dedicated larval fish survey in this region was made by Ken Waldron of the Bureau of Commercial Fisheries in 1967. Extensive cruises were conducted starting in 1969 and continuing through the 1970s by William Pearcy at Oregon State University (OSU) and the ichthyoplankton were analyzed by Sally Richardson and her colleagues. Much new information on larval taxonomy, spatial and temporal distributions, and relationships to environmental conditions was generated as part of these studies. Nearshore studies continued in the early 1980s by OSU focusing on the recruitment and connections of mainly flatfish species to the local estuaries. At the same time, there were a series of eight joint U.S.-Soviet large-scale cruises covering the entire region organized by Art Kendall of NMFS, with the data analyzed primarily by Miriam Doyle. After a hiatus in the early to mid-1990s, sampling began anew by NMFS and OSU focusing initially off the central Oregon coast, but by the mid-2000s was expanded over a broader area of the NCC over multiple years and seasons to provide information to managers on the outlook for future recruitment. We discuss current gaps in our knowledge, and give examples of applications of ichthyoplankton data to fisheries management and to improving our understanding of ecosystem processes and their relationships to environmental variability.

Auth, T. D., R. D. Brodeur and J. O. Peterson (2015). "Anomalous ichthyoplankton distributions and concentrations in the northern California Current during the 2010 El Nino and La Nina events." Progress in Oceanography 137: 103-120.

In late spring of 2010, the northern California Current (NCC) experienced a transition from El Niño to La Niña conditions resulting in anomalous distributions and concentrations within the ichthyoplankton community. We analyzed larval fish data collected during the four months before and after this transition and compared them to data from three previous studies conducted in the NCC. In one comparison, concentrations of larvae collected during winter from stations 2 to 46 km offshore along the central Oregon coast were higher in 2010 than in any other year from 1998 to 2011. In a second comparison of nearshore larvae collected during six periods (1971–1972, 1978, 1983, 1998, 1999–2002, and 2003–2005) previous to 2010, concentrations of total larvae and most dominant larval taxa were higher during the winter/spring and lower during the summer/fall seasons in 2010 (corresponding to the shift from El Niño to La Niña conditions) than during similar seasons in any other annual period. In a third comparison, larvae collected from stations 21 to 102 km offshore along the southern Washington to south-central Oregon coast in May 2010, at the end of the El Niño event, were found in higher concentrations than during any May from 2004 to 2009 and 2011. The high concentration of larvae in the winter and spring of 2010 was likely the direct result of El Niño and warm-ocean conditions (high values of the MEI, NOI, and PDO) along with strong

downwelling and onshore transport that increased the abundance of offshore taxa over the shelf. Continued monitoring of the NCC is warranted as El Niño effects on larval fish observed in the past may not be indicative of future effects.

Beacham, T. D., R. J. Beamish, J. R. Candy, C. Wallace, S. Tucker, J. H. Moss and M. Trudel (2014). "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.

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., R. J. Beamish, J. R. Candy, C. Wallace, S. Tucker, J. H. Moss and M. Trudel (2014). "Stock-Specific Size of Juvenile Sockeye Salmon in British Columbia Waters and the Gulf of Alaska." Transactions of the American Fisheries Society 143(4): 876-888.

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., R. J. Beamish, C. M. Neville, J. R. Candy, C. Wallace, S. Tucker and M. Trudel (2016). "Stock-Specific Size and Migration of Juvenile Coho Salmon in British Columbia and Southeast Alaska Waters." Marine and Coastal Fisheries 8(1): 292-314.

The variation at 17 microsatellites was analyzed for 5,270 juvenile Coho Salmon Oncorhynchus kisutch obtained from coastal British Columbia and Gulf of Alaska surveys during 1998-2012. A 270-population baseline was used to determine the individual identifications of the fish sampled, with individuals being identified to 22 stocks of origin. Columbia River and Washington juveniles were consistently larger than those from British Columbia and Alaska. During June, the larger individuals within a stock were observed in more northerly locations. There was a relationship between the timing of northward migration and juvenile body size, with larger individuals migrating earlier than smaller individuals from the same stocks. Stock composition was more diverse in the northern sampling regions than in those in southern British Columbia. There was only a modest change in stock composition between fall and winter samples in both the Strait of Georgia and west coast of Vancouver Island sampling regions, indicating that juvenile migration had largely been completed by the fall. There was a wide divergence among stocks in juvenile size and dispersion among sampling locations.

Beakes, M. P., W. H. Satterthwaite, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard and M. Mangel (2010). "Smolt Transformation in Two California Steelhead Populations: Effects of Temporal Variability in Growth." Transactions of the American Fisheries Society 139(5): 1263-1275.

We tested the effect of temporal patterns in food supply on life history decisions in coastal steelhead Oncorhynchus mykiss irideus from a Central California coastal (CCC) population (Scott Creek) and a Northern California Central Valley (NCCV) population (upper Sacramento River basin). We manipulated growth through feeding experiments conducted from May to the following March using warm (2006 cohort) and cool (2007 cohort) temperature regimes. Survival in seawater challenges just before the time of typical juvenile emigration provided an index of steelhead smolt versus nonsmolt life history pathways. Survival varied significantly with fish size (with larger fish being more likely to survive than smaller fish) and by source population (with CCC steelhead being more likely to survive than NCCV steelhead of the same size). The timing of increased food supply (treatment group) did not significantly affect seawater survival rates in either NCCV or CCC steelhead. For both strains, the eventual survivors of seawater challenges (putative smolts) diverged from the eventual mortalities (putative nonsmolts) in both size and growth rate by June in both years, suggesting that the initial growth advantages were maintained throughout the experiments. A significant

divergence in condition factor between smolts and nonsmolts by December matched the expected morphological transition of smolts, which showed faster growth in length than weight compared with nonsmolts. The apparent timing of the decision window, several months before the typical period of smolt emigration, matches the patterns observed for other salmonids. In coastal California, this decision must occur before fish have had the opportunity to take advantage of improved winter-early spring feeding conditions. These results support the role of early growth opportunity in life history decisions and provide insight into the applicability of life history models for managing California steelhead.

Beakes, M. P., S. Sharron, R. Charish, J. W. Moore, W. H. Satterthwaite, E. Sturm, B. K. Wells, S. M. Sogard and M. Mangel (2014). "Using scale characteristics and water temperature to reconstruct growth rates of juvenile steelhead Oncorhynchus mykiss." Journal of Fish Biology 84(1): 58-72.

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 degrees 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. (C) 2013 The Fisheries Society of the British Isles

Beamish, R. J., R. M. Sweeting, C. M. Neville, K. L. Lange, T. D. Beacham and D. Preikshot (2012). "Wild chinook salmon survive better than hatchery salmon in a period of poor production." Environmental Biology of Fishes 94(1): 135-148.

The population dynamics of chinook salmon (Oncorhynchus tshawytscha) from the Cowichan River on Vancouver Island, British Columbia, Canada are used by the Pacific Salmon Commission as an index of the general state of chinook salmon coast wide. In recent years the production declined to very low levels despite the use of a hatchery that was intended to increase production by improving the number of smolts entering the ocean. In 2008, we carried out an extensive study of the early marine survival of the hatchery and wild juvenile chinook salmon. We found that both rearing types mostly remained within the Gulf Islands study area during the period when most of the marine mortality occurred for the hatchery fish. By mid September, approximately 1.3% of all hatchery fish survived, compared to 7.8%-31.5% for wild fish. This six to 24 times difference in survival could negate an estimated increased egg-to-smolt survival of about 13% that is theorized to result through the use of a hatchery. Estimates of the early

marine survival are approximate, but sufficient to show a dramatic difference in the response of the two rearing types to the marine nursery area. If the declining trend in production continues for both rearing types, modifications to the hatchery program are needed to improve survival or an emphasis on improving the abundances of wild stocks is necessary, or both. The discovery that the juvenile Cowichan River chinook salmon remain within a relatively confined area of the Gulf Islands within the Strait of Georgia offers an excellent opportunity to research the mechanisms that cause the early marine mortalities and hopefully contribute to a management that improves the production.

Beckman, B. R., D. L. Harstad, D. K. Spangenberg, R. S. Gerstenberger, C. V. Brun and D. A. Larsen (2017). "The Impact of Different Hatchery Rearing Environments on Smolt-to-Adult Survival of Spring Chinook Salmon." Transactions of the American Fisheries Society 146(3): 539-555.

The aim of this study was to assess the effect of differing hatchery rearing environments on smolting, early male maturation, and smolt-to-adult return rates (SARs) in Chinook Salmon Oncorhynchus tshawytscha. In this investigation, SARs were compared for spring Chinook Salmon from Hood River stock reared at three different hatcheries and then released into the Hood River, replicated over three separate years (2010-2012). Differences in SARs were found both between rearing groups and release years. Smolts reared at Pelton Ladder had consistently higher SARs than those reared at either Parkdale or Carson hatcheries. Smolt length at release was positively correlated to SARs across years and rearing groups. In addition, multiple regression models suggested that attributes related to smolt quality were positively related to SARs while the minijack rate was negatively related to SAR. Migration of smolts downstream after release was also assessed. Larger smolts were faster downstream migrants and migration rate was positively related to subsequent SAR. Differences in smolt quality and SAR between rearing groups is attributed to differing patterns of growth in the different hatchery environments. The best-performing smolts came from rearing groups that experienced a strong seasonal change in growth rate: relatively high growth in the summer, reduced growth and depletion of energetic stores in the autumn and winter, and then increased growth again in the spring. This pattern of seasonal anabolic and catabolic changes has been termed the wild fish template, and generating this physiological pattern generally may be applicable to hatchery-reared Chinook Salmon.

Benjamin, J. R., P. J. Connolly, J. G. Romine and R. Perry (2013). "Potential Effects of Changes in Temperature and Food Resources on Life History Trajectories of Juvenile Oncorhynchus mykiss." Transactions of the American Fisheries Society 142(1): 208-220.

Increasing temperatures and changes in food resources owing to climate change may alter the growth and migratory behavior of organisms. This is particularly important for salmonid species like Oncorhynchus mykiss, where some individuals remain in freshwater to mature (nonanadromous Rainbow Trout) and others migrate to sea (anadromous Steelhead). Whether

one strategy is adopted over the other may depend on the individual's growth and size. In this study, we explored (1) how water temperature in Beaver Creek, a tributary to the Methow River, Washington, may increase under four climate scenarios, (2) how these thermal changes may alter the life history trajectory followed by O. mykiss (i.e., when and if to smolt), and (3) how changes in food quality or quantity might interact with increasing temperatures. We combined bioenergetic and state-dependent life history models parameterized for O. mykiss in Beaver Creek to mimic baseline life history trajectories. Based on our simulations, when mean water temperature was increased by 0.6 degrees C there was a reduction in life history diversity and a 57% increase in the number of individuals becoming smolts. When mean temperature was increased by 2.7 degrees C, it resulted in 87% fewer smolts than in the baseline and fewer life history trajectories expressed. A reduction in food resources led to slower growth, more life history trajectories, and a greater proportion of smolts. In contrast, when food resources were increased, fish grew faster, which reduced the proportion of smolts and life history diversity. Our modeling suggests that warmer water temperatures associated with climate change could decrease the life history diversity of O. mykiss in the central portion of their range and thereby reduce resiliency to other disturbances. In addition, changes in food resources could mediate or exacerbate the effect of water temperature on the life history trajectories of O. mykiss.

Bond, M. H., P. A. H. Westley, A. H. Dittman, D. Holecek, T. Marsh and T. P. Quinn (2017). "Combined Effects of Barge Transportation, River Environment, and Rearing Location on Straying and Migration of Adult Snake River Fall-Run Chinook Salmon." Transactions of the American Fisheries Society 146(1): 60-73.

Homing and straying in salmon have been extensively studied, yet it has proven difficult to disentangle the biotic and abiotic factors that influence straying. In the Columbia River basin, some juvenile salmon are collected at dams and transported downstream to increase survival during seaward migration, and as returning adults they experience a range of environmental conditions as they ascend the river. We examined 8 years of PIT tag detection data for hatchery-reared, fall-run Chinook Salmon Oncorhynchus tshawytscha released in the Snake River to evaluate the combined effects of juvenile barging, rearing and release locations, and environmental conditions on adult migration speed and straying below and above the Columbia River-Snake River confluence. Straying to the upper Columbia River was 10-19 times more likely among adults that were barged as juveniles from Snake River dams than among adults that were in-river migrants or that were transported from McNary Dam (below the confluence) as juveniles. Similarly, barging from Snake River dams and warmer Columbia River temperatures increased the likelihood of straying into streams below the confluence. Furthermore, adult upstream migration was slower among juveniles that were reared at two mid-Columbia River hatcheries and juveniles that were barged, indicating possible navigational impairment. However, rearing location, release distance, and release age had relatively minimal effects on straying. Collectively, our results indicate that (1) adult migration and homing are affected by a complex combination of processes that take place during smolt out-migration and the adult return migration, and (2) enhancement efforts can inadvertently add to the challenge. The straying of barged fish demonstrates the potential for increasing adult returns to the Snake

River by changing the barging process so that it more adequately supports the proper imprinting of juveniles.

Bourret, S. L., C. C. Caudill and M. L. Keefer (2016). "Diversity of juvenile Chinook salmon life history pathways." Reviews in Fish Biology and Fisheries 26(3): 375-403.

Life history variability includes phenotypic variation in morphology, age, and size at key stage transitions and arises from genotypic, environmental, and genotype-by-environment effects. Life history variation contributes to population abundance, productivity, and resilience, and management units often reflect life history classes. Recent evidence suggests that past Chinook salmon (Oncorhynchus tshawytscha) classifications (e.g., 'stream' and 'ocean' types) are not distinct evolutionary lineages, do not capture the phenotypic variation present within or among populations, and are poorly aligned with underlying ecological and developmental processes. Here we review recently reported variation in juvenile Chinook salmon life history traits and provide a refined conceptual framework for understanding the causes and consequences of the observed variability. The review reveals a broad continuum of individual juvenile life history pathways, defined primarily by transitions among developmental stages and habitat types used during freshwater rearing and emigration. Life history types emerge from discontinuities in expressed pathways when viewed at the population scale. We synthesize recent research that examines how genetic, conditional, and environmental mechanisms likely influence Chinook salmon life history pathways. We suggest that threshold models hold promise for understanding how genetic and environmental factors influence juvenile salmon life history transitions. Operational life history classifications will likely differ regionally, but should benefit from an expanded lexicon that captures the temporally variable, multi-stage life history pathways that occur in many Chinook salmon populations. An increased mechanistic awareness of life history diversity, and how it affects population fitness and resilience, should improve management, conservation, and restoration of this iconic species.

Bourret, S. L., B. P. Kennedy, C. C. Caudill and P. M. Chittaro (2014). "Using otolith chemical and structural analysis to investigate reservoir habitat use by juvenile Chinook salmon Oncorhynchus tshawytscha." Journal of Fish Biology 85(5): 1507-1525.

Isotopic composition of Sr-87:Sr-86 and natural elemental tracers (Sr, Ba, Mg, Mn and Ca) were quantified from otoliths in juvenile and adult Chinook salmon Oncorhynchus tshawytscha to assess the ability of otolith microchemistry and microstructure to reconstruct juvenile O. tshawytscha rearing habitat and growth. Daily increments were measured to assess relative growth between natal rearing habitats. Otolith microchemistry was able to resolve juvenile habitat use between reservoir and natal tributary rearing habitats (within headwater basins), but not among catchments. Results suggest that 90% (n=18) of sampled non-hatchery adults returning to the Middle Fork Willamette River were reared in a reservoir and 10% (n=2) in natal tributary habitat upstream from the reservoir. Juveniles collected in reservoirs had higher growth rates than juveniles reared in natal streams. The results demonstrate the utility of

otolith microchemistry and microstructure to distinguish among rearing habitats, including habitats in highly altered systems. (C) 2014 The Fisheries Society of the British Isles

Brewitt, K. S., E. M. Danner and J. W. Moore (2017). "Hot eats and cool creeks: juvenile Pacific salmonids use mainstem prey while in thermal refuges." Canadian Journal of Fisheries and Aquatic Sciences 74(10): 1588-1602.

Thermal refuges form important habitat for cold-water fishes in the face of rising temperatures. As fish become concentrated in refuges, food resources may become depleted. In this study, we used invertebrate drift sampling and fish density surveys to quantify potential in-refuge food limitation, temperature-sensitive radio-tagging studies to quantify thermal habitat use, and isotopic analyses to determine diet sources for juvenile Pacific salmonids using thermal refuges in California's Klamath River. Juvenile salmonids using refuges formed by tributary junctions with the mainstem river obtained the majority (range = 47%-97%) of their diet from mainstem prey sources. Mean steelhead (Oncorhynchus mykiss) body temperatures were significantly cooler (similar to 3.5 degrees C) than diet-inferred foraging temperatures. Thus, while fish seek cooler habitat for physiological benefits, they rely primarily on mainstem prey. Moreover, consistently high densities of fish in refuges (mean = 3.5 fish.m(-2)) could lead to density-dependent food limitation. Thus, mobile consumers like fish can exploit existing heterogeneity associated with cold-water refuges by gaining thermal benefits from a food-limited cold-water habitat while deriving the majority of their prey from the warm mainstem river.

Brodeur, R. D., E. A. Daly, C. E. Benkwitt, C. A. Morgan and R. L. Emmett (2011). "Catching the prey: Sampling juvenile fish and invertebrate prey fields of juvenile coho and Chinook salmon during their early marine residence." Fisheries Research 108(1): 65-73.

Marine diets of juvenile coho (Oncorhynchus kisutch) and Chinook salmon (Oncorhynchus tshawytscha) in the northern California Current are made up primarily of micronekton prey including juvenile fish, adult euphausiids, and large crab megalopae. However, these animals are seldom caught in the conventional plankton gears used to define juvenile salmon prey fields in ocean salmon programs. Four types of sampling gears with various mouth openings and configurations were examined for the ability to catchknown juvenile salmon prey. Samples were examined for differences in species composition, relative biomass, length distribution, and taxonomic overlap with prey in the diets of salmon sampled concurrently. The herring, Marinovich, and Methot trawl nets generally caught juvenile prey fish such as hexagrammids, rockfish, cottids, and osmerids. These prey were in the 15–95mmfork-length range, consistent with the type and size eaten by juvenile salmon. The bongo net sampled smaller invertebrate prey, which are rarely eaten by juvenile salmon, but instead are common prey of the juvenile fish that salmon consume. Overlap between prey fields and salmon diets was moderate for samples from the larger gear types but low for those from bongo nets towed in the same area. The fact that no gear matched exactly with coho and Chinook salmon diets was related to

differences in catchability of the prey in different gears but may also in part be probably due to the high mobility of juvenile salmon, which enables these fish to consume food in locations distant from where they are sampled, and also to selectively feed in areas of high prey concentration. Based on our analysis, we recommend the use of micronekton gears with larger mouth openings and mesh sizes for better filtration rather than standard plankton gears (i.e., bongo nets) for direct estimates of available prey resources for juvenile coho or Chinook salmon. Sampling the abundance, size, and distribution of prey fields for juvenile salmon during their first summer in the ocean, a period of high natural mortality, may help us to better understand the mechanisms of bottom-up forcing on interannual changes in salmon mortality.

Bronmark, C., K. Hulthen, P. A. Nilsson, C. Skov, L. A. Hansson, J. Brodersen and B. B. Chapman (2014). "There and back again: migration in freshwater fishes." Canadian Journal of Zoology 92(6): 467-479.

Animal migration is an amazing phenomenon that has fascinated humans for long. Many freshwater fishes also show remarkable migrations, whereof the spectacular mass migrations of salmonids from the spawning streams are the most well known and well studied. However, recent studies have shown that migration occurs in a range of freshwater fish taxa from many different habitats. In this review we focus on the causes and consequences of migration in freshwater fishes. We start with an introduction of concepts and categories of migration, and then address the evolutionary causes that drive individuals to make these migratory journeys. The basis for the decision of an individual fish to migrate or stay resident is an evaluation of the costs and benefits of different strategies to maximize its lifetime reproductive effort. We provide examples by discussing our own work on the causes behind seasonal migration in a cyprinid fish, roach (Rutilus rutilus (L., 1758)), within this framework. We then highlight different adaptations that allow fish to migrate over sometimes vast journeys across space, including capacity for orientation, osmoregulation, and efficient energy expenditure. Following this we consider the consequences of migration in freshwater fish from ecological, evolutionary, and conservation perspectives, and finally, we detail some of the recent developments in the methodologies used to collect data on fish migration and how these could be used in future research.

Brosnan, I. G., D. W. Welch, E. L. Rechisky and A. D. Porter (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.

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.

Brosnan, I. G., D. W. Welch and M. J. Scott (2016). "Survival Rates of Out-Migrating Yearling Chinook Salmon in the Lower Columbia River and Plume after Exposure to Gas-Supersaturated Water." Journal of Aquatic Animal Health 28(4): 240-251.

In 2011, unusually high flows caused total dissolved gas (TDG) levels in the Columbia River, USA, to escalate well above the 120% regulatory limit that was imposed to prevent harmful impacts to aquatic organisms. After observing gas bubble trauma (GBT) in dead yearling Chinook Salmon Oncorhynchus tshawytscha (smolts) held in tanks, we compared estimated survival rates of acoustic-tagged in-river-migrating (IR) and transported (TR) smolts that were released below Bonneville Dam prior to and during the period of elevated TDG (>120%). The log odds of estimated daily survival in the lower river and plume was significantly lower for IR smolts that were released during elevated TDG (maximum possible exposure = 134%) than for IR smolts released when TDG was less than 120%. The TR smolts that were released 10–13 km below Bonneville Dam during elevated TDG had lower maximum possible exposure levels (126% TDG), and the log odds of estimated daily survival in the lower river and plume did not differ from that of TR smolts released when TDG was less than 120%. Direct mortality due to GBT is probably reduced in natural settings relative to laboratory experiments because smolts can move to deeper water, where pressure keeps gasses in solution, and can migrate downstream of the spillway, where TDG levels decrease as the river returns to equilibrium with the atmosphere. However, initially nonlethal GBT may reduce survival rates by increasing smolt susceptibility to predation and infection. Although our findings are limited by the observational nature of the study, our analysis is the first direct assessment of gas supersaturation's potential influence on survival of free-ranging smolts in the river and coastal ocean below a large dam. Experiments using simultaneous releases of control and gas-exposed groups are warranted and should consider the possibility that the chronic effects of TDG exposure on survival are important and persist into the early marine period.

Burke, B. J., J. J. Anderson, J. A. Miller, L. Tomaro, D. J. Teel, N. S. Banas and A. M. Baptista (2016). "Estimating behavior in a black box: how coastal oceanographic dynamics influence yearling Chinook salmon marine growth and migration behaviors." Environmental Biology of Fishes 99(8-9): 671-686.

Ocean currents or temperature may substantially influence migration behavior in many marine species. However, high-resolution data on animal movement in the marine environment are scarce; therefore, analysts and managers must typically rely on unvalidated assumptions regarding movement, behavior, and habitat use. We used a spatially explicit, individual-based model of early marine migration with two stocks of yearling Chinook salmon to quantify the influence of external forces on estimates of swim speed, consumption, and growth. Model results suggest that salmon behaviorally compensate for changes in the strength and direction of ocean currents. These compensations can result in salmon swimming several times farther than their net movement (straight-line distance) would indicate. However, the magnitude of discrepancy between compensated and straight-line distances varied between oceanographic models. Nevertheless, estimates of relative swim speed among fish groups were less sensitive to the choice of model than estimates of absolute individual swim speed. By comparing groups of fish, this tool can be applied to management questions, such as how experiences and behavior may differ between groups of hatchery fish released early vs. later in the season. By taking into account the experiences and behavior of individual fish, as well as the influence of physical ocean processes, our approach helps illuminate the "black box" of juvenile salmon behavior in the early marine phase of the life cycle.

Burke, B. J., W. T. Peterson, B. R. Beckman, C. Morgan, E. A. Daly and M. Litz (2013). "Multivariate Models of Adult Pacific Salmon Returns." Plos One 8(1): e54134.

Most modeling and statistical approaches encourage simplicity, yet ecological processes are often complex, as they are influenced by numerous dynamic environmental and biological factors. Pacific salmon abundance has been highly variable over the last few decades and most forecasting models have proven inadequate, primarily because of a lack of understanding of the processes affecting variability in survival. Better methods and data for predicting the abundance of returning adults are therefore required to effectively manage the species. We combined 31 distinct indicators of the marine environment collected over an 11-year period into a multivariate analysis to summarize and predict adult spring Chinook salmon returns to the Columbia River in 2012. In addition to forecasts, this tool quantifies the strength of the relationship between various ecological indicators and salmon returns, allowing interpretation of ecosystem processes. The relative importance of indicators varied, but a few trends emerged. Adult returns of spring Chinook salmon were best described using indicators of bottom-up ecological processes such as composition and abundance of zooplankton and fish prey as well as measures of individual fish, such as growth and condition. Local indicators of temperature or coastal upwelling did not contribute as much as large-scale indicators of temperature variability, matching the spatial scale over which salmon spend the majority of their ocean residence. Results suggest that effective management of Pacific salmon requires multiple types of data and that no single indicator can represent the complex early-ocean ecology of salmon.

Cavole, L. M., A. M. Demko, R. E. Diner, A. Giddings, I. Koester, C. Pagniello, M. L. Paulsen, A. Ramirez-Valdez, S. M. Schwenck, N. K. Yen, M. E. Zill and P. J. S. Franks (2016). "Biological Impacts of the 2013-2015 Warm-Water Anomaly in the Northeast Pacific." Oceanography 29(2): 273-285.

A large patch of anomalously warm water (nicknamed "the Blob") appeared off the coast of Alaska in the winter of 2013-2014 and subsequently stretched south to Baja California. This northeastern Pacific warm-water anomaly persisted through the end of 2015. Scientists and the public alike noted widespread changes in the biological structure and composition of both open ocean and coastal ecosystems. Changes included geographical shifts of species such as tropical copepods, pelagic red crabs, and tuna; closures of commercially important fisheries; and mass strandings of marine mammals and seabirds. The ecological responses to these physical changes have been sparsely quantified and are largely unknown. Here, we provide a bottom-up summary of some of the biological changes observed in and around the areas affected by the Blob.

Chasco, B., I. C. Kaplan, A. Thomas, A. Acevedo-Gutierrez, D. Noren, M. J. Ford, M. B. Hanson, J. Scordino, S. Jeffries, S. Pearson, K. N. Marshall and E. J. Ward (2017). "Estimates of Chinook salmon consumption in Washington State inland waters by four marine mammal predators from 1970 to 2015." Canadian Journal of Fisheries and Aquatic Sciences 74(8): 1173-1194.

Conflicts can arise when the recovery of one protected species limits the recovery of another through competition or predation. The recovery of many marine mammal populations on the west coast of the United States has been viewed as a success; however, within Puget Sound in Washington State, the increased abundance of three protected pinniped species may be adversely affecting the recovery of threatened Chinook salmon (Oncorhynchus tshawytscha) and endangered killer whales (Orcinus orca) within the region. Between 1970 and 2015, we estimate that the annual biomass of Chinook salmon consumed by pinnipeds has increased from 68 to 625 metric tons. Converting juvenile Chinook salmon into adult equivalents, we found that by 2015, pinnipeds consumed double that of resident killer whales and six times greater than the combined commercial and recreational catches. We demonstrate the importance of interspecific interactions when evaluating species recovery. As more protected species respond positively to recovery efforts, managers should attempt to evaluate tradeoffs between these recovery efforts and the unintended ecosystem consequences of predation and competition on other protected species.

Claiborne, A. M., J. A. Miller, L. A. Weitkamp, D. J. Teel and R. L. Emmett (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.

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.

Clark, T. D., N. B. Furey, E. L. Rechisky, M. K. Gale, K. M. Jeffries, A. D. Porter, M. T. Casselman, A. G. Lotto, D. A. Patterson, S. J. Cooke, A. P. Farrell, D. W. Welch and S. G. Hinch (2016). "Tracking wild sockeye salmon smolts to the ocean reveals distinct regions of nocturnal movement and high mortality." Ecological Applications 26(4): 959-978.

Few estimates of migration rates or descriptions of behavior or survival exist for wild populations of out-migrating Pacific salmon smolts from natal freshwater rearing areas to the ocean. Using acoustic transmitters and fixed receiver arrays across four years (2010-2013), we tracked the migration of >1850 wild sockeye salmon (Oncorhynchus nerka) smolts from Chilko Lake, British Columbia, to the coastal Pacific Ocean (>1000 km distance). Cumulative survival to the ocean ranged 3-10% among years, although this may be slightly underestimated due to technical limitations at the final receiver array. Distinct spatial patterns in both behavior and survival were observed through all years. In small, clear, upper-river reaches, downstream migration largely occurred at night at speeds up to 50 km/d and coincided with poor survival. Among years, only 57-78% of smolts survived the first 80 km. Parallel laboratory experiments revealed excellent short-term survival and unhindered swimming performance of dummy-tagged smolts, suggesting that predators rather than tagging effects were responsible for the initial high mortality of acoustic-tagged smolts. Migration speeds increased in the Fraser River mainstem (similar to 220 km/d in some years), diel movement patterns ceased, and smolt survival generally exceeded 90% in this segment. Marine movement rates and survival were variable across years, with among-year segment-specific survival being the most variable and lowest (19-61%) during the final (and longest, 240 km) marine migration segment. Osmoregulatory preparedness was not expected to influence marine survival, as smolts could maintain normal levels of plasma chloride when experimentally exposed to saltwater (30 ppt) immediately upon commencing their migration from Chilko Lake. Transportation of smolts downstream generally increased survival to the farthest marine array. The act of tagging may

have affected smolts in the marine environment in some years as dummy-tagged fish had poorer survival than control fish when transitioned to saltwater in laboratory-based experiments. Current fisheries models for forecasting the number of adult sockeye returning to spawn have been inaccurate in recent years and generally do not incorporate juvenile or smolt survival information. Our results highlight significant potential for early migration conditions to influence adult recruitment.

Comparative Survival Study Oversight Committee (CSSOC). (2017). Documentation of Experimental Spill Management: Models, Hypotheses, Study Design and response to the ISAB. Memorandum from Fish Passage Center, Portland, Oregon to Northwest Power & Conservation Council, Portland, Oregon: 139 pp.

Connon, R. E., L. S. D'Abronzo, N. J. Hostetter, A. Javidmehr, D. D. Roby, A. F. Evans, F. J. Loge and I. Werner (2012). "Transcription Profiling in Environmental Diagnostics: Health Assessments in Columbia River Basin Steelhead (Oncorhynchus mykiss)." Environmental Science & Technology 46(11): 6081-6087.

The health condition of out-migrating juvenile salmonids can influence migration success. Physical damage, pathogenic infection, contaminant exposure, and immune system status can affect survival probability. The present study is part of a wider investigation of out-migration success in juvenile steelhead (Oncorhynchus mykiss) and focuses on the application of molecular profiling to assess sublethal effects of environmental stressors in field-collected fish. We used a suite of genes in O. mykiss to specifically assess responses that could be directly related to steelhead health condition during out-migration. These biomarkers were used on juvenile steelhead captured in the Snake River, a tributary of the Columbia River, in Washington, USA, and were applied on gill and anterior head kidney tissue to assess immune system responses, pathogen-defense (NRAMP, Mx, CXC), general stress (HSP70), metal-binding (metallothionein-A), and xenobiotic metabolism (Cyp1a1) utilizing quantitative polymerase chain reaction (PCR) technology. Upon capture, fish were ranked according to visual external physical conditions into good, fair, poor, and bad categories; gills and kidney tissues were then dissected and preserved for gene analyses. Transcription responses were tissue-specific for gill and anterior head kidney with less significant responses in gill tissue than in kidney. Significant differences between the condition ranks were attributed to NRAMP, MX, CXC, and Cyp1a1 responses. Gene profiling correlated gene expression with pathogen presence, and results indicated that gene profiling can be a useful tool for identifying specific pathogen types responsible for disease. Principal component analysis (PCA) further correlated these responses with specific health condition categories, strongly differentiating good, poor, and bad condition ranks. We conclude that molecular profiling is an informative and useful tool that could be applied to indicate and monitor numerous population-level parameters of management interest.

Connor, W. P. and K. F. Tiffan (2012). "Evidence for Parr Growth as a Factor Affecting Parr-to-Smolt Survival." Transactions of the American Fisheries Society 141(5): 1207-1218.

Data collected on juvenile anadromous salmonids implanted with passive integrated transponder (PIT) tags are used in mark-recapture analyses to understand the factors affecting survival of fish estimated between rearing in riverine habitat and dam passage. We estimated parr-to-smolt survival of PIT-tagged naturally produced subyearling fall Chinook salmon Oncorhynchus tshawytscha to examine the previously unexplored influences of environmental and biological conditions measured prior to reservoir entry. Mean (+/- SE) parr-to-smolt survival of the early migrating cohorts was 45.4 +/- 6.3% (n = 13) compared with 37.4 +/- 4.7% (n = 13) for later migrating cohorts. Annual mean parr-to-smolt survival differed widely across years ranging from a low of 9.6 +/- 0.5% (n = 2) in 2001 to a high of 81.7 +/- 4.6% (n = 2) in 1999. Parr growth prior to reservoir entry and reservoir velocity provided the most information on variability in parr-to-smolt survival (N = 26, R-2 = 0.75, corrected Akaike's information criterion [AIC(c)] = -5.01). We suggest that parr growth and reservoir velocity were directly proportional to parr-to-smolt survival because fast growth and downstream movement reduces the time when fish are vulnerable to predators. The effect of reservoir velocity comports with previous published studies and supports management efforts to increase reservoir velocity. Few if any published studies explicitly relate parr growth measured on individual fish to survival estimated for their cohorts in freshwater. This study provides empirical evidence that upholds the long-held belief that any anthropogenic activity that reduces growth of juvenile salmonids during freshwater rearing has the potential to reduce their survival.

Connor, W. P., K. F. Tiffan, J. M. Plumb and C. M. Moffitt (2013). "Evidence for Density-Dependent Changes in Growth, Downstream Movement, and Size of Chinook Salmon Subyearlings in a Large-River Landscape." Transactions of the American Fisheries Society 142(5): 1453-1468.

We studied the growth rate, downstream movement, and size of naturally produced fall Chinook Salmon Oncorhynchus tshawytscha subyearlings (age 0) for 20years in an 8th-order river landscape with regulated riverine upstream rearing areas and an impounded downstream migration corridor. The population transitioned from low to high abundance in association with U.S. Endangered Species Act and other federally mandated recovery efforts. The mean growth rate of parr in the river did not decline with increasing abundance, but during the period of higher abundance the timing of dispersal from riverine habitat into the reservoir averaged 17 d earlier and the average size at the time of downstream dispersal was smaller by 10mm and 1.8g. Changes in apparent abundance, measured by catch per unit effort, largely explained the time of dispersal, measured by median day of capture, in riverine habitat. The growth rate of smolts in the reservoir declined from an average of 0.6 to 0.2g/d between the abundance periods because the reduction in size at reservoir entry was accompanied by a tendency to migrate rather than linger and by increasing concentrations of smolts in the reservoir. The median date of passage through the reservoir was 14 d earlier on average, and average smolt

size was smaller by 38mm and 22.0g, in accordance with density-dependent behavioral changes reflected by decreased smolt growth. Unexpectedly, smolts during the high-abundance period had begun to reexpress the migration timing and size phenotypes observed before the river was impounded, when abundance was relatively high. Our findings provide evidence for density-dependent phenotypic change in a large river that was influenced by the expansion of a recovery program. Thus, this study shows that efforts to recover native fishes can have detectable effects in large-river landscapes. The outcome of such phenotypic change, which will be an important area of future research, can only be fully judged by examining the effect of the change on population viability and productivity. Received November 26, 2012; accepted May 13, 2013

Cook, C. N. and C. M. Sgrò (2017). "Aligning science and policy to achieve evolutionarily enlightened conservation." Conservation Biology 31(3): 501-512.

There is increasing recognition among conservation scientists that long-term conservation outcomes could be improved through better integration of evolutionary theory into management practices. Despite concerns that the importance of key concepts emerging from evolutionary theory (i.e., evolutionary principles and processes) are not being recognized by managers, there has been little effort to determine the level of integration of evolutionary theory into conservation policy and practice. We assessed conservation policy at 3 scales (international, national, and provincial) on 3 continents to quantify the degree to which key evolutionary concepts, such as genetic diversity and gene flow, are being incorporated into conservation practice. We also evaluated the availability of clear guidance within the applied evolutionary biology literature as to how managers can change their management practices to achieve better conservation outcomes. Despite widespread recognition of the importance of maintaining genetic diversity, conservation policies provide little guidance about how this can be achieved in practice and other relevant evolutionary concepts, such as inbreeding depression, are mentioned rarely. In some cases the poor integration of evolutionary concepts into management reflects a lack of decision-support tools in the literature. Where these tools are available, such as risk-assessment frameworks, they are not being adopted by conservation policy makers, suggesting that the availability of a strong evidence base is not the only barrier to evolutionarily enlightened management. We believe there is a clear need for more engagement by evolutionary biologists with policy makers to develop practical guidelines that will help managers make changes to conservation practice. There is also an urgent need for more research to better understand the barriers to and opportunities for incorporating evolutionary theory into conservation practice.

Cooke, S. J., D. T. Blumstein, R. Buchholz, T. Caro, E. Fernandez-Juricic, C. E. Franklin, J. Metcalfe, C. M. O'Connor, C. C. St Clair, W. J. Sutherland and M. Wikelski (2014). "Physiology, Behavior, and Conservation." Physiological and Biochemical Zoology 87(1): 1-14.

Many animal populations are in decline as a result of human activity. Conservation practitioners are attempting to prevent further declines and loss of biodiversity as well as to facilitate recovery of endangered species, and they often rely on interdisciplinary approaches to generate conservation solutions. Two recent interfaces in conservation science involve animal behavior (i.e., conservation behavior) and physiology (i.e., conservation physiology). To date, these interfaces have been considered separate entities, but from both pragmatic and biological perspectives, there is merit in better integrating behavior and physiology to address applied conservation problems and to inform resource management. Although there are some institutional, conceptual, methodological, and communication-oriented challenges to integrating behavior and physiology to inform conservation actions, most of these barriers can be overcome. Through outlining several successful examples that integrate these disciplines, we conclude that physiology and behavior can together generate meaningful data to support animal conservation and management actions. Tangentially, applied conservation and management problems can, in turn, also help advance and reinvigorate the fundamental disciplines of animal physiology and behavior by providing advanced natural experiments that challenge traditional frameworks.

Crossin, G. T., S. J. Cooke, J. A. Goldbogen and R. A. Phillips (2014). "Tracking fitness in marine vertebrates: current knowledge and opportunities for future research." Marine Ecology Progress Series 496: 1-17.

For more than 60 yr, electronic tags (including acoustic transmitters, archival loggers, and satellite tags) have been applied to free-ranging marine vertebrates to track their behaviour and characterize their spatial ecology. However, only recently have researchers begun using electronic tags to elucidate the processes that relate directly to fitness, i.e. the ability of organisms to survive and reproduce. We briefly review the history of tracking studies focused on marine vertebrates and then provide a general overview of studies that have used tracking to address fitness-related questions. Although many studies have used at-sea movement and activity data to better understand feeding ecology, physiology, and energetics, there is growing interest in the coupling of electronic tracking techniques with other disciplines to resolve the mechanisms underlying individual fitness, or more precisely the proxies thereof (survival, timing of reproduction, foraging success, etc.). We categorized studies into 4 general fitness-related areas: (1) foraging dynamics, energetics, and growth; (2) migration and other non-breeding season activities; (3) survival; and (4) reproduction. Despite recent advances in tracking technologies, which include multi-sensor loggers, tri-axial accelerometers, and miniaturized geopositioning systems, etc., very few studies on wild marine vertebrates truly measure individual fitness or proxies thereof. There is thus a need to design experimental, multi-disciplinary, and longitudinal studies that use genetics, individual-based modeling, and other techniques in an effort to resolve the mechanisms responsible for individual variation in fitness in marine vertebrates.

Crozier, L., E. Dorfmeier, T. Marsh, B. Sandford and D. Widener (2016). Refining our understanding of early and late migration of adult Upper Columbia spring and Snake River spring/summer Chinook salmon: passage timing, travel time, fallback and survival, Report of research by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, Washington.

Adult spring/summer Chinook salmon migrate through the lower Columbia River over a protracted period from March through September. We explored run timing, travel time, survival, and fallback for groups of Chinook salmon from two evolutionarily significant units (ESUs) listed under the U.S. Endangered Species Act. Passage metrics were evaluated for 5,062 adults from the Upper Columbia spring run Chinook salmon ESU and 11,496 from the Snake River spring/summer run Chinook salmon ESU. All analyses were based on detections fish marked as juveniles with passive integrated transponder (PIT) tags. Although the numbers of tagged fish are not necessarily representative of all levels of biological aggregation, we included fish from all of the major population groups (MPGs) of both ESUs, and many individual populations within these MPGs, as determined by release site in the PIT Tag Information System (PTAGIS) database.

Among fish from these ESUs, the earliest migrants were mostly from the Upper Columbia ESU, although fish originating in the Lower Snake River were also among the earliest to arrive at Bonneville Dam. Fish from the Clearwater and Rapid River were much earlier than any other Snake River populations.

For analyses of run timing and its effects on survival and travel time within the hydrosystem, we separated the Snake River spring/summer run ESU into early and late groups. Most fish from the Lower Snake, Grande Ronde, Middle Fork Salmon, and Upper Salmon River MPGs fell into the early group. However, Pahsimeroi and Imnaha fish were separated from their respective MPGs (Upper Salmon River and Grande Ronde) because these fish appeared to have distinctly later run timing. They were grouped as late migrants, along with fish from the South Fork Salmon River MPG.

Variation in run timing within and among tagged groups was extensive, even within early and late population groupings; therefore, further understanding of the factors that determine run timing is still needed. Nonetheless, median run timing of fish from the South Fork Salmon River MPG, along with those fish from the Imnaha and Pahsimeroi Rivers, was 2-4 weeks later than that of other Snake River spring/summer Chinook. Consequently, 30-40% of these late fish passed McNary Dam after 15 June, when the summer harvest period begins. In late-arrival years (2006, 2008, and 2011), a majority of the tagged fish from these late-migrant groups migrated during the summer harvest period.

Hatchery fish from the upper Columbia showed a strong tendency to arrive at Bonneville Dam before wild fish. Hatchery fish from the Wenatchee Basin, in particular, entered the reach from Bonneville to McNary Dam 3 weeks earlier, on average, than wild fish—a difference of 1.5

standard deviations. For Snake River hatchery fish, arrival timing at Bonneville was more similar to that of wild fish, or in some cases later.

Variation in survival across years was greater among the three late-migrant Snake River tag groups than among the earlier groups. Snake River late-migrant groups exhibited especially low survival in the reach from Bonneville to McNary Dam in 2011, 2014 and 2015 (range 61-67%). Within this same reach, and during the same years, late Snake River migrants also displayed unusually long median travel times (8 d).

Otherwise, median travel time was 5-6.5 d through this stretch across all groups. Two factors stood out as affecting survival within populations.
1) Estimated survival during the upstream migration was higher for wild than for hatchery fish from both Chinook salmon ESUs (0.84 vs. 0.81 for Upper Columbia and 0.84 vs. 0.79 for Snake River fish).
2) For Snake River fish, estimated survival over the upstream migration was higher for fish that had migrated downstream naturally as juveniles than for fish that had been transported downstream in barges (0.81 vs 0.79).

After controlling for early vs. late runs, hatchery vs. natural origin, and juvenile migration history of transport vs. inriver migration, there was no difference survival from Bonneville to McNary Dam between Snake and Upper Columbia River fish.

Crozier, L., E. Dorfmeier, B. Sandford and B. J. Burke (2015). Passage and Survival of Adult Snake River Sockeye Salmon within and Upstream from the Federal Columbia River Power System: 2014 Update. Report by the Fish Ecology Division, Northwest Fisheries Science Center National Marine Fisheries Service, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Sockeye salmon Oncorhynchus nerka originating in the Sawtooth Valley make up the only remaining population of this species in the upper Snake River Basin. These fish are listed as an evolutionary significant unit (ESU) under the U.S. Endangered Species Act. With adult returns as low as one in 1992 and three in 2006, this ESU is considered one of the most threatened among the listed stocks of Pacific salmon Oncorhynchus spp.

In 1991, a captive broodstock rearing program was established for Snake River sockeye salmon. Production from this program has maintained genetic variation in the population. In recent years, larger numbers of hatchery smolt releases and relatively high ocean survival have led to an increased number of returning adults.

The increased number of Snake River sockeye returns has made it possible to investigate factors influencing migration survival, an important step in reestablishing natural production of the anadromous population and determining strategies for recovery.

In a previous report, Passage and survival of adult Snake River sockeye salmon within and upstream from the Federal Columbia River Power System by Crozier et al. 2014, we examined patterns of migration and survival for Snake River sockeye from 2008 to 2013 and characterized possible threats impacting recovery of this population. Here we summarize factors affecting survival and fallback of adult Snake River sockeye from 2008 to 2014. This analysis supplements our previous report, incorporating data from 347 Snake River sockeye adults that returned in 2014 to better identify factors influencing adult migration survival and fallback at Columbia and Snake River dams.

Adult survival was explored using three categories of covariates: 1) juvenile characteristics, such as hatchery origin and downstream migration history; 2) adult migration characteristics, such as timing and fallback; and 3) environmental conditions in river reaches from Bonneville Dam to the Sawtooth Valley. Key findings from this analysis are listed below:

Adult Survival and Migration Timing

- Survival increased in 2014 relative to 2013 in all reaches except the initial stretch from Bonneville to McNary Dam. However, survival was lower than previous years, both within the hydrosystem (McNary to Lower Granite Dam) and upstream (Lower Granite Dam to Sawtooth).
- The majority of losses occurred within the reach between Bonneville and McNary Dam, where survival was the second lowest of all years examined (64%).
- Columbia River sockeye exhibited higher survival than Snake River sockeye where the runs co-migrate, between Bonneville and McNary Dam.
- Snake River sockeye migration travel time in 2014 was one of the fastest of all years examined.

Fallback

- Fallback rates continued to be very high at Bonneville (39 fallbacks per 100 successful passages) and Lower Granite Dam (36 fallbacks per 100 fish that passed the dam).
- Fish with a history of juvenile transport were 2.9 times more likely than non-transported fish to fall back.

Factors Affecting Survival and Fallback

- In-river temperature and migration travel time continued to be major factors associated with sockeye survival through the hydrosystem, contributing to both high fallback rates and lower survival.
- Adult migration survival varied strongly as a function of temperature and dropped below 50% when river temperature surpassed 18°C.
- In the Columbia River, the major factors associated with migration survival were history of juvenile transport and age at adult migration.
- Analysis of data from 2008 to 2014 showed that environmental conditions in the river, including spill, flow, and percent dissolved gas, had lower predictive power for responses of both survival and fallback compared to analyses using data from 2008 to 2013.

• Juvenile transportation and fishery catch strongly influenced adult survival and fallback at Columbia River dams, whereas temperature was the primary factor associated with fallback at Snake River dams

Crozier, L., L. Wiesebron, E. Dorfmeier and B. J. Burke (2017). River conditions, fisheries and fish history drive variation in upstream survival and fallback for Upper Columbia River spring and Snake River spring/summer Chinook salmon.

To identify what factors drove variation in survival during upstream migration, we analyzed a large database of spring/summer Chinook salmon from both the Upper Columbia River spring run and Snake River spring/summer run evolutionarily significant units (ESUs). We analyzed how individual fish characteristics and environmental conditions were related to adult migration survival from 2004-2015 for 5,062 Upper Columbia and 11,496 Snake River Chinook salmon.

We examined survival over two reaches within the hydrosystem: one in the Columbia River (Bonneville to McNary Dam, both ESUs) and one in the Snake River (Ice Harbor to Lower Granite Dam, Snake River populations only). Based on a bimodal distribution of migration times described in Crozier et al. (2016), we separated Snake River populations into early- and late-migrating sets, differentiated as “spring” and “summer” run fish in this report.

To identify the best predictors of survival and fallback over dams, we used a generalized linear modelling approach. For the Snake River ESU, we initially tested whether run was a significant factor. If it was, we analyzed spring and summer populations separately. If not, we analyzed the Snake River ESU populations together. We used the term stock to differentiate between 1) upper Columbia spring, 2) Snake River spring, and 3) Snake River summer populations.

Temperature had the most consistent influence on survival across all stocks through both reaches. Temperature generally showed a quadratic relationship with survival in both Columbia and Snake River reaches. Thus when the two reaches were combined for the Snake River ESU, survival from Bonneville to Lower Granite Dam varied from a low of 20% at temperatures over 20°C to a high of 80% at optimal temperatures (13-16°C). The year of lowest annual survival for all stocks, 2015, was also the warmest year, with a mean temperature of 17.9°C during the summer run (65% survival from Bonneville to Lower Granite).

Survival from Bonneville to McNary also responded negatively to high spill. The year of second lowest survival was 2011, when flows were 50% above normal. These high flows likely reduced adult survival through the Columbia River reach.

Annual and seasonal variation in harvest significantly affected the survival of all stocks. The year of third lowest survival was 2014, which had normal temperature and flow, but especially high catch during the Snake River summer Chinook migration (21% of the run at large). An even higher catch rate (25%) exacerbated the impacts from temperature in 2015. We found a

significant interaction between catch and run, such that summer-run populations appeared to suffer more indirect effects of catch as well as higher catch rates in some years.

Fish characteristics important in some of the analyses were hatchery/wild origin, fish age, and a history of juvenile transportation. However, impacts of these factors were less consistent than those from the primary factors of temperature, spill, and catch.

Survival through the Snake River reach from Ice Harbor to Lower Granite Dam was closely related to temperature and previous travel time in the hydrosystem (Bonneville to Ice Harbor Dam).

Fallback rates were highest and most variable at Lower Granite Dam, followed by McNary and Bonneville Dam. Temperature was important at all dams, although the shape of the relationship varied. Cumulative temperature, which is a combination of travel time and temperature, consistently had a positive correlation with fallback. Cumulative temperature was a better predictor of fallback rate than travel time alone at three dams. Flow, spill and prior travel time were also important at several dams.

Managing natural variation in temperature and flow across the enormous Columbia River Basin while accommodating economic and social needs is extremely complex. Logistical constraints and trade-offs make simplistic solutions impractical. However, to the extent that climate change will increase the frequency of years like 2015, lower survival in warm years could be a growing management concern.

Some engineering solutions are already being implemented to prevent the extreme temperatures that fish experienced in 2015. But additional mitigations might entail tradeoffs between juvenile and adult migration survival. The results of this analysis clarify the sensitivity of this crucial life stage. Net costs and benefits of catch and spill regimes over the entire salmon life cycle need to be analyzed comprehensively under alternative management scenarios to plot a successful course toward long-term recovery of these threatened species.

Crozier, L. G., T. E. Bowerman, B. J. Burke, M. L. Keefer and C. C. Caudill (2017). "High-stakes steeplechase: a behavior-based model to predict individual travel times through diverse migration segments." Ecosphere 8(10): e01965.

Many migratory species traverse highly heterogeneous landscapes, often including habitats that have been altered by human activities. Modeling migration dynamics is challenging because individual variability in behavior at multiple spatial and temporal scales can produce complex, multi-modal distributions in migration travel times. Moreover, behavioral responses to conditions encountered en route can affect habitat-specific migration rates which then influence bioenergetic costs and mortality risk over the entire migration. To quantify impacts of conditions within migration corridors, refined analyses of behavior are needed. In this study, we developed a behavior-based simulation model that predicts individual adult salmon migration

duration over 24 distinct river reaches totaling 922 km, including eight hydropower dams. The study population, threatened Snake River spring/summer Chinook salmon (Oncorhynchus tshawytscha), had observed migration durations ranging from 23 to 108 d. In a novel application of N-dimensional mixture models, which can account for subpopulations that behave differently, we simulated “fast” vs. “slow” travel through migration reaches. The proportion of migrants in each category was determined by diel, seasonal, and proximate river conditions, which captured the temporally shifting bimodal patterns in the data. We fit reach-specific models with data from 2188 tagged salmon migrating in 2000–2013 and validated the cumulative model with additional data through 2015. By accounting for multiple behaviors in this way, the model successfully recreated the breadth and variability in total travel times to within 3% of observed durations throughout the 5th–95th quantiles. En route mortality appeared to account for the loss of the slowest fish that encountered record-breaking high temperatures in 2015. For Chinook salmon, this combined reach and cumulative travel-time model provides an opportunity to link high-resolution behavioral data to individual fitness and population-level impacts on viability. More generally, the N-dimensional modeling approach offers a framework for assessing the cumulative impacts of alternative behaviors at small spatial and temporal scales. Improved accounting of changes in migration rate in response to local conditions will aid recovery efforts for species of concern traversing complex migration corridors.

Crozier, L. G., B. J. Burke, B. P. Sandford, G. A. Axel and B. L. Sanderson (2014). Passage and Survival of Adult Snake River Sockeye Salmon within and Upstream from the Federal Columbia River Power System. Report to USACE, Walla Walla District, Walla Walla, Washington, by Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, Washington.

Snake River sockeye salmon Oncorhynchus nerka is among the most endangered of all evolutionarily significant units (ESUs) of Pacific salmon, with production sourced primarily from captive broodstock since 1990. The adult migration presents an especially significant challenge to recovery of this population because adults must migrate through various fisheries, pass 8 hydroelectric dams, and travel over 1,500 km to reach native spawning areas. Since 2008, survival for adult Snake River sockeye salmon from Bonneville Dam to the Sawtooth Weir has ranged from 60% in 2010 to 13% in 2013.

To increase the number of spawners for natural production and hatchery broodstock, one potential management strategy under consideration is adult transportation from Lower Granite Dam. When conditions in the river are unfavorable for in-river migrant survival, fish would be collected at the dam and transported to the Sawtooth Valley. As a first step in assessing this option, we analyzed existing data from 920 fish marked with passive integrated transponder (PIT) tags and detected at Bonneville Dam from 2008 through 2013. The goal of our analysis was to determine whether we could identify the river conditions most unfavorable for migration success and to explore the implications of potential triggers for transportation.

Specifically, we evaluated the extent to which migration success varied with juvenile characteristics such as origin and downstream migration history, adult migration characteristics such as timing and fallback, and river conditions in reaches from Bonneville Dam to the Sawtooth Valley. We then explored potential "triggers" to initiate transportation by comparing the survival rates of various proportions of the population with expected survival from transportation scenarios based on different types of triggers (date and temperature). Scenarios were constructed for different locations of potential transport (Bonneville, Ice Harbor, or Lower Granite Dam) and for different threshold values on transportation triggers. Below we summarize major findings from these analyses.

During 2008-2013, fallback affected a relatively small percentage of fish at McNary Dam (~3-6% of fish fell back at least once) but increasingly larger percentages at Bonneville (4-15%), Ice Harbor (7-18%) and Lower Granite Dam (6-38%). Because some sockeye salmon fell back multiple times, the fallback rate (total number of fallback events divided by unique fish passing the dam) was quite high compared to that reported for spring/summer Chinook salmon and steelhead, particularly at Lower Granite Dam. Fallback rate peaked at Lower Granite Dam in 2012 (49.2%) and 2013 (48.4%). In 2013, fish that had been transported as juveniles fell back at Bonneville, The Dalles, and McNary Dam at higher rates than fish that had not been transported.

After summing the 2013 fallbacks at these three dams during 2013, we found that fish transported as juveniles exhibited 50 fallbacks per 100 fish, whereas those that migrated in-river as juveniles exhibited 12 fallbacks per 100 fish. However, this effect was weak or absent in other years, so further investigation is needed to determine whether this factor was confounded with something else. Temperature and/or flow correlated strongly with the probability of falling back, but dissolved gas and fish history also influenced fallback risk.

Based on magnitude of effect, the most important predictors of survival across reaches and years were thermal exposure and fish travel time. Dramatically higher temperature exposure in the lower Snake River contributed to both high fallback rates and lower survival rates observed in 2013. In the Columbia River, juvenile transportation and fishery catch also strongly influenced adult survival. In comparison to upper Columbia River sockeye, Snake River sockeye had lower conversion rates from Bonneville Dam to McNary Dam. Snake River sockeye migrated 3-5 d later than upper Columbia River sockeye but had similar travel times.

Adult migration survival varied strongly as a function of temperature and dropped below 50% when river temperatures surpassed 18°C. In most years, no particular trigger or threshold produced a dramatic or strongly non-linear advantage over others, but a threshold temperature of 18°C or higher at Bonneville, Ice Harbor or Lower Granite Dam noticeably improved in-river survival to the Sawtooth Valley in our scenarios. Across years, 23 to 92% of the run experienced temperatures over 18°C at Lower Granite Dam.

An early onset of warm temperatures in 2013 likely exacerbated cumulative thermal stress, and this cumulative stress, rather than maximum temperature per se, may be primarily responsible

for the reduced survival observed in 2013. If so, a useful strategy might include combining temperature and day information in any decision to transport.

Additional data nearly always improve the predictive ability of models, but this is especially true when few data are available for model fit. We had just 3-4 years of data. Moreover, the observed range in predictive factors was relatively narrow compared to the likely future conditions over which we are trying to project. Our analysis also suffered from unbalanced representation of observations for the various options across years, particularly for the juvenile history traits. We demonstrated challenges for forecasting by trying to predict survival in 2013 based on data from prior years. Although temperature emerged as a key driving factor in these forecasts, the magnitude of negative effects from higher temperatures was underestimated, especially for survival in reaches from Ice Harbor Dam to the Sawtooth Valley.

We identified the following five areas of outstanding need for data important to the management of adult Snake River sockeye:

1) Refine understanding of how thermal experience affects survival, especially to determine the relative roles of acute vs. cumulative thermal stress for both survival and fallback
2) Explore factors that affect migration timing both between years and within a year, and the extent to which run timing affects losses in the Bonneville to McNary Dam reach, and tolerance of warm years
3) Better discriminate among the influences of flow, spill, and gas, especially for fallback at Columbia River dams and survival through the Snake River
4) Obtain more accurate estimates of fallback rates
5) Pursue a more conclusive evaluation of whether juvenile transportation truly influences fallback and adult survival

To resolve these questions, finer-scale resolution of fish behavior and the river environment is needed, along with experimental manipulations and further data analysis.

To obtain data at this resolution, we recommend studies using radio telemetry with data-intensive tags (i.e., depth and temperature sensors) to help clarify the thermal habitats selected by adult sockeye during migration. This approach would provide information on both acute and cumulative thermal effects and would provide the data needed to improve estimates of the factors that affect fallback. Experimental thermal exposures followed by intensive monitoring of condition and survival (e.g., Crossin et al. 2008b) would help to identify delayed effects of thermal exposure in the hydrosystem that affect fish upstream in the Snake and Salmon Rivers. In addition, it would help to determine thresholds of exposure tolerance and to separate cross-correlated environmental factors. Minimally, additional years of PIT-tag data collection and analysis are needed to broaden our predictive power

It is important to note that the practicality of transporting fish when conditions are already stressful (e.g., over 18°C) needs to be evaluated. High temperatures during collection may substantially reduce the survival of transported fish. If this is the case, an alternative option

would be to collect fish earlier in the migration season, perhaps at Bonneville Dam. However, this option would require some means of identifying and collecting Snake River sockeye, which are a small proportion of the run at Bonneville Dam compared to the proportion from unlisted upper Columbia sockeye populations.

These data can provide the unique combinations of information on environmental and biological conditions that will allow refinement of the models to better inform management decisions.

Crozier, L. G. and J. A. Hutchings (2014). "Plastic and evolutionary responses to climate change in fish." Evolutionary Applications 7(1): 68-87.

The physical and ecological 'fingerprints' of anthropogenic climate change over the past century are now well documented in many environments and taxa. We reviewed the evidence for phenotypic responses to recent climate change in fish. Changes in the timing of migration and reproduction, age at maturity, age at juvenile migration, growth, survival and fecundity were associated primarily with changes in temperature. Although these traits can evolve rapidly, only two studies attributed phenotypic changes formally to evolutionary mechanisms. The correlation-based methods most frequently employed point largely to 'fine-grained' population responses to environmental variability (i.e. rapid phenotypic changes relative to generation time), consistent with plastic mechanisms. Ultimately, many species will likely adapt to long-term warming trends overlaid on natural climate oscillations. Considering the strong plasticity in all traits studied, we recommend development and expanded use of methods capable of detecting evolutionary change, such as the long term study of selection coefficients and temporal shifts in reaction norms, and increased attention to forecasting adaptive change in response to the synergistic interactions of the multiple selection pressures likely to be associated with climate change.

Crozier, L. G., M. D. Scheuerell and R. W. Zabel (2011). "Using Time Series Analysis to Characterize Evolutionary and Plastic Responses to Environmental Change: A Case Study of a Shift toward Earlier Migration Date in Sockeye Salmon." American Naturalist 178(6): 755-773.

Environmental change can shift the phenotype of an organism through either evolutionary or nongenetic processes. Despite abundant evidence of phenotypic change in response to recent climate change, we typically lack sufficient genetic data to identify the role of evolution. We present a method of using phenotypic data to characterize the hypothesized role of natural selection and environmentally driven phenotypic shifts (plasticity). We modeled historical selection and environmental predictors of interannual variation in mean population phenotype using a multivariate state-space model framework. Through model comparisons, we assessed the extent to which an estimated selection differential explained observed variation better than environmental factors alone. We applied the method to a 60-year trend toward earlier migration in Columbia River sockeye salmon Oncorhynchus nerka, producing estimates of

annual selection differentials, average realized heritability, and relative cumulative effects of selection and plasticity. We found that an evolutionary response to thermal selection was capable of explaining up to two-thirds of the phenotypic trend. Adaptive plastic responses to June river flow explain most of the remainder. This method is applicable to other populations with time series data if selection differentials are available or can be reconstructed. This method thus augments our toolbox for predicting responses to environmental change.

Crozier, L. G., L. Wiesebron and B. J. Burke (*In progress*). "Adult steelhead migration and survival in the Columbia River."

Crozier, L. G., L. Wiesebron, T. Marsh and B. P. Sandford (*In progress*). Adult Snake River sockeye salmon passage and conversion within and upstream of the FCRPS.

Dale, K. E., E. A. Daly and R. D. Brodeur (2017). "Interannual variability in the feeding and condition of subyearling Chinook salmon off Oregon and Washington in relation to fluctuating ocean conditions." Fisheries Oceanography 26(1): 1-16.

Chinook salmon (Oncorhynchus tshawytscha) is one of several economically-important species of salmon found in the Northeast Pacific Ocean. The first months at sea are believed to be the most critical for salmon survival, with the highest rate of mortality occurring during this period. In the present study, we examined interannual diet composition and body condition trends for late-summer subyearling Chinook salmon caught off Oregon and Washington from 1998 to 2012. Interannual variability was observed in juvenile salmon diet composition by weight of prey consumed. Juvenile subyearling Chinook salmon were mainly piscivorous, with northern anchovy (Engraulis mordax) being especially important, making up half the diet by weight in some years. Annual diets clustered into two groups, primarily defined by their proportion of invertebrate prey (14% versus 39% on average). Diet composition was found to influence adult returns, with salmon from high-invertebrate years returning in significantly larger numbers 2-3 yrs later. However, years that had high adult returns had overall lower stomach fullness and poorer body condition as juveniles, a counterintuitive result potentially driven by the enhanced survival of less fit individuals in better ocean conditions (top-down effect). Ocean conditions in years with a higher percentage of invertebrates in salmon diets were significantly cooler from May to August, and bottom-up processes may have led to a fall plankton community with a larger proportion of invertebrates. Our results suggest that the plankton community assemblage during this first fall may be critical in predicting adult returns of Chinook salmon in the Pacific Northwest.

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

Diets of juvenile coho Oncorhynchus kisutch and Chinook O. tshawytscha salmon are made up primarily of winter-spawning fish taxa in the late-larval and early juvenile stages that are undersampled in plankton and larger trawl nets. Although we have no direct measure of the availability of fish prey important to juvenile salmon during early marine residence, we do have data on the larval stage of their prey that may be used as a surrogate for the later stages. Data on these prey items were obtained from ichthyoplankton samples collected along the Newport Oregon Hydrographic line (44.65°N) during January–March in 1998–2010. We explored winter biomass of prey fish larvae as a potential indicator of marine feeding conditions for young salmon the following spring. The proportion of total winter ichthyoplankton biomass considered to be common salmon fish prey fluctuated from 13.9% in 2006 to 95.0% in 2000. The relationship between biomass of fish larvae in winter and subsequent coho salmon survival was highly significant (r2 = 50.0, p = 0.004). When the 2 outlier years of 1998 (El Niño) and 1999 (La Niña) were removed, this relationship was also highly significant for spring Chinook (r2 = 70.7, p = 0.0002) and significant for fall Chinook salmon (r2 = 34.0, p = 0.03) returns. Winter larval fish composition showed a high degree of overlap with juvenile salmon diets during May, but less overlap in June. Larval fishes appeared to be an early and cost-effective indicator of ocean ecosystem conditions and future juvenile salmon survival.

Daly, E. A. and R. D. Brodeur (2015). "Warming Ocean Conditions Relate to Increased Trophic Requirements of Threatened and Endangered Salmon." Plos One 10(12).

The trophic habits, size and condition of yearling Chinook salmon (Oncorhynchus tshawytscha) caught early in their marine residence were examined during 19 survey years (1981–1985; 1998–2011). Juvenile salmon consumed distinct highly piscivorous diets in cold and warm ocean regimes with major differences between ocean regimes driven by changes in consumption of juvenile rockfishes, followed by several other fish prey, adult euphausiids and decapod larvae. Notable, Chinook salmon consumed 30% more food in the warm versus cold ocean regime in both May and June. Additionally, there were about 30% fewer empty stomachs in the warm ocean regime in May, and 10% fewer in warm June periods. The total prey energy density consumed during the warmer ocean regime was also significantly higher than in cold. Chinook salmon had lower condition factor and were smaller in fork length during the warm ocean regime, and were longer and heavier for their size during the cold ocean regime. The significant increase in foraging during the warm ocean regime occurred concurrently with lower available prey biomass. Adult return rates of juvenile Chinook salmon that entered the ocean during a warm ocean regime were lower. Notably, our long term data set contradicts the long held assertion that juvenile salmon eat less in a warm ocean regime when low growth and survival is observed, and when available prey are reduced. Comparing diet changes between decades under variable ocean conditions may assist us in understanding the effects of projected warming ocean regimes on juvenile Chinook salmon and their survival in the ocean

environment. Bioenergetically, the salmon appear to require more food resources during warm ocean regimes.

Daly, E. A., R. D. Brodeur and T. D. Auth (2017). "Anomalous ocean conditions in 2015: impacts on spring Chinook salmon and their prey field." Marine Ecology Progress Series 566: 169-182.

In the northern California Current, Columbia River Chinook salmon Oncorhynchus tshawytscha that return as adults in spring are primarily hatchery-produced, though they include natural-origin fish listed under the US Endangered Species Act. Anomalously warm ocean conditions persisted in the California Current during 2015 (> 2.5 degrees C above normal) through the winter period when fish prey resources of juvenile salmon develop and during spring as salmon enter the ocean. The biomass of ichthyoplankton in winter 2015 was the 4th highest of our 18 yr time-series (1998-2015), predicting good food conditions for salmon and high adult salmon returns several years later. The larval composition of 2015 ichthyoplankton included abnormally large amounts of the warm-water taxa northern anchovy Engraulis mordax and rockfish Sebastes spp. When the composition of ichthyoplankton is dominated by warm-water taxa in winter, we would predict poor returns of salmon. May diets of juvenile Chinook salmon collected in coastal waters reflected high proportions of juvenile rockfish, no evidence of northern anchovy, and most closely resembled those of other warm years. June diets also reflected a warm prey community being consumed, predicting poor returns of salmon. Chinook salmon had high percentages of empty stomachs and were small and thin in 2015, with fish weighing 17.6% less than the same-length fish in a cold year (2008). Lower condition of juvenile Chinook salmon related to decreased returns of adult salmon. Overall, all but one biological predictor (biomass of prey) suggests that the prospects for the 2015 ocean-entry smolts were not favorable for survival.

Daly, E. A., R. D. Brodeur, J. P. Fisher, L. A. Weitkamp, D. J. Teel and B. R. Beckman (2012). "Spatial and trophic overlap of marked and unmarked Columbia River Basin spring Chinook salmon during early marine residence with implications for competition between hatchery and naturally produced fish." Environmental Biology of Fishes 94(1): 117-134.

Ecological interactions between natural and hatchery juvenile salmon during their early marine residence, a time of high mortality, have received little attention. These interactions may negatively influence survival and hamper the ability of natural populations to recover. We examined the spatial distributions and size differences of both marked (hatchery) and unmarked (a high proportion of which are natural) juvenile Chinook salmon in the coastal waters of Oregon andWashington from May to June 1999–2009. We also explored potential trophic interactions and growth differences between unmarked and marked salmon. Overlap in spatial distribution between these groups was high, although catches of unmarked fish were low compared to those of marked hatchery salmon. Peak catches of hatchery fish occurred in May, while a prolonged migration of small unmarked salmon entered our study area toward

the end of June. Hatchery salmon were consistently longer than unmarked Chinook salmon especially by June, but unmarked salmon had significantly greater body condition (based on length-weight residuals) for over half of the May sampling efforts. Both unmarked and marked fish ate similar types and amounts of prey for small (station) and large (month, year) scale comparisons, and feeding intensity and growth were not significantly different between the two groups. There were synchronous interannual fluctuations in catch, length, body condition, feeding intensity, and growth between unmarked and hatchery fish, suggesting that both groups were responding similarly to ocean conditions.

Daly, E. A., R. D. Brodeur and L. A. Weitkamp (2009). "Ontogenetic Shifts in Diets of Juvenile and Subadult Coho and Chinook Salmon in Coastal Marine Waters: Important for Marine Survival?" Transactions of the American Fisheries Society 138(6): 1420-1438.

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

Daly, E. A., J. A. Scheurer, R. D. Brodeur, L. A. Weitkamp, B. R. Beckman and J. A. Miller (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.

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.

Diefenderfer, H. L., G. E. Johnson, R. M. Thom, K. E. Buenau, L. A. Weitkamp, C. M. Woodley, A. B. Borde and R. K. Kropp (2016). "Evidence-based evaluation of the cumulative effects of ecosystem restoration." Ecosphere 7(3).

This study adapts and applies the evidence-based approach for causal inference, a medical standard, to the restoration and sustainable management of large-scale aquatic ecosystems. Despite long-term investments in restoring aquatic ecosystems, it has proven difficult to adequately synthesize and evaluate program outcomes, and no standard method has been adopted. Complex linkages between restorative actions and ecosystem responses at a landscape scale make evaluations problematic and most programs focus on monitoring and analysis. Herein, we demonstrate a new transdisciplinary approach integrating techniques from evidence- based medicine, critical thinking, and cumulative effects assessment. Tiered hypotheses about the effects of landscape-scale restorative actions are identified using an ecosystem conceptual model. The systematic literature review, a health sciences standard since the 1960s, becomes just one of seven lines of evidence assessed collectively, using critical thinking strategies, causal criteria, and cumulative effects categories. As a demonstration, we analyzed data from 166 locations on the Columbia River and estuary representing 12 indicators of habitat and fish response to floodplain restoration actions intended to benefit culturally and economically important, threatened and endangered salmon. Synthesis of the lines of evidence demonstrated that hydrologic reconnection promoted macrodetritis export, prey availability, and juvenile fish access and feeding. Upon evaluation, the evidence was sufficient to infer cross-boundary, indirect, compounding, and delayed cumulative effects, and suggestive of nonlinear, landscape-scale, and spatial density effects. Therefore, on the basis of causal inferences regarding foodweb functions, we concluded that the restoration program is having a cumulative beneficial effect on juvenile salmon. The lines of evidence developed are

transferable to other ecosystems: modeling of cumulative net ecosystem improvement, physical modeling of ecosystem controlling factors, meta-analysis of restoration action effectiveness, analysis of data on target species, research on critical ecological uncertainties, evidence-based review of the literature, and change analysis on the landscape setting. As with medicine, the science of ecological restoration needs scientific approaches to management decisions, particularly because the consequences affect species extinctions and the availability of ecosystem services. This evidence based approach will enable restoration in complex coastal, riverine, and tidal-fluvial ecosystems like the lower Columbia River to be evaluated when data have accumulated without sufficient synthesis.

Dietrich, J., K. Eder, D. Thompson, R. Buchanan, J. Skalski, G. McMichael, D. Fryer and F. Loge (2016). "Survival and transit of in-river and transported yearling Chinook salmon in the lower Columbia River and estuary." Fisheries Research 183: 435-446.

The lower Columbia River and estuary (LRE) is a critically important environment for outmigrating salmonids, yet uncertainties remain about the survival and behavior of barged and in-river migrating fish. Although studies have used telemetry to monitor Chinook salmon movement and survival through the LRE, comparisons between outmigration years are confounded by differences in tag technologies, array locations, and experimental designs. In the present study, multiple releases of barged and in-river Snake River spring/summer Chinook salmon were implanted with acoustic tags and monitored at multiple locations between Lower Granite Dam on the Snake River (695 km from the mouth of the Columbia River) to within 3 km of the Pacific Ocean. LRE survival estimates and transit rates of barged fish significantly varied throughout the outmigration season. The transit rates of in-river fish also varied, but without a corresponding seasonal difference in LRE survival estimates. Early release groups of barged salmon were slower and had lower survival in the LRE than in-river salmon. Estuary arrival timing and the magnitude of transit rates may contribute to significant differences in LRE mortality between in-river and barged juvenile salmon. Survival in the Lower River reaches was stable and exceeded 0.90 for both barged and in-river fish, while survival decreased markedly in the Estuary. Differential distributions of arrival to the LRE, transit rates, and survival suggest that the outmigration experience is not homogenous for barged and in-river yearling Snake River Chinook salmon, and that previous outmigration experience of threatened and endangered salmon should be considered in future management decisions and recovery plans.

Dietrich, J. P., M. S. Myers, S. A. Strickland, A. Van Gaest and M. R. Arkoosh (2013). "Toxicity of forest fire retardant chemicals to stream-type chinook salmon undergoing parr-smolt transformation." Environmental Toxicology and Chemistry 32(1): 236-247.

Long-term fire retardants are used to prevent the spread of wildland fires. These products are normally applied by aircraft and are intended specifically for terrestrial application, but fire retardants have entered aquatic habitats by misapplication and/or accidental spills and have resulted in fish mortalities. The authors examined the toxicity of two fire retardant products,

PHOS-CHEK 259F and LC-95A, to salmon undergoing parr-smolt transformation. Yearling stream-type chinook salmon at the smolt stage were exposed to eight concentrations of each retardant in freshwater and a no-PHOS-CHEK control for 96 h to determine acute toxicity. Concentrations of the products that caused 50% mortality were 140.5 and 339.8 mg/L for 259F and LC-95A, respectively, and could occur during accidental drops into aquatic habitats. Damage to gill tissues seen in histopathological sections was attributed to fire retardant exposure. Un-ionized ammonia levels, from 259F, were sufficient to cause acute mortality; but additional factors, indicated by increased phagosome prevalence in the gills, might have contributed to mortality during LC-95A exposure. Seawater and disease challenges were performed to determine sublethal effects of product exposures on fish health. Although PHOS-CHEK exposure did not adversely affect chinook salmon's susceptibility to Listonella anguillarum, exposure did significantly reduce seawater survival. Reduced salmon survival resulting from prior fire retardant exposure during their transition from freshwater rearing environments to seawater may decrease the abundance of salmon populations.

Dietrich, J. P., A. L. Van Gaest, S. A. Strickland and M. R. Arkoosh (2014). "The impact of temperature stress and pesticide exposure on mortality and disease susceptibility of endangered Pacific salmon." Chemosphere 108: 353-359.

Anthropogenic stressors, including chemical contamination and temperature stress, may contribute to increased disease susceptibility in aquatic animals. Specifically, the organophosphate pesticide malathion has been detected in surface waters inhabited by threatened and endangered salmon. In the presence of increasing water temperatures, malathion may increase susceptibility to disease and ultimately threaten salmon survival. This work examines the effect of acute and sublethal exposures to malathion on ocean-type subyearling Chinook salmon held under two temperature regimes. Chinook salmon were exposed to malathion at optimal (11 °C) or elevated (19 and 20 °C) temperatures. The influence of temperature on the acute toxicity of malathion was determined by generating 96-h lethal concentration (LC) curves. A disease challenge assay was also used to assess the effects of sublethal malathion exposure. The malathion concentration that resulted in 50% mortality (LC50; 274.1 μg L^{-1}) of the Chinook salmon at 19 °C was significantly less than the LC50 at 11 °C (364.2 μg L^{-1}). Mortality increased 11.2% in Chinook salmon exposed to malathion at the elevated temperature and challenged with Aeromonas salmonicida compared to fish held at the optimal temperature and exposed to malathion or the carrier control. No difference in disease challenge mortality was observed among malathion-exposed and unexposed fish at the optimal temperature. The interaction of co-occurring stressors may have a greater impact on salmon than if they occur in isolation. Ecological risk assessments considering the effects of an individual stressor on threatened and endangered salmon may underestimate risk when additional stressors are present in the environment.

Doctor, K., B. Berejikian, J. J. Hard and D. VanDoornik (2014). "Growth-Mediated Life History Traits of Steelhead Reveal Phenotypic Divergence and Plastic Response to Temperature." Transactions of the American Fisheries Society 143(2): 317-333.

Growth-mediated early life history traits affect an individual's fitness and reflect both evolutionary adaptations and phenotypic responses to environmental conditions. We tested for phenotypic plasticity of growth-mediated life history traits between and within two depressed populations of steelhead Oncorhynchus mykiss from Hood Canal, Washington. We conducted a reciprocal transplant "common garden" experiment at two temperature regimes and measured individual growth rate, condition factor, proportion of age-1 smolts and proportion of age-1 mature males. We found phenotypic plasticity in growth rate, condition factor, and proportion of age-1 smolts in both populations, demonstrating that genotype-temperature interaction plays an important role in determining phenotypic expression of growth and development. Growth rates were highest in the warm temperature treatment for both populations. More Dewatto River individuals smolted in their first year than Duckabush River individuals, which is consistent with data from the natural populations and provides evidence for phenotypic divergence in this life history trait. However, direct tests of neutrality provided no evidence that this divergence had resulted from diversifying selection, suggesting instead that the divergence may be largely plastic. All age-1 mature males were observed in the warm temperature treatments for both populations, indicating that temperature plays a large role in determining age-1 male maturation under these conditions. Broad-sense heritability estimates for growth rate, condition factor, and smolts at age-1 were generally high, revealing the potential opportunity for selection to act on these traits in both populations. Understanding the effect of temperature on life history differences between populations is important for management decisions and conservation, including anticipating responses to changing environmental conditions.

Donaldson, M. R., S. G. Hinch, D. A. Patterson, A. P. Farrell, J. M. Shrimpton, K. M., D. R. Miller-Saunders, J. Hills, K. A. Hruska, K. C. Hanson, K. K. English, G. Van Der and S. J. C. Kraak (2010). "Physiological Condition Differentially Affects the Behavior and Survival of Two Populations of Sockeye Salmon during Their Freshwater Spawning Migration." Physiological and Biochemical Zoology 83(3): 446-458.

Recently, a segment of the Adams-Shuswap sockeye salmon (Oncorhynchus nerka) population initiated freshwater migration several weeks earlier than historically recorded, resulting in high mortality rates. The comigrating Chilko population maintained their historic river entry timing and did not experience elevated mortality. To test the hypothesis that population-specific differences in physiological condition would differentially influence behavior and survival when exposed to fisheries capture stress, we physiologically sampled individuals from both populations at the onset of the freshwater phase of their reproductive migration and tracked the remainder of their migrations using radio telemetry. Adams-Shuswap individuals had slower migration rates and were less likely to reach natal subwatersheds relative to Chilko individuals. Metabolic and osmoregulatory impairment was related to mortality for Adams-Shuswap

individuals but not for Chilko individuals. Similarly, physiological condition correlated with migration rate for Adams-Shuswap but not Chilko fish. Survival to natal subwatersheds was 1.9 times higher for Chilko relative to Adams-Shuswap, a result that did not emerge until individuals approached natal subwatersheds several days after the stressor was applied. We conclude that physiological condition differentially affects the behavior and survival of these two populations, which may be a consequence of the early-entry phenomenon by a segment of the Adams-Shuswap population.

Drenner, S. M., T. D. Clark, C. K. Whitney, E. G. Martins, S. J. Cooke and S. G. Hinch (2012). "A Synthesis of Tagging Studies Examining the Behaviour and Survival of Anadromous Salmonids in Marine Environments." Plos One 7(3).

This paper synthesizes tagging studies to highlight the current state of knowledge concerning the behaviour and survival of anadromous salmonids in the marine environment. Scientific literature was reviewed to quantify the number and type of studies that have investigated behaviour and survival of anadromous forms of Pacific salmon (Oncorhynchus spp.), Atlantic salmon (Salmo salar), brown trout (Salmo trutta), steelhead (Oncorhynchus mykiss), and cutthroat trout (Oncorhynchus clarkii). We examined three categories of tags including electronic (e. g. acoustic, radio, archival), passive (e. g. external marks, Carlin, coded wire, passive integrated transponder [PIT]), and biological (e. g. otolith, genetic, scale, parasites). Based on 207 papers, survival rates and behaviour in marine environments were found to be extremely variable spatially and temporally, with some of the most influential factors being temperature, population, physiological state, and fish size. Salmonids at all life stages were consistently found to swim at an average speed of approximately one body length per second, which likely corresponds with the speed at which transport costs are minimal. We found that there is relatively little research conducted on open-ocean migrating salmonids, and some species (e. g. masu [O. masou] and amago [O. rhodurus]) are underrepresented in the literature. The most common forms of tagging used across life stages were various forms of external tags, coded wire tags, and acoustic tags, however, the majority of studies did not measure tagging/handling effects on the fish, tag loss/failure, or tag detection probabilities when estimating survival. Through the interdisciplinary application of existing and novel technologies, future research examining the behaviour and survival of anadromous salmonids could incorporate important drivers such as oceanography, tagging/handling effects, predation, and physiology.

Elder, T., C. M. Woodley, M. A. Weiland and A. L. Strecker (2016). "Factors influencing the survival of outmigrating juvenile salmonids through multiple dam passages: an individual-based approach." Ecology and Evolution 6(16): 5881-5892.

Substantial declines of Pacific salmon populations have occurred over the past several decades related to large-scale anthropogenic and climatic changes in freshwater and marine environments. In the Columbia River Basin, migrating juvenile salmonids may pass as many as

eight large-scale hydropower projects before reaching the ocean; however, the cumulative effects of multiple dam passages are largely unknown. Using acoustic transmitters and an extensive system of hydrophone arrays in the Lower Columbia River, we calculated the survival of yearling Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) passing one, two, or three dams. We applied a unique index of biological characteristics and environmental exposures, experienced by each fish individually as it migrated downstream, in order to examine which factors most influence salmonid survival. High outflow volumes led to involuntary spill in 2011 and created an environment of supersaturated dissolved gas concentrations. In this environment, migrating smolt survival was strongly influenced by barometric pressure, fish velocity, and water temperature. The effect of these variables on survival was compounded by multiple dam passages compared to fish passing a single dam. Despite spatial isolation between dams in the Lower Columbia River hydrosystem, migrating smolt appear to experience cumulative effects akin to a press disturbance. In general, Chinook salmon and steelhead respond similarly in terms of survival rates and responses to altered environmental conditions. Management actions that limit dissolved gas concentrations in years of high flow will benefit migrating salmonids at this life stage.

Evans, A. F., N. J. Hostetter, K. Collis, D. D. Roby and F. J. Loge (2014). "Relationship between Juvenile Fish Condition and Survival to Adulthood in Steelhead." Transactions of the American Fisheries Society 143(4): 899-909.

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.

Evans, A. F., N. J. Hostetter, D. D. Roby, K. Collis, D. E. Lyons, B. P. Sandford, R. D. Ledgerwood and S. Sebring (2012). "Systemwide Evaluation of Avian Predation on Juvenile Salmonids from the Columbia River Based on Recoveries of Passive Integrated Transponder Tags." Transactions of the American Fisheries Society 141(4): 975-989.

We recovered passive integrated transponder (PIT) tags from nine piscivorous waterbird colonies in the Columbia River basin to evaluate avian predation on Endangered Species Act (ESA)-listed salmonid Oncorhynchus spp. populations during 2007-2010. Avian predation rates were calculated based on the percentage of PIT-tagged juvenile salmonids that were detected as passing hydroelectric dams and subsequently were consumed and deposited by birds on their nesting colonies. Caspian terns Hydroprogne caspia (hereafter, "terns") and double-crested cormorants Phalacrocorax auritus (hereafter, "cormorants") nesting on East Sand Island in the Columbia River estuary consumed the highest proportions of available PIT-tagged salmonids, with minimum predation rates ranging from 2.5% for Willamette River spring Chinook salmon O. tshawytscha to 16.0% for Snake River steelhead O. mykiss. Estimated predation rates by terns, cormorants, gulls of two species (California gull Larus californicus and ring-billed gull L. delawarensis), and American white pelicans Pelecanus erythrorhynchos nesting near the confluence of the Snake and Columbia rivers were also substantial; minimum predation rates ranged from 1.4% for Snake River fall Chinook salmon to 13.2% for upper Columbia River steelhead. Predation on ESA-listed salmonids by gulls and American white pelicans were minor (<2.0% per ESA-listed salmonid population) relative to predation by terns and cormorants. Cumulative impacts were greater for Snake River and upper Columbia River salmonids than for salmonids originating closer to the estuary because upriver salmonids must migrate past more bird colonies to reach the ocean. Predation rates adjusted for colony size (per capita rates) were significantly higher for terns and cormorants nesting at inland colonies (upstream of Bonneville Dam) than for those nesting in the estuary, suggesting that inland colonies have a greater reliance on salmonids as a food source. Management actions to increase salmonid survival by reducing avian predation in the estuary could be offset if birds that disperse from the estuary relocate to inland nesting sites on or near the Columbia River.

Faulkner, J. R., D. L. Widener, S. G. Smith, T. M. Marsh and R. W. Zabel (2017). Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2016. B. P. A. Report for the Division of Fish and Wildlife, U.S. Department of Energy, by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration.

In 2016, we completed the 24th year of a study to estimate survival and travel time of juvenile Pacific salmon Oncorhynchus spp. passing dams and reservoirs on the Snake and Columbia Rivers. All estimates were derived from detections of fish tagged with passive integrated transponder (PIT) tags.

We tagged and released a total of 17,974 hatchery steelhead O. mykiss, 14,775 wild steelhead, and 22,145 wild yearling Chinook salmon O. tshawytscha at Lower Granite Dam on the Snake River. In addition to detections of these fish, we used detections of yearling Chinook and steelhead tagged by other researchers upstream from Lower Granite Dam and at other hatcheries and traps on the Snake and Columbia Rivers.

Detection sites were the juvenile bypass systems at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dam, as well as the Bonneville corner collector and PIT-tag detector trawl operated in the Columbia River estuary. Survival estimates were calculated using a statistical model for tag-recapture data from single release groups (the single-release model). Primary research objectives in 2016 were:

1) Estimate reach survival and travel time in the Snake and Columbia Rivers throughout the migration period of yearling Chinook salmon and steelhead
2) Evaluate relationships between survival estimates and migration conditions
3) Evaluate the survival estimation models under prevailing conditions

In 2016, we estimated reach survival and travel time for hatchery and wild yearling Chinook salmon, hatchery sockeye O. nerka and coho salmon O. kisutch, and hatchery and wild steelhead. During most of the migration season, detections of yearling Chinook salmon and steelhead were sufficient to estimate survival and detection probabilities for daily or weekly groups leaving Lower Granite and McNary Dam.

Hatchery and wild fish were combined in some analyses. For PIT-tagged fish detected or released at Lower Granite Dam, overall percentages by origin were 68% hatchery and 32% wild for yearling Chinook and 76% hatchery and 24% wild for steelhead. Based on collection counts at Lower Granite Dam by the Fish Passage Center and on our estimates of daily detection probability, we estimated that 86.4% of the overall yearling Chinook salmon run in 2016 was of hatchery origin. We could not calculate this number for steelhead because separate collection counts of hatchery and wild fish were not available.

All estimates of survival in reaches between dams were calculated from tailrace to tailrace. Estimates of average survival and associated standard errors (SE) are listed by reach in Table E1 for combined groups of wild and hatchery yearling Chinook salmon and steelhead.

We also estimated average survival through the entire hydropower system from the Snake River smolt trap at the head of Lower Granite reservoir to the tailrace of Bonneville Dam (eight hydroelectric projects). These estimates were the product of average survival estimates through the following three reaches: Snake River smolt trap to Lower Granite Dam, Lower Granite to McNary Dam, and McNary to Bonneville Dam (Table E1). For combined groups of wild and hatchery Snake River fish, estimated survival through the entire hydropower system was 0.473 (95% CI 0.388-0.558) for yearling Chinook and 0.443 (0.380-0.506) for steelhead.

We estimated survival for hatchery fish originating upstream from the confluence of the Columbia and Yakima Rivers. For yearling Chinook salmon, estimated survival to McNary Dam ranged from 0.796 (0.032) for Chelan Hatchery fish released to Dryden Pond on the Wenatchee River, to 0.273 (0.012) for Cle Elum Hatchery fish released to Jack Creek Pond. For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.691 (0.063) for Wells Hatchery fish released to the Methow River to 0.210 (0.024) for Wells Hatchery fish released to Twisp Acclimation Pond on the Methow River.

For smolts that arrived at Lower Granite Dam, we estimated that 20.2% of yearling Chinook (wild and hatchery combined) and 23.7% of steelhead were transported from a Snake River collector dam. These estimates were among the lowest on record (1993-2016); only estimates in 2015 were lower.

Low estimated proportions of transported smolts resulted in part from timing of the transportation program in 2016. We estimated that 74% of the yearling Chinook and 58% of the steelhead populations had already passed Lower Granite Dam by the time transportation began on 2 May. After transportation began, the proportion of fish that entered juvenile collection facilities was also lower than average because a large proportion of flow was spilled, with multiple dams using surface-passage structures to encourage spillway passage. As a result of this practice, fewer smolts were guided into the juvenile bypass system of dams with facilities for collection and transport.

In addition to estimates of survival, we calculated travel time for yearling Chinook salmon and steelhead over individual reaches between dams and over the entire hydropower system from Lower Granite to Bonneville Dam (461 km). For both species, median travel time through the entire hydropower system was shorter than the long-term average during April but approached average over the rest of the season.

The estimated proportion of PIT-tagged fish detected as they passed monitoring sites at dams was higher in 2016 than in 2015, which were the lowest we have recorded at most dams. The increase in detection was mostly due to increased flows reducing the proportion of fish passing through spill or surface passage routes.

We believe the need is now urgent to develop PIT-tag detection capability through passage routes other than the juvenile bypass systems. Specifically, the region should continue to place high priority on development and installation of PIT-monitoring systems for normal spill bays as well as for surface-passage structures. As we have suggested in recent years, higher rates of detection are necessary if we are to maintain or enhance the precision of survival estimates based on data collected from annual efforts to PIT-tag juvenile salmon.

Fiechter, J., D. D. Huff, B. T. Martin, D. W. Jackson, C. A. Edwards, K. A. Rose, E. N. Curchitser, K. S. Hedstrom, S. T. Lindley and B. K. Wells (2015). "Environmental conditions impacting

juvenile Chinook salmon growth off central California: An ecosystem model analysis." Geophysical Research Letters 42(8): 2910-2917.

A fully coupled ecosystem model is used to identify the effects of environmental conditions and upwelling variability on growth of juvenile Chinook salmon in central California coastal waters. The ecosystem model framework consists of an ocean circulation submodel, a biogeochemical submodel, and an individual-based submodel for salmon. Simulation results indicate that years favorable for juvenile salmon growth off central California are characterized by particularly intense early season upwelling (i.e., March through May), leading to enhanced krill concentrations during summer near the location of ocean entry (i.e., Gulf of the Farallones). Seasonally averaged growth rates in the model are generally consistent with observed values and suggest that juvenile salmon emigrating later in the season (i.e., late May and June) achieve higher weight gains during their first 90 days of ocean residency.

Freshwater, C., M. Trudel, T. D. Beacham, L. Godbout, C. E. M. Neville, S. Tucker and F. Juanes (2016). "Disentangling individual- and population-scale processes within a latitudinal size gradient in sockeye salmon." Canadian Journal of Fisheries and Aquatic Sciences 73(8): 1190-1201.

We examined how individual processes contribute to a latitudinal gradient in body size within populations of migrating juvenile sockeye salmon (Oncorhynchus nerka) while simultaneously testing for size-selective mortality, a potentially confounding population scale process. Using otolith microstructure techniques and structural equation modeling, we determined that ocean entry size and phenology had strong, direct effects on size at capture. Population identity and freshwater age also had strong indirect effects, moderated by size at entry. Conversely, marine growth rates immediately after entry or before capture were relatively weak predictors of size during migration. We next tested for shifts in size distribution indicative of selective mortality, but detected no evidence of smaller individuals experiencing lower survival during early marine migrations. These results indicate that the migratory distributions of juvenile sockeye salmon are influenced by body size and that this variation is predominantly driven by traits present prior to freshwater outmigration, rather than marine growth or differential survival. We suggest integrating individual variation in migratory characteristics with the effects of environmental conditions experienced en route to provide an improved understanding of migratory species.

Freshwater, C., M. Trudel, T. D. Beacham, L. Godbout, C. E. M. Neville, S. Tucker and F. Juanes (2016). "Divergent migratory behaviours associated with body size and ocean entry phenology in juvenile sockeye salmon." Canadian Journal of Fisheries and Aquatic Sciences 73(12): 1723-1732.

Survival during early marine life stages is hypothesized to contribute disproportionately to variation in salmonid recruitment, yet estimates of cumulative mortality are constrained by knowledge of how long juveniles reside in specific regions. We used otolith microstructure

techniques to examine the relationship between migratory rate and ocean entry characteristics of juvenile sockeye salmon (Oncorhynchus nerka). We observed differences in migratory rate between catch locations that are consistent with divergent migratory behaviours. Individuals captured in northern regions were typically older, larger at ocean entry, and migrated more rapidly. Migratory rate was also correlated with entry size, phenology, population group, and year. Next, we compared "lingering" individuals captured nearshore during fall surveys to juveniles from the same populations captured during the peak summer migratory period. We determined that individuals that entered after 24 May and at smaller sizes (<85 mm) had a greater probability of being captured late in the year. Our findings demonstrate that the entry characteristics of sockeye salmon are strongly correlated with migratory variation within populations and suggest these traits may directly influence juvenile behaviour.

Friedland, K. D., B. R. Ward, D. W. Welch and S. A. Hayes (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.

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.

Furey, N. B., S. G. Hinch, A. L. Bass, C. T. Middleton, V. Minke-Martin and A. G. Lotto (2016). "Predator swamping reduces predation risk during nocturnal migration of juvenile salmon in a high-mortality landscape." Journal of Animal Ecology 85(4): 948-959.

Animal migrations are costly and are often characterized by high predation risk for individuals. Three of the most oft-assumed mechanisms for reducing risk for migrants are swamping predators with high densities, specific timing of migrations and increased body size. Assessing the relative importance of these mechanisms in reducing predation risk particularly for migrants is generally lacking due to the difficulties in tracking the fate of individuals and population-level characteristics simultaneously. We used acoustic telemetry to track migration behaviour and survival of juvenile sockeye salmon (Oncorhynchus nerka) smolts released over a wide range of conspecific outmigration densities in a river associated with poor survival. The landscape was indeed high risk; smolt survival was poor (68%) over 135km of river examined even though migration was rapid (generally <48h). Our results demonstrate that smolts largely employ swamping of predators to reduce predation risk. Increased densities of co-migrant conspecifics dramatically improved survival of smolts. The strong propensity for nocturnal migration resulted in smolts pausing downstream movements until the next nightfall, greatly increasing relative migration durations for smolts that could not traverse the study area in a single night. Smolt size did not appear to impact predation risk, potentially due to unique characteristics of the system or our inability to tag the entire size range of outmigrants. Movement behaviours were important in traversing this high-risk landscape and provide rare evidence for swamping to effectively reduce individual predation risk.

Garcia, A. P., W. P. Connor, D. J. Milks, S. J. Rocklage and R. K. Steinhorst (2004). "Movement and spawner distribution of hatchery fall Chinook salmon adults acclimated and released as yearlings at three locations in the Snake River basin." North American Journal of Fisheries Management 24(1134-1144).

As part of the supplementation program for fall Chinook salmon Oncorhynchus tshawytscha in the Snake River basin, yearlings from Lyons Ferry Hatchery were released at acclimation facilities stationed along the lower Clearwater River and the lower and upper reaches of the Snake River. The distance required for migration out of the release reach was greatest for juveniles released in the lower Clearwater River. The distance required for migration out of the release river was greatest for juveniles released in the upper Snake River. We captured and radio-tagged returning adults at Lower Granite Dam (the last dam encountered prior to entering the release reaches), monitored adult movements, and assessed the performance of acclimation facilities in terms of their ability to distribute adults to their corresponding release reaches. Adults from the lower Clearwater River acclimation group had the lowest frequency of movement, the most restricted spatial movement, and the highest observed rate of spawning in the intended reach. The upper Snake River acclimation facility distributed spawners to the intended river at the highest rate observed. Though differences in water flow and temperature during immigration were possible explanations for these findings, acclimation facility location provided the most plausible explanation. We conclude that acclimation facility location can affect prespawning movement and the spawning distribution of hatchery fall Chinook salmon in the Snake River basin.

Goertler, P. A. L., M. D. Scheuerell, C. A. Simenstad and D. L. Bottom (2016). "Estimating Common Growth Patterns in Juvenile Chinook Salmon (Oncorhynchus tshawytscha) from Diverse Genetic Stocks and a Large Spatial Extent." Plos One 11(10).

Life history variation in Pacific salmon (Oncorhynchus spp.) supports species resilience to natural disturbances and fishery exploitation. Within salmon species, life-history variation often manifests during freshwater and estuarine rearing, as variation in growth. To date, however, characterizing variability in growth patterns within and among individuals has been difficult via conventional sampling methods because of the inability to obtain repeated size measurements. In this study we related otolith microstructures to growth rates of individual juvenile Chinook salmon (O. tshawytscha) from the Columbia River estuary over a two-year period (2010-2012). We used dynamic factor analysis to determine whether there were common patterns in growth rates within juveniles based on their natal region, capture location habitat type, and whether they were wild or of hatchery origin. We identified up to five large-scale trends in juvenile growth rates depending on month and year of capture. We also found that hatchery fish had a narrower range of trend loadings for some capture groups, suggesting that hatchery fish do not express the same breadth of growth variability as wild fish. However, we were unable to resolve a relationship between specific growth patterns and habitat transitions. Our study exemplifies how a relatively new statistical analysis can be applied to dating or aging techniques to summarize individual variation, and characterize aspects of life history diversity.

Goertler, P. A. L., C. A. Simenstad, D. L. Bottom, S. Hinton and L. Stamatiou (2016). "Estuarine Habitat and Demographic Factors Affect Juvenile Chinook (Oncorhynchus tshawytscha) Growth Variability in a Large Freshwater Tidal Estuary." Estuaries and Coasts 39(2): 542-559.

Estuarine rearing has been shown to enhance within watershed biocomplexity and support growth and survival for juvenile salmon (Oncorhynchus sp.). However, less is known about how growth varies across different types of wetland habitats and what explains this variability in growth. We focused on the estuarine habitat use of Columbia River Chinook salmon (Oncorhynchus tshawytscha), which are listed under the Endangered Species Act. We employed a generalized linear model (GLM) to test three hypotheses: (1) juvenile Chinook growth was best explained by temporal factors, (2) habitat, or (3) demographic characteristics, such as stock of origin. This study examined estuarine growth rate, incorporating otolith microstructure, individual assignment to stock of origin, GIS habitat mapping, and diet composition along similar to 130 km of the upper Columbia River estuary. Juvenile Chinook grew on average 0.23 mm/day in the freshwater tidal estuary. When compared to other studies in the basin our growth estimates from the freshwater tidal estuary were similar to estimates in the brackish estuary, but similar to 4 times slower than those in the plume and upstream reservoirs. However, previous survival studies elucidated a possible tradeoff between growth and survival in the Columbia River basin. Our GLM analysis found that variation in growth was best explained by habitat and an interaction between fork length and month of capture. Juvenile Chinook salmon captured in backwater channel habitats and later in the summer (mid-summer and late summer/fall subyearlings) grew faster than salmon from other habitats and time

periods. These findings present a unique example of the complexity of understanding the influences of the many processes that generate variation in growth rate for juvenile anadromous fish inhabiting estuaries.

Gosselin, J. L. and J. J. Anderson (2017). "Combining Migration History, River Conditions, and Fish Condition to Examine Cross-Life-Stage Effects on Marine Survival in Chinook Salmon." Transactions of the American Fisheries Society 146(3): 408-421.

We examined delayed effects (or carryover effects) on marine survival from the freshwater experiences of migrating Chinook Salmon Oncorhynchus tshawytscha. Juvenile Chinook Salmon that differed in their freshwater experience in passing hydroelectric power dams of the Columbia and Snake rivers (Pacific Northwest) as run-of-the-river or barged fish were tested in challenge experiments at 23.5°C to determine the freshwater survival index m (i.e., the time to 80% mortality). Seasonal patterns of *m* were best predicted by (1) an index of migration timing (*t*) at the exit of the hydropower system and a barge index (*B*) or (2) a temperature exposure index (ϑ; i.e., 7-d average of river temperatures experienced prior to collection). Other predictors tested included river flow, wet mass, and Fulton's condition factor. Predicted *m* (m_{pred}) based on *t* and *B* or based on ϑ was then related to seasonal patterns of marine survival. Significant relationships between m_{pred} and marine survival provide support for the hypothesis that the seasonal patterns of freshwater experiences during hydropower system passage influence the biological condition of juvenile salmon at seawater entry and consequently their seasonal pattern of marine survival to the adult stage. Because temperature is a more direct and biologically relevant variable than migration timing with a barging index offset, further investigation of temperature-related factors affecting the biological condition of anadromous fishes as they exit freshwater—and subsequently their marine survival—is warranted.

Gosselin, J. L., R. W. Zabel, J. J. Anderson, J. R. Faulkner, A. Baptista and B. P. Sandford (2018). "Conservation planning for freshwater-marine carryover effects on Chinook salmon survival " Ecology and Evolution 3: 319-332.

Experiences of migratory species in one habitat may affect their survival in the next habitat, in what is known as carryover effects. These effects are especially relevant for understanding how freshwater experience affects survival in anadromous fishes. Here, we study the carryover effects of juvenile salmon passage through a hydropower system (Snake and Columbia rivers, northwestern United States). To reduce the direct effect of hydrosystem passage on juveniles, some fishes are transported through the hydrosystem in barges, while the others are allowed to migrate in-river. Although hydrosystem survival of transported fishes is greater than that of their run-of-river counterparts, their relative juvenile-to-adult survival (hereafter survival) can be less. We tested for carryover effects using generalized linear mixed effects models of survival with over 1 million tagged Chinook salmon, Oncorhynchus tshawytscha (Walbaum) (Salmonidae), migrating in 1999-2013. Carryover effects were identified with rear-type (wild vs. hatchery), passage-type (run-of-river vs. transported), and freshwater and marine covariates.

Importantly, the Pacific Decadal Oscillation (PDO) index characterizing cool/warm (i.e., productive/nonproductive) ocean phases had a strong influence on the relative survival of rear- and passage-types. Specifically, transportation benefited wild Chinook salmon more in cool PDO years, while hatchery counterparts benefited more in warm PDO years. Transportation was detrimental for wild Chinook salmon migrating early in the season, but beneficial for later season migrants. Hatchery counterparts benefited from transportation throughout the season. Altogether, wild fish could benefit from transportation approximately 2 weeks earlier during cool PDO years, with still a benefit to hatchery counterparts. Furthermore, we found some support for hypotheses related to higher survival with increased river flow, high predation in the estuary and plume areas, and faster migration and development-related increased survival with temperature. Thus, pre- and within-season information on local- and broad-scale conditions across habitats can be useful for planning and implementing real-time conservation programs.

Haeseker, S. (2013). "Nonrepresentative fish and ocean migration assumptions confound inferences in Rechisky et al." Proceedings of the National Academy of Sciences of the United States of America 110(37): E3464-E3464.

Haeseker, S. L., J. A. McCann, J. Tuomikoski and B. Chockley (2012). "Assessing Freshwater and Marine Environmental Influences on Life-Stage-Specific Survival Rates of Snake River Spring-Summer Chinook Salmon and Steelhead." Transactions of the American Fisheries Society 141(1): 121-138.

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

downstream migration conditions. Our results indicate that improvements in life-stage-specific and smolt-to-adult survival may be achievable across a range of marine conditions through increasing spill percentages and reducing water transit times during juvenile salmon out-migration.

Harrison, X. A., J. D. Blount, R. Inger, D. R. Norris and S. Bearhop (2011). "Carry-over effects as drivers of fitness differences in animals." Journal of Animal Ecology 80(1): 4-18.

1. Carry-over effects occur when processes in one season influence the success of an individual in the following season. This phenomenon has the potential to explain a large amount of variation in individual fitness, but so far has only been described in a limited number of species. This is largely due to difficulties associated with tracking individuals between periods of the annual cycle, but also because of a lack of research specifically designed to examine hypotheses related to carry-over effects. 2. We review the known mechanisms that drive carry-over effects, most notably macronutrient supply, and highlight the types of life histories and ecological situations where we would expect them to most often occur. We also identify a number of other potential mechanisms that require investigation, including micronutrients such as antioxidants. 3. We propose a series of experiments designed to estimate the relative contributions of extrinsic and intrinsic quality effects in the pre-breeding season, which in turn will allow an accurate estimation of the magnitude of carry-over effects. To date this has proven immensely difficult, and we hope that the experimental frameworks described here will stimulate new avenues of research vital to advancing our understanding of how carry-over effects can shape animal life histories. 4. We also explore the potential of state-dependent modelling as a tool for investigating carry-over effects, most notably for its ability to calculate optimal rates of acquisition of a multitude of resources over the course of the annual cycle, and also because it allows us to vary the strength of density-dependent relationships which can alter the magnitude of carry-over effects in either a synergistic or agonistic fashion. 5. In conclusion carry-over effects are likely to be far more widespread than currently indicated, and they are likely to be driven by a multitude of factors including both macro- and micronutrients. For this reason they could feasibly be responsible for a large amount of the observed variation in performance among individuals, and consequently warrant a wealth of new research designed specifically to decompose components of variation in fitness attributes related to processes across and within seasons.

Hertz, E., M. Trudel, R. D. Brodeur, E. A. Daly, L. Eisner, E. V. Farley, Jr., J. A. Harding, R. B. MacFarlane, S. Mazumder, J. H. Moss, J. M. Murphy and A. Mazumder (2015). "Continental-scale variability in the feeding ecology of juvenile Chinook salmon along the coastal Northeast Pacific Ocean." Marine Ecology Progress Series 537: 247-263.

Trophic interactions within and among species vary widely across spatial scales and species' ontogeny. However, the drivers and implications of this variability are not well understood. Juvenile Chinook salmon Oncorhynchus tshawytscha have a wide distribution, ranging from

northern California to the eastern Bering Sea in North America, but it is largely unknown how their feeding ecology varies and changes with ontogeny across this range. We collected juvenile Chinook salmon and zooplankton using standardized protocols along the coastal Northeast Pacific Ocean. Using a combination of stomach contents and stable isotopes of nitrogen (δ15N) and carbon (δ13C) to characterize feeding ecology, we found regional differences in prey utilization by juvenile Chinook salmon. With growth and ontogeny, juvenile salmon in all regions became equilibrated with oceanic isotopic values. There were regional differences in the δ13C values of juvenile Chinook salmon that may correspond to regional differences in sea surface temperature. There were also regional differences in stable isotope-derived trophic level, and these estimates differed from those derived from stomach contents, possibly due to the different periods over which these metrics integrate. Dietary niche width, as indicated by stable isotopes, corresponded to the expected dietary diversity from stomach contents, combined with the isotopic variability seen in baseline values. Our results indicate strong geographic and ontogenetic differences in feeding ecology of juvenile Chinook salmon. These differences are likely influenced by a combination of ocean-entry date, ocean-entry size, ontogeny, growth rates and regional conditions.

Hertz, E., M. Trudel, R. El-Sabaawi, S. Tucker, J. F. Dower, T. D. Beacham, A. M. Edwards and A. Mazumder (2016). "Hitting the moving target: modelling ontogenetic shifts with stable isotopes reveals the importance of isotopic turnover." Journal of Animal Ecology 85(3): 681-691.

1. Ontogenetic niche shifts are widely prevalent in nature and are important in shaping the structure and dynamics of ecosystems. Stable isotope analysis is a powerful tool to assess these shifts, with d15N providing a measure of trophic level and d13C a measure of energy source.
2. Previous applications of stable isotopes to study ontogenetic niche shifts have not considered the appreciable time lag between diet and consumer tissue associated with isotopic turnover. These time lags introduce significant complexity into field studies of ontogenetic niche shifts.
3. Juvenile Chinook salmon (Oncorhynchus tshawytscha) migrate from freshwater to marine ecosystems and shift their diet from feeding primarily on invertebrates to feeding primarily on fish. This dual ontogenetic habitat and diet shift, in addition to the long time lag associated with isotopic turnover, suggests that there is potential for a disconnect between the prey sources that juvenile salmon are consuming, and the inferred prey sources from stable isotopes.
4. We developed a model that considered ontogenetic niche shifts and time lags associated with isotopic turnover, and compared this 'ontogeny' model to one that considered only isotopic turnover. We used a Bayesian framework to explicitly account for parameter uncertainty.
5. Data showed overwhelming support for the ontogeny model relative to the isotopic turnover model. Estimated variables from best model fits indicate that the ontogeny model predicts a much greater reliance on fish prey than does the stomach content data. Overall, we found that this method of quantifying ontogenetic niche shifts effectively accounted for both isotopic turnover and ontogenetic diet shifts; a finding that could be widely applicable to a variety of systems.

Hertz, E., M. Trudel, S. Tucker, T. D. Beacham, C. Parken, D. Mackas and A. Mazumder (2016). "Influences of ocean conditions and feeding ecology on the survival of juvenile Chinook Salmon (Oncorhynchus tshawytscha)." Fisheries Oceanography 25(4): 407-419.

Recruitment variability in many fish populations is postulated to be influenced by climatic and oceanographic variability. However, a mechanistic understanding of the influence of specific variables on recruitment is generally lacking. Feeding ecology is one possible mechanism that more directly links ocean conditions and recruitment. We test this mechanism using juvenile Chinook Salmon (Oncorhynchus tshawytscha) collected off the west coast of Vancouver Island, British Columbia, Canada, in 2000-2009. Stable isotopes of carbon (C-13), an indicator of temperature or primary productivity, and nitrogen (N-15), an indicator of trophic position, were taken from muscle tissues of genetically stock-identified salmon. We also collated large-scale climate indices (e.g., Pacific Decadal Oscillation, North Pacific Gyre Oscillation), local climate variables (e.g., sea surface temperature) and copepod community composition across these years. We used a Bayesian network to determine how ocean conditions influenced feeding ecology, and subsequent survival rates. We found that smolt survival of Chinook Salmon is predicted by their C-13 value, but not their N-15. In turn, large-scale climate variability determined the C-13 values of salmon, thus linking climate to survival through feeding ecology, likely through qualities propagated from the base of the food chain.

Holsman, K. K., M. D. Scheuerell, E. Buhle and R. Emmett (2012). "Interacting Effects of Translocation, Artificial Propagation, and Environmental Conditions on the Marine Survival of Chinook Salmon from the Columbia River, Washington, USA." Conservation Biology 26(5): 912-922.

Captive rearing and translocation are often used concurrently for species conservation, yet the effects of these practices can interact and lead to unintended outcomes that may undermine species recovery efforts. Controls in translocation or artificial-propagation programs are uncommon; thus, there have been few studies on the interacting effects of these actions and environmental conditions on survival. The Columbia River basin, which drains 668,000 km2 of the western United States and Canada, has an extensive network of hydroelectric and other dams, which impede and slow migration of anadromous Pacific salmon (Oncorhynchus spp.) and can increase mortality rates. To mitigate for hydrosystem-induced mortality during juvenile downriver migration, tens of millions of hatchery fish are released each year and a subset of wild- and hatchery-origin juveniles are translocated downstream beyond the hydropower system. We considered how the results of these practices interact with marine environmental conditions to affect the marine survival of Chinook salmon (O. tshawytscha). We analyzed data from more than 1 million individually tagged fish from 1998 through 2006 to evaluate the probability of an individual fish returning as an adult relative to its rearing (hatchery vs. wild) and translocation histories (translocated vs. in-river migrating fish that traveled downriver through the hydropower system) and a suite of environmental variables. Except during select

periods of very low river flow, marine survival of wild translocated fish was approximately two-thirds less than survival of wild in-river migrating fish. For hatchery fish, however, survival was roughly two times higher for translocated fish than for in-river migrants. Competition and predator aggregation negatively affected marine survival, and the magnitude of survival depended on rearing and translocation histories and biological and physical conditions encountered during their first few weeks of residence in the ocean. Our results highlight the importance of considering the interacting effects of translocation, artificial propagation, and environmental variables on the long-term viability of species.

Honea, J. M., M. M. McClure, J. C. Jorgensen and M. D. Scheuerell (2017). "Assessing freshwater life-stage vulnerability of an endangered Chinook salmon population to climate change influences on stream habitat." Climate Research 71(2): 127-137.

We linked a set of climate, hydrology, landscape, and fish population models to estimate the relative influence of freshwater habitat variables on the abundance of a population of endangered stream-type Chinook salmon Oncorhynchus tshawytscha responding to a warming climate. The hydrology models estimated that increases in annual air temperature and winter precipitation would lead to increases in water temperature and changes in discharge, including higher flows during the egg-incubation period and lower flows during the summer rearing period. The spatially explicit population model estimated a resulting decline of 0 to 7% in the number of spawners, with 3 of 4 global climate models estimating a decline of 4 to 7%. Increased water temperature during the summer spawning period was the most limiting among habitat variables modeled, but our modeling suggested that aggressive habitat restoration (increasing forested area and reducing impervious area) could mitigate some spawner abundance reductions. Better knowledge of the links between climate changes and habitat response, including increased streambed scour due to the larger and more frequent winter high-discharge events predicted by our hydrology models, would improve our ability to estimate climate effects on populations. Future limitation by elevated summer water temperature, and potentially egg-pocket scour, would further stress an endangered population currently limited by the percentage of fine sediment around egg pockets. Identifying such changes demonstrates the utility of models that consider climate and integrate life-stage-specific habitat influences over a species' life cycle, thereby indicating restoration actions with the potential to benefit sensitive life stages.

Horodysky, A. Z., S. J. Cooke and R. W. Brill (2015). "Physiology in the service of fisheries science: Why thinking mechanistically matters." Reviews in Fish Biology and Fisheries 25(3): 425-447.

Behavioral responses of fishes to variability in environmental conditions and habitat quality are central to population-level demographic processes. Although field surveys can correlate abundance to habitat variables (physiochemical, biotic, and structural), they cannot provide mechanistic explanations. Moreover, field surveys are often stratified by time or geographic

criteria relevant to humans, whereas fishes stratify by habitat variables relevant to them. If mechanisms underlying behavior are not explicitly understood, conclusions based on survey data can lead to biased inferences as to species-specific habitat requirements and preferences, as well as changes in stock size occurring over time. Because physiology is the transfer function that links specific environmental conditions to behavior and fitness, we argue great gains can be made through the integration of physiology and fisheries science. These are complementary disciplines, albeit ones that generally function at very different temporal and spatial scales, as well as different levels of biological organization. We argue more specifically that integrating physiological approaches with behavioral studies and traditional fisheries survey data (where each approach develops hypotheses to be tested in the other) can mechanistically link processes from cells through populations to place fisheries management in an appropriate ecosystem context. We further contend that population- and species-specific mechanistic understanding of physiological abilities and tolerances can significantly help to: improve stock assessments, describe essential fish habitat, predict rates of post-release mortality, develop effective bycatch reduction strategies, and forecast the population effects of increases in global temperatures and ocean acidification.

Hostetter, N. J., A. F. Evans, B. M. Cramer, K. Collis, D. E. Lyons and D. D. Roby (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.

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.

Hostetter, N. J., A. F. Evans, F. J. Loge, R. R. O'Connor, B. M. Cramer, D. Fryer and K. Collis (2015). "The Influence of Individual Fish Characteristics on Survival and Detection: Similarities across Two Salmonid Species." North American Journal of Fisheries Management 35(5): 1034-1045.

Trait-selective mortality is of considerable management and conservation interest, especially when trends are similar across multiple species of conservation concern. In the Columbia River basin, thousands of juvenile Pacific salmonids Oncorhynchus spp. are collected each year and are tagged at juvenile bypass system (JBS) facilities located at hydroelectric dams, thus allowing the tracking of population-level performance metrics (e.g., juvenile survival and juvenile-to-adult survival). Several studies have suggested that juvenile salmonid survival is both size dependent and condition dependent, but little is known about trait-selective collection at JBS facilities. Trait-selective collection (e.g., length-based or condition-based selectivity) is particularly important, as inferences to population-level performance metrics may be biased if both the survival and collection processes are influenced by similar characteristics. We used a capture-mark-recapture study to investigate length-and condition-selective survival and detection probabilities for two salmonid species in the Columbia River basin. In 2014, juvenile steelhead O. mykiss (n = 11,201) and yearling Chinook Salmon O. tshawytscha (n = 7,943) were PIT-tagged, measured (FL), examined for external condition characteristics (descaling, body injuries, fin damage, or disease symptoms), and released into the Lower Granite Dam JBS facility on the Snake River to continue seaward migration. Results indicated similar trends in both length-and condition-selective juvenile survival and detection probabilities. For both species, survival probability was higher for longer, nondegraded individuals (those without descaling, body injuries, or fin damage). Trends in detection probability were also consistent across species: shorter, degraded individuals were more likely to be detected at downstream JBS facilities than longer, healthier individuals. These results suggest that similar characteristics (FL and external condition) affect survival and detection processes for PIT-tagged steelhead and yearling Chinook Salmon and that JBS facilities may selectively collect smaller, degraded individuals with lower probabilities of survival. The consistency in trait-selective survival and detection results has important management implications for several species of conservation concern.

Hostetter, N. J., A. F. Evans, D. D. Roby and K. Collis (2012). "Susceptibility of Juvenile Steelhead to Avian Predation: the Influence of Individual Fish Characteristics and River Conditions." Transactions of the American Fisheries Society 141(6): 1586-1599.

Identification of the factors that influence susceptibility to predation can aid in developing management strategies to recover fish populations of conservation concern. Predator-prey relationships can be influenced by numerous factors, including prey condition, prey size, and environmental conditions. We investigated these factors by using juvenile steelhead Oncorhynchus mykiss from the Snake River (Pacific Northwest, USA), a distinct population segment that is listed as threatened under the U. S. Endangered Species Act. During 2007-2009, steelhead smolts (n = 25,909) were captured, examined for external condition characteristics (e. g., body injuries, descaling, external signs of disease, fin damage, and ectoparasite infestations), marked with passive integrated transponder (PIT) tags, and released to continue their out-migration. Recoveries of PIT tags on a downstream colony of Caspian terns Hydroprogne caspia (n = 913 tags) indicated that steelhead susceptibility to Caspian tern predation increased significantly with decreases in steelhead external condition, decreased water discharge, and decreased water clarity. Susceptibility to Caspian tern predation also increased with increasing steelhead fork length up to 202 mm but then decreased for longer steelhead. Recoveries of PIT tags on a downstream colony of double-crested cormorants Phalacrocorax auritus (n = 493 tags) indicated that steelhead susceptibility to double-crested cormorant predation increased significantly with declining external condition of steelhead, and that steelhead of hatchery origin were more susceptible than their wild counterparts. Results indicate that steelhead susceptibility to avian predation is dependent on fish condition and length and is influenced by river conditions and rearing environment.

Hostetter, N. J., A. F. Evans, D. D. Roby, K. Collis, M. Hawbecker, B. P. Sandford, D. E. Thompson and F. J. Loge (2011). "Relationship of External Fish Condition to Pathogen Prevalence and Out-Migration Survival in Juvenile Steelhead." Transactions of the American Fisheries Society 140(5): 1158-1171.

Understanding how the external condition of juvenile salmonids is associated with internal measures of health and subsequent out-migration survival can be valuable for population monitoring programs. This study investigated the use of a rapid, nonlethal, external examination to assess the condition of run-of-the-river juvenile steelhead Oncorhynchus mykiss migrating from the Snake River to the Pacific Ocean. We compared the external condition (e. g., body injuries, descaling, external signs of disease, fin damage, and ectoparasite infestations) with (1) the internal condition of a steelhead as measured by the presence of selected pathogens detected by histopathology and polymerase chain reaction analysis and (2) out-migration survival through the Snake and Columbia rivers as determined by passive integrated transponder (PIT) tag technology. The results from steelhead captured and euthanized (n = 222) at Lower Monumental Dam on the lower Snake River in 2008 indicated that external condition was significantly correlated with selected measures of internal condition. The odds of testing positive for a pathogen were 39.2, 24.3, and 5.6 times greater for steelhead with severe or moderate external signs of disease or more than 20% descaling, respectively. Capture-recapture models of 22,451 PIT-tagged steelhead released at Lower Monumental Dam in 2007-2009 indicated that external condition was significantly correlated with juvenile survival. The

odds of out-migration survival for steelhead with moderate or severe external signs of disease, more than 20% descaling, or severe fin damage were 5.7, 4.9, 1.6, and 1.3 times lower, respectively, than those for steelhead without these external conditions. This study effectively demonstrated that specific measures of external condition were associated with both the internal condition and out-migration survival of juvenile steelhead.

ISAB/ISRP (2016). Critical Uncertainties for the Columbia River Basin Fish and Wildlife Program. Report by the Independent Scientific Advisory Board (ISAB) for the Northwest Power and Conservation Council, the Columbia River Indian Tribes, and the National Marine Fishries Service, and by the Independent Scientific Review Panel (ISRP) for the Northwest Power and Conservation Council, Protland, Oregon: 162 pp.

Jeffries, K. M., S. G. Hinch, M. K. Gale, T. D. Clark, A. G. Lotto, M. T. Casselman, S. R. Li, E. L. Rechisky, A. D. Porter, D. W. Welch and K. M. Miller (2014). "Immune response genes and pathogen presence predict migration survival in wild salmon smolts." Molecular Ecology 23(23): 5803-5815.

We present the first data to link physiological responses and pathogen presence with subsequent fate during migration of wild salmonid smolts. We tagged and non-lethally sampled gill tissue from sockeye salmon (Oncorhynchus nerka) smolts as they left their nursery lake (Chilko Lake, BC, Canada) to compare gene expression profiles and freshwater pathogen loads with migration success over the first similar to 1150km of their migration to the North Pacific Ocean using acoustic telemetry. Fifteen per cent of smolts were never detected again after release, and these fish had gene expression profiles consistent with an immune response to one or more viral pathogens compared with fish that survived their freshwater migration. Among the significantly upregulated genes of the fish that were never detected postrelease were MX (interferon-induced GTP-binding protein Mx) and STAT1 (signal transducer and activator of transcription 1-alpha/beta), which are characteristic of a type I interferon response to viral pathogens. The most commonly detected pathogen in the smolts leaving the nursery lake was infectious haematopoietic necrosis virus (IHNV). Collectively, these data show that some of the fish assumed to have died after leaving the nursery lake appeared to be responding to one or more viral pathogens and had elevated stress levels that could have contributed to some of the mortality shortly after release. We present the first evidence that changes in gene expression may be predictive of some of the freshwater migration mortality in wild salmonid smolts.

Johnson, D. W., K. Grorud-Colvert, S. Sponaugle and B. X. Semmens (2014). "Phenotypic variation and selective mortality as major drivers of recruitment variability in fishes." Ecology Letters 17(6): 743-755.

An individual's phenotype will usually influence its probability of survival. However, when evaluating the dynamics of populations, the role of selective mortality is not always clear. Not all mortality is selective, patterns of selective mortality may vary, and it is often unknown how selective mortality compares or interacts with other sources of mortality. As a result, there is seldom a clear expectation for how changes in the phenotypic composition of populations will translate into differences in average survival. We address these issues by evaluating how selective mortality affects recruitment of fish populations. First, we provide a quantitative review of selective mortality. Our results show that most of the mortality during early life is selective, and that variation in phenotypes can have large effects on survival. Next, we describe an analytical framework that accounts for variation in selection, while also describing the amount of selective mortality experienced by different cohorts recruiting to a single population. This framework is based on reconstructing fitness surfaces from phenotypic selection measurements, and can be employed for either single or multiple traits. Finally, we show how this framework can be integrated with models of density-dependent survival to improve our understanding of recruitment variability and population dynamics.

Jonsson, B., M. Jonsson and N. Jonsson (2016). "Optimal size at seaward migration in an anadromous salmonid." Marine Ecology Progress Series 559: 193-200.

In this study, the probabilistic reaction norm was calculated for length at different ages of smolting before seaward migration of Atlantic salmon Salmo salar spawning in the Norwegian River Imsa. The reaction norm was compared with the optimal length at smolting estimated as the product of survival and female fecundity on the return, given their length at smolting. Logistic regression analysis on pre-migratory and migratory fish was used to estimate the probabilistic reaction norm. Length at 50% probability of smolting varied between 11.5 cm and 13.4 cm for age groups 1 to 3 yr with a minimum at Age-2. The estimated optimal length at smolting exhibited a maximum at 13.5 cm. Fecundity of adult females was not significantly affected by their length at smolting, making survival the chief variable influencing the optimal smolt size. The results lend support to the hypotheses that body length at 50% probability of seaward migration was similar for all smolt-age-groups independent of growth, and that mean length at each age of the young fish in fresh water reflected the probability of seaward migration. The slight difference between estimated optimal length at smolting and size at 50% probability of smolting may be chiefly caused by size dependent mortality at sea because of the tagging and larger pre-migratory mortality of young than older juveniles in the river. Thus, size appears crucially important for when to migrate.

Jonsson, B. and N. Jonsson (2009). "A review of the likely effects of climate change on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta, with particular reference to water temperature and flow." Journal of Fish Biology 75(10): 2381-2447.

The present paper reviews the effects of water temperature and flow on migrations, embryonic development, hatching, emergence, growth and life-history traits in light of the ongoing climate

change with emphasis on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta. The expected climate change in the Atlantic is for milder and wetter winters, with more precipitation falling as rain and less as snow, decrease in ice-covered periods and frequent periods with extreme weather. Overall, thermal limits for salmonids are species specific. Scope for activity and growth and optimal temperature for growth increase with temperature to an optimal point before constrain by the oxygen content of the water. The optimal temperature for growth decreases with increasing fish size and varies little among populations within species, whereas the growth efficiency may be locally adapted to the temperature conditions of the home stream during the growth season. Indirectly, temperature influences age and size at smolting through its effect on growth. Time of spawning, egg hatching and emergence of the larvae vary with temperature and selective effects on time of first feeding. Traits such as age at first maturity, longevity and fecundity decrease with increasing temperature whilst egg size increases with temperature. Water flow influences the accessibility of rivers for returning adults and speed of both upstream and downstream migration. Extremes in water flow and temperature can decrease recruitment and survival. There is reason to expect a northward movement of the thermal niche of anadromous salmonids with decreased production and population extinction in the southern part of the distribution areas, migrations earlier in the season, later spawning, younger age at smolting and sexual maturity and increased disease susceptibility and mortality. Future research challenges are summarized at the end of the paper.

Jonsson, B., N. Jonsson and J. Albretsen (2016). "Environmental change influences the life history of salmon Salmo salar in the North Atlantic Ocean." Journal of Fish Biology 88(2): 618-637.

Annual mean total length (L-T) of wild one-sea-winter (1SW) Atlantic salmon Salmo salar of the Norwegian River Imsa decreased from 63 to 54 cm with a corresponding decrease in condition factor (K) for cohorts migrating to sea from 1976 to 2010. The reduction in L-T is associated with a 40% decline in mean individual mass, from 2 to 12 kg. Hatchery fish reared from parental fish of the same population exhibited similar changes from 1981 onwards. The decrease in L-T correlated negatively with near-surface temperatures in the eastern Norwegian Sea, thought to be the main feeding area of the present stock. Furthermore, S. salar exhibited significant variations in the proportion of cohorts attaining maturity after only one winter in the ocean. The proportion of S. salar spawning as 1SW fish was lower both in the 1970s and after 2000 than in the 1980s and 1990s associated with a gradual decline in post-smolt growth and smaller amounts of reserve energy in the fish. In wild S. salar, there was a positive association between post-smolt growth and the sea survival back to the River Imsa for spawning. In addition, among smolt year-classes, there were significant positive correlations between wild and hatchery S. salar in L-T, K and age at maturity. The present changes may be caused by ecosystem changes following the collapse and rebuilding of the pelagic fish abundance in the North Atlantic Ocean, a gradual decrease in zooplankton abundance and climate change with increasing surface temperature in the Norwegian Sea. Thus, the observed variation in the life-history traits of S. salar appears primarily associated with major changes in the pelagic food web in the ocean.

Jonsson, N. and B. Jonsson (2014). "Time and size at seaward migration influence the sea survival of Salmo salar." Journal of Fish Biology 84(5): 1457-1473.

Whether time of seaward migration of young Atlantic salmon Salmo salar influences their subsequent survival and growth was investigated in the River Imsa, south-western Norway. Salmo salar were tagged when moving downstream through a trap near the outlet between 1976 and 2010 and recaptured on their adult return. Most descended as smolts in April and May, but some descended during the other months of the year. Annual variation in timing of the smolt migration was significantly correlated with variation in water temperature during spring. Mean total body length of the descending S. salar varied with month of seaward migration. The sea survival of S. salar emigrating from the River Imsa between January and May was 2.8 times higher than for those descending between June and December. The sea survival of the various cohorts decreased with increasing river temperature in April to May, prior to the smolt migration, and decreasing day number when the smolts moved to sea. The size of smolts descending the river between April and May did not affect the survival at sea as much as it affected the survival of migrants descending in any other month of the year. The majority of the downstream migrating S. salar were 2 years old, but proportionally, more 1 year olds moved downstream in the autumn than in the rest of the year. Mean duration between downstream migration of the young and the return migration of the grilse was shortest (12.7 months) for those descending in July and August and longest for those descending in October (21 months). Mean monthly specific growth rate was highest for those migrating downstream between May and July and lowest for those emigrating in September. Based on the present results, it was hypothesized that S. salar emigrating between April and August migrated directly out into the ocean, while those that emigrated between October and March stayed in the estuary until the subsequent spring.

Keefer, M., C. Caudill, T. Clabough, K. Collis, A. Evans, C. Fitzgerald, M. Jepson, G. Naughton, R. O'Connor and Q. Payton (2016). Adult steelhead Passage Behaviors and Survival in the Federal Colmbia River Power System, University of Idaho, Real Time Research, Inc., and Blue Leaf Environment, Inc.

Upstream Migration Timing – Summary
Key findings
● Winter and early spring fishway operations and counting protocols differ among projects
● Upstream-migrant steelhead pass FCRPS dams in all months
● Small winter-run populations have distinctive timing at Bonneville Dam
● Considerable overlap in the timing of summer-run populations, but median dates vary by weeks to months
● Summer water temperatures strongly influence timing at dams upstream from Bonneville Dam
● Tributary entry timing varies among sites and occurs throughout the year

Critical uncertainties
● Population-specific migration timing summaries limited, especially for wild fish (but see Section 3.6)
● Data gaps are greater for wild fish than for hatchery fish in most populations
● Data limited on the timing of movement from FCRPS reservoir into tributaries
● Timing of winter-run passage at Bonneville dam is not well described, especially for wild fish
● Unknown whether there are within-population differences in timing based on age, sex or other demographics
Technical recommendations
● Use of A-run / B-run terminology and the 25 August run separation date at Bonneville should be reconsidered
● Manual or video counting of adult steelhead at main stem dams could be seasonally extended
● Installation of in-stream PIT-detection sites would provide tributary entry timing for PIT-tagged adults

Kelt Outmigration Timing – Summary
Key findings
● Kelts are present in the FCRPS from approximately March through July, with peak numbers in April-May
● Kelt outmigration timing data have been collected primarily at JBSs
● Outmigration timing varies among kelt populations, among dams as composition changes, and among years
Critical uncertainties
● Downstream passage timing via non-JBS routes is not well described
● Population-specific timing is largely unknown for all downstream passage routes
● Timing of the onset of kelt migration is poorly understood and likely varies among populations
Technical recommendations
● Earlier operation of JBSs could help identify when kelt outmigration begins in FCRPS
● Methods need to be developed to monitor kelt passage timing and frequency via non-JBS routes
● Population composition of kelts could be addressed by genetic sampling and/or increased tagging

FCRPS Overwintering: Rates – Summary
Key findings
● FCRPS overwintering estimates: ~6-12% of early run, ~22-38% of late run
● FCRPS overwintering rates substantially vary among populations
● Individual probability of FCRPS overwintering is positively correlated with migration date at Bonneville
Critical uncertainties
● Rate estimates are sensitive to how overwintering onset is defined
● Rate estimates are sensitive to how harvest and mortality is treated in denominators

● There may be behavioral differences between wild and hatchery fish
● Winter harvest rates in FCRPS reservoirs have not been regularly quantified
● Effects of fishway closures on FCRPS overwintering rates is unknown
Technical recommendations
● Better population-specific estimates would help guide management decisions
● Clear definitions for FCRPS overwintering (e.g., start and end timing, duration, etc.) are needed

FCRPS Overwintering: Locations – Summary
Key findings
● Some steelhead overwinter in all FCRPS reservoirs
● Steelhead tend to overwinter in reservoirs closest to natal tributaries, though there are many exceptions
● Largest proportion overwinters in Lower Granite reservoir, especially among late-run populations
Critical uncertainties
● Unknown whether adult fishway closures affect the distribution of overwintering fish
● Steelhead movements among reaches and into tributaries complicates distribution summaries
● Data limited on many populations, especially from early-run and wild groups
● Not clear which FCRPS habitats (e.g., tailraces, forebays, confluence areas, main reservoir) are used
Technical recommendations
● Active telemetry combined with known-origin fish provides best spatial data

FCRPS Overwintering: Timing – Summary
Key findings
● Indirect evidence for a temperature (~8-12 °C) or photoperiod threshold for the onset of overwintering
● Nadir in steelhead movements in December-January at temperatures ~4-5 °C
Critical uncertainties
● Overwintering onset and migration resumption timing uncertain
● Causal mechanisms (e.g., environmental cues) for overwintering onset and migration resumption uncertain
● Unknown whether movement thresholds or cues differ among populations
Technical recommendations
● Existing databases could be mined to test overwintering mechanism hypotheses
● FCRPS operational decisions should integrate information on steelhead movement timing

FCRPS Overwintering: Survival – Summary
Key findings
● Survival to tributaries by radio-tagged FCRPS-overwintering fish was ~82-92%
● Fish not detected in tributaries (non-survivors) were distributed throughout the FCRPS
● Winter harvest estimates were ~4-12%, much lower than during summer and fall migration

Critical uncertainties
● True fates of fish that did not reach tributaries were unknown except for reported harvest
● Very little population-level survival data because early radiotelemetry studies used unknown-origin fish
Technical recommendations
● Genetic sampling from winter creel surveys could help identify population composition of overwintering fish
● Targeted studies using known-origin steelhead may reduce uncertainty

Tributary Overshoot: Percentages – Summary
Key findings
● Steelhead overshoot of natal tributaries and past upstream FCRPS dams is common and may represent the
majority of individuals in some populations
● Highest overshoot rates identified for Fifteenmile, John Day, Umatilla, Walla Walla, & Tucannon steelhead
Critical uncertainties
● Previous studies have been ad hoc, with no systematic evaluations (but see Section 3.8)
● Radiotelemetry studies used mostly unknown-origin steelhead and therefore underestimated overshoot
● Potential causal mechanisms have not been evaluated and may differ among populations
Technical recommendations
● Increase monitoring of tributary confluence areas to detect steelhead before and after overshoot
● Single populations: mine existing data for causal relationships between overshoot and river environment
● Across populations: test for common mechanisms, synchronous movements

Tributary Overshoot: Timing – Summary
Key findings
● Overshoot timing has not been systematically studied (but see Section 3.8.3)
● There may be timing differences for overshoot fish moving up the Columbia versus into the Snake
Critical uncertainties
● Potential causal mechanisms have not been evaluated and may differ among populations
● Overshoot behavior may be adaptive, but difficult to disentangle from FCRPS and hatchery effects
Technical recommendations
● Mine existing data for causal relationships between overshoot timing and river / tributary environments
● Test for potential hatchery effects within tributaries that have wild and hatchery populations
● Increase monitoring of tributary confluence areas to improve pre- and post-overshoot detection rates

Tributary Overshoot: Homing and Straying – Summary

Key findings

● There are few previous summaries of homing and straying by overshoot fish (but see Section 3.8.4)

● Permanent straying appears to be common among some steelhead that overshoot natal tributaries

Critical uncertainties

● True fates of fish that do not reach natal tributaries are generally unknown

● Substantial monitoring differences among sites and populations means behaviors may be misclassified

● Unknown whether some steelhead attempt to move downstream but fail to pass dams

● Considerable ambiguity regarding movement in and out of natal and non-natal tributaries

● Inter-basin stray rates are likely underestimated

Technical recommendations

● Active-tagging of prespawn adults at JBSs could generate behavioral and homing data for overshoot fish

● Increase monitoring of tributary confluence areas to better estimate both homing and straying

Fallback: Percentages and Rates – Summary

Key findings

● Mean annual pre-spawn fallback: 6-9% at lower Columbia dams and 3-6% at lower Snake River dams

● Fallback is lower, on average, for late-run steelhead than for steelhead migrating during the spill season

● Fallback by early-run fish can be high at McNary and at Snake River dams; associated with overshoot

Critical uncertainties

● Fallback estimates derived from PIT-tag detection data have several potential sources of error

● Population-level estimates have not been routinely reported but are likely to differ

● Volitional (overshoot-related) and non-volitional fallback difficult to separate in most existing datasets

Technical recommendations

● Accuracy and precision of PIT-based fallback estimates could be tested using data from double-tagged fish

● Population-specific fallback estimates could be generated using existing radiotelemetry data

● Increased PIT monitoring at dam fallback routes could improve fallback rate indices

Fallback: Enumeration – Summary

Key findings

● Hydroacoustic studies identified steelhead-sized fish passing downstream in fall, winter, and spring

● Hundreds of likely kelts passed Bonneville corner collector in March-April

● ~900-2000 pre-spawn and/or post-spawn fish passed The Dalles Ice/Trash sluice in fall and spring
● ~950-1800 pre-spawn and/or post-spawn fish passed McNary turbines in winter and spring
Critical uncertainties
● Species identification and population composition not possible with hydroacoustic data
● Not all passage routes were monitored, so estimates were incomplete and/or extrapolations
● Monitoring periods were truncated in most studies and some experiments were compromised by operations
Technical recommendations
● Experiments to evaluate passage route use under different operational criteria could be continued
● Species and population data could be matched to enumeration data by sampling from JBSs in winter, spring
● Seasonally-extended surface bypass operations (e.g., McNary TSW) may benefit kelts and overshoot fish

Fallback: Routes and Timing – Summary
Key findings
● Pre-spawn and kelt steelhead fallback primarily via spillways at FCRPS dams when spill is occurring
● Pre- and post-spawn fish also pass JBSs, ice & trash sluiceways, navigation locks, fishways, turbines
● Kelts preferentially pass surface-oriented routes when they are available
Critical uncertainties
● All routes at dams were rarely monitored simultaneously; many route-use estimates were approximate
● Origin populations were rarely considered in fallback route summaries
● Surface-flow volume needed to divert fallback fish from more hazardous routes is not well understood
Technical recommendations
● Genetic sampling of steelhead passing JBSs could provide time-specific index of populations falling back
● Accurate fallback route partitioning will require extensive monitoring effort

Fallback: Survival and Injury Rates – Summary
Key findings
● Direct survival tests: 48 h survival ≥98% through Bonneville Ice/Trash sluiceway & corner collector
● Direct survival tests: 48 h survival ~98% through McNary TSW and ~91% through McNary turbine
● Radio-tagged, pre-spawn steelhead that fell back had 8-20% lower survival to tributaries than no-fallback fish
● Fallback effects on survival vary among dams and seasonally, likely reflecting route differences

● Acoustic-tagged kelt survival was higher via spillways & spillway weirs and lower via JBSs & turbines

Critical uncertainties

● Experimental data limited to narrow set of conditions and limited routes at Bonneville and McNary dams
● Actual post-fallback fates mostly unknown in acoustic and radiotelemetry studies
● Sample sizes were limiting for route-specific kelt survival estimates
● Cause and effect very difficult to determine in non-experimental fallback-survival analyses
● Very little population-specific information on post-fallback survival

Technical recommendations

● Provision of surface-flow routes may improve post-fallback survival for pre-spawn and kelt steelhead
● Resolving route-specific survival questions may require additional direct release tests
● Active tag studies with mortality sensors may reduce uncertainty associated with post-fallback fates
● It may be possible to assess fallback-related injuries using recaptured PIT-tagged fish

FCRPS Reach Conversion Rates: Pre-spawn Adults – Summary

Key findings

● Hundreds of dam-to-dam and multi-dam conversion estimates have been reported for pre-spawn steelhead
● Dam-to-dam conversion estimates generally lowest in Bonneville-The Dalles reach
● Dam-to-dam conversion estimates generally highest between pairs of Snake River dams
● Population-specific estimates based on PIT-tagged fish indicate seasonal and among-group differences
● Transportation of juveniles steelhead from the Snake River associated with lower adult reach conversion
● Late-run steelhead appear to have higher FCRPS conversion than some early-run populations

Critical uncertainties

● In radiotelemetry studies, use of unknown-origin site steelhead complicated data interpretation
● Across study types, statistical treatment of tributary turnoff, straying, and harvest differed
● Populations without PIT-tag programs have not been well represented in reach conversion summaries
● Wild-origin groups are under-represented in existing conversion summaries
● PIT-based estimates limited to recent years for reaches including The Dalles, Lower Monumental, and Little Goose dams

Technical recommendations

● Better PIT-tag monitoring in tributaries would identify more strays and improve conversion interpretation
● Better accounting for population-specific harvest would improve conversion rate interpretation
● Installation of PIT antennas at John Day Dam would provide more precise reach conversion estimates

● Strategies to increase adult conversion of transported steelhead need to be further developed

FCRPS Reach Conversion: Kelts – Summary
Key findings
● Kelt survival rates vary with several traits, including sex, size and origin population
● Survival of Snake River kelts from Lower Granite to Bonneville is low (~4-37%)
● Mean reach conversion estimates were lower through the Snake River than the lower Columbia River
Critical uncertainties
● FCRPS reach conversion estimates for kelts based on small sample sizes and non-random samples
● Very little previous data for upper and mid-Columbia River populations
● Very difficult to partition kelt mortality among dam passage, reservoir passage, and fish condition effects
Technical recommendations
● Early-season operation of JBSs may improve conversion estimates for PIT-tagged kelts
● Timely provision of surface-flow routes would likely increase kelt conversion rates
● PIT-tag detection capability for additional routes (Ice/Trash sluiceways, spillway weirs) may improve estimates
● Route-specific mortality tests would inform operational decisions
● Better understanding of proportional route use and kelt detection probabilities is needed

Sample Composition – Summary
Key findings
● On average, 2.5% of adult steelhead annual counts at Bonneville Dam were PIT-tagged as juveniles (n=78,226)
● Fish were assigned to three broad geographic groups and 37 site-specific groups for summaries
● 15,171 steelhead were PIT-tagged as adults at Bonneville Dam, but without population-specific information
● Samples included multiple age classes (half pounders, 1, 2, and 3-ocean fish), rear-types (hatchery, wild), & life history classes (winter, summer, A- and B-group)
Critical uncertainties
● There is uncertainty regarding how representative PIT-tagged samples were to runs
● Wild-origin populations were under-represented in samples
● Some hatcheries were represented by disproportionate numbers of PIT-tagged fish
● Many sea-age assignments were uncertain due to incomplete emigration timing data
● Smolt transportation history was not included, but would likely affect behavioral summaries
Technical recommendations
● More representative juvenile tagging would improve inferences about adult behavior & survival in the FCRPS
● Relationship between juvenile transport and targeted adult behaviors in the FCRPS should be assessed

● Non-invasive techniques / tools to more accurately age juvenile and adult steelhead are needed

Upstream Migration: A- Versus B-Group Timing at Bonneville Dam – Summary
Key findings
● Most populations had a mix of nominal A- and B-group fish, based on the 25-Aug run-separation at Bonneville
● Lower, mid-, and upper Columbia tributaries were predominantly A-group (early run) fish
● Several Snake River tributary groups were primarily A-group (early run) fish
● B-group (late run) fish were predominately from the Clearwater and Salmon River basins
● Similar timing patterns were evident for hatchery and wild fish within the A- and B-groups
Critical uncertainties
● The 25 August run separation date at Bonneville Dam does not reflect biological distinction
● All populations, rear-types, age classes, and life history classes were not likely represented
Technical recommendations
● Use of A-run / B-run terminology and the 25 August run separation date at Bonneville should be reconsidered

Upstream Migration: Population-specific Timing at FCRPS Dams – Summary
Key findings
● Adult steelhead pass lower FCRPS dams in a well-mixed population continuum from late-spring to late-fall
● Adults pass Snake River dams primarily in fall, with extensive overlap among populations
● Many apparent strays from the Clearwater, Salmon and Snake rivers had early or late run timing at dams
● Tributary overshoot fish from lower and mid-Columbia populations often had early or late timing at dams
Critical uncertainties
● All populations, rear-types, age classes, and life history classes were not likely represented
Technical recommendations
● Further separation among populations within tributaries could better differentiate group timing
● Further separation among affiliated hatchery and wild groups may be useful for managers
● Multi-modal distributions are likely for some populations at some sites and may be more useful for managers

Upstream Migration: Tributary Entry Timing – Summary
Key findings
● Only nine tributaries had PIT antennas suitable for estimating tributary entry timing, all below the Snake River
● Winter-run steelhead had the most distinct tributary entry timing (March-May)
● Majorities of Fifteenmile Creek and Umatilla River steelhead were first detected in the spring
● Detections at other monitored tributaries were predominately during summer and fall
Critical uncertainties

● A large majority of tributaries did not have PIT antennas near confluence areas
● There was little or no detection efficiency information across sites or within seasons at tributary PIT arrays
● Distributions may be misleading for sites with both winter- and summer-run steelhead
Technical recommendations
● Additional tributary PIT interrogation sites would allow for a more robust and holistic evaluation of timing
● PIT-tag detection efficiency data at tributary arrays would improve timing inferences
● Further separation among populations within tributaries could better differentiate group timing

FCRPS Overwintering: Percentages – Summary
Key findings
● Estimated minimums of 2.9% (A-group) and 3.6% (B-group) of steelhead overwintered in the FCRPS, based on
dam passage
● Population-specific overwintering percentages within the FCRPS ranged from 0 – 13%
● FCRPS overwintering estimates increased considerably when tributary entry date was a criterion (9 sites only)
Critical uncertainties
● Use of dam passage timing as sole criterion resulted in significant underestimation of FCRPS overwintering
● Limited monitoring at The Dalles, John Day, Lower Monumental, & Little Goose limited identification of overwintering
● Limited tributary monitoring also resulted in minimum overwintering estimates
● PIT monitoring configuration limited comparisons across populations and years
Technical recommendations
● PIT-based overwintering estimates should be considered minimums and be interpreted cautiously
● Additional tributary PIT interrogation sites would improve population-specific FCRPS overwintering estimates
● Clear definitions for FCRPS overwintering (e.g., start timing) are needed

FCRPS Overwintering: Timing – Summary
Key findings
● Timing distributions for 2,256 FCRPS overwintering fish showed variety of behaviors
● First-year passages of overwintering fish were before 1 November at Bonneville and The Dalles dams
● First-year passages of overwintering fish at Snake River dams were generally (but not always) after 1 Nov.
● Second-year passage events at most dams were concentrated in March and early-April
● Population-specific dam passage timing was variable and often associated with tributary overshoot
Critical uncertainties

● See list for Section 3.7.2 - FCRPS Overwintering: Percentages
Technical recommendations
● See list for Section 3.7.2 - FCRPS Overwintering: Percentages

FCRPS Overwintering: Locations – Summary
Key findings
● A large majority of FCRPS overwintering was upstream from John Day Dam, especially in Snake River reservoirs
● Few steelhead were identified overwintering in reservoirs upstream of Wanapum Dam
● Some fish moved among reservoirs during winter
● Upstream movement through the FCRPS was rapid in spring
Critical uncertainties
● See list for Section 3.7.2 - FCRPS Overwintering: Percentages
Technical recommendations
● See list for Section 3.7.2 - FCRPS Overwintering: Percentages

FCRPS Overwintering: Estimated Fate – Summary
Key findings
● Estimated fates / last known detections of overwintering steelhead varied greatly by population
● In general, wild fish were more likely to home and less like to stray than hatchery fish
● Large numbers and percentages of adults were last detected at a FCRPS dam
Critical uncertainties
● True fates of fish that did not reach natal tributaries were generally unknown
● Substantial monitoring differences among sites and populations means behaviors may be misclassified
● Fish harvest influenced results to an unknown degree
● Also see list associated with Section 3.7.2 - FCRPS Overwintering: Percentages
Technical recommendations
● Population-specific data on the location and rate of harvest events in the FCRPS are needed to generate more complete and accurate fate estimates
● Additional PIT interrogation sites, particularly in tributaries, would improve fate estimation and it would also provide data to more accurately and precisely estimate tributary overshoot, conversion, and staying
● Also see list for Sections 3.8, 3.10, and 3.11 below

Tributary Overshoot: Percentages – Summary
Key findings
● Estimates of the percentage of steelhead that overshot natal tributaries varied by more than two orders of
magnitude among populations and also varies by year
● Overshoot estimates were higher when natal tributary was a short distance downstream from a FCRPS dam

● Overshoot past dams >50% was detected for steelhead from Mill Cr, Fifteenmile Cr, Rock Cr, John Day R, Umatilla R, Walla Walla R, Lyons Ferry H, and Tucannon R

Critical uncertainties

● Overshoot estimates past The Dalles, Lower Monumental, and Little Goose dams were data limited

● There may be important behavioral differences among tributary sub-populations, hatchery/wild groups, and transport/in-river juvenile migration groups

● It is unknown whether natal tributary overshoot is an adaptive behavior or if mechanisms differ among
populations and locations

● Fish harvest and monitoring locations influenced overshoot estimates to an unknown degree

Technical recommendations

● Additional PIT interrogation sites, at John Day Dam and in tributaries, could improve overshoot estimates

● Data on location, rate, and timing of harvest could improve overshoot estimates

● Single populations: mine existing data for causal relationships between overshoot and river environment

● Across populations: test for common mechanisms; compare overshoot past Ice Harbor vs. Priest Rapids dams

Tributary Overshoot: Timing – Summary

Key findings

● Overshoot timing was roughly commensurate with each population's migrating timing

● A small proportion of fish from many populations overshoot in spring (March-April), likely in response to environmental (discharge, water temperature) or maturation cues

Critical uncertainties

● See list for Section 3.8.2 - Tributary Overshoot: Percentages

Technical recommendations

● Mine existing data for environmental cues associated with tributary overshoot events

● Also see list for Section 3.8.2 - Tributary Overshoot: Percentages

Tributary Overshoot: Estimated Fate – Summary

Key Findings

● Overall, a minority of overshoot fish successfully homed to their natal stream

● Average annual homing of overshoot steelhead varied greatly by population and year

● In general, wild fish were more likely than hatchery fish to home and less likely to stray after overshoot

● In most but not all cases, early- and late-run overshoot steelhead were similarly likely to home and stray

Critical uncertainties

● True fates of fish that do not reach natal tributaries are generally unknown

● A lack of PIT interrogation sites in tributaries results in unknown bias(es) in homing estimates

● Apparent straying (i.e., last detection in non-natal tributary) may simply reflect limited PIT monitoring

Technical recommendations
● Terminology associated with tributary overshoot and post-overshoot outcomes should be standardized
● Future evaluations should attempt to adjust for variation in detection efficiencies within and among sites
● Also see list for Section 3.7.5 - FCRPS Overwintering: Estimated Fate

Fallback: JBS Rates and Timing – Summary
Key findings
● Hundreds of PIT-tagged steelhead were detected falling back through JBS routes at FCRPS dams
● JBS fallback was detected for most populations, but timing varied among sites and groups
● More than 1,000 steelhead were detected at the Bonneville Corner Collector (BCC)
● Fallbacks were generally more frequent in Year 1 at lower Columbia dams, and in Year 2 at Snake River dams, indicating a mix of pre-spawn steelhead and kelt fallback events
● Reported rates are minimums and should be considered an index for comparison among sites and groups
Critical uncertainties
● True rates were underestimated to some degree because harvest and other mortality was not accounted for
in denominators
● Maturation status was unknown for many steelhead that fell back in Year 2
● It is unknown whether fallback rates via JBSs and the BCC are good indicators of fallback via other routes
● Relationships between JBS and BCC fallback rates and operational or environmental conditions are unknown
Technical recommendations
● Installation of PIT antennas at other FCRPS dam passage routes (e.g., spillway weirs) will allow for a more robust and holistic evaluation of fallback rates and timing
● Mine existing data for causal relationships between JBS and BCC fallback and river environment / operations
● Accounting for harvest, hatchery collection and other adult 'loss' would provide more realistic estimates of population-specific fallback through JBSs and the BCC

Fallback Identified Using Fishway Antenna Algorithms – Summary
Key findings
● JBS fallback percentages calculated using adults that passed individual dams (different from previous Section)
● Highest fallback percentages were for tributary overshoot populations
Critical uncertainties
● Only McNary, Ice Harbor, and Lower Granite fishways had antenna details sufficient to assess directionality
● Fishway detection data and elapsed times before fallback were highly variable and difficult to interpret

● Also see list for Section 3.9.2 - Fallback: JBS rates and timing

Technical recommendations

● PIT-based fallback estimates for non-JBS routes need to be rigorously evaluated

● PIT-based fallback estimates could be tested using double-tagged (i.e., radio+PIT) steelhead

● Antenna redundancy in adult fishways would improve evaluation of movements and possible fallback

● Also see list for Section 3.9.2 - Fallback: JBS rates and timing

FCRPS Reach Conversion – Summary

Key findings

● Reach conversion point estimates varied by year, rear-type, run-timing and population

● Conversion between adjacent FCRPS dams was > 0.95 for most populations, in most years

● The lowest conversion estimates were in the Bonneville–The Dalles reach (~ 0.80 - 0.90 for most groups)

● Bonneville-Lower Granite conversion was ~ 0.70 for aggregate Snake River populations and rear-type groups

● Conversions were often +0.01 to +0.04 higher for wild and late-run fish than for hatchery and early-run fish

● Steelhead PIT-tagged at Snake River dams had lower survival, on average, than many other groups, suggesting a likely negative effect of juvenile transportation on aggregate samples (transport + in-river) summarized herein

Critical uncertainties

● PIT tag arrays were not installed at all FCRPS dams in all years, limiting comparisons across years and reaches

● Some populations, and especially wild groups, were under-represented in conversion estimates

● Fates of 'unsuccessful' fish were unknown but likely included harvest and strays

● Juvenile transportation effects were not assessed but likely contributed to reduced reach conversion

Technical recommendations

● Formal survival analyses that incorporate detection probabilities would improve precision and provide confidence intervals for reach conversion estimates

● Existing data could be mined to assess relationships between reach conversion and environmental covariates, including river environment and FCRPS operations

● Existing data could be mined to assess relationships between reach conversion and biological covariates, including fish traits (e.g., migration timing, age, origin) and behaviors (e.g., fallback, temporary straying)

● Agencies currently use different methods for estimating PIT-based FCRPS reach conversion estimates. We recommend that methods be standardized to reduce confusion and potential misinterpretation

Inter-basin Straying – Summary

Key findings

● Apparent straying into non-natal tributaries was detected in nearly all populations

● Strays to non-natal tributaries were widely dispersed, although most were in tributaries near natal rivers
● Some of the highest stray rates into non-natal tributaries were by overshoot fish
● Strays from Snake River populations mostly entered lower Columbia River tributaries (e.g., Deschutes)
● Small percentages of Snake River steelhead strayed into the upper Columbia River and vice versa
● 'Potential' strays detected at FCRPS dams upstream from natal tributaries were common in some populations
Critical uncertainties
● Non-natal tributary stray estimates were likely minimums given limited PIT monitoring in many tributaries
● Final fates and reproductive status were unknown and therefore all stray assignments were inferred
● Status was ambiguous for fish last recorded at FCRPS dams upstream from natal tributaries
● Fish last detected in non-natal tributaries may have exited undetected and been misclassified as strays
● Also see lists for Sections 3.8.2 to 3.8.4
Technical recommendations
● Additional tributary PIT interrogation sites are needed to provide more robust straying evaluations
● Terminology associated with homing and straying / non-homing outcomes should be standardized
● Also see lists for Sections 3.8.2 to 3.8.4 (Tributary Overshoot)

Keefer, M. L. and C. C. Caudill (2012). A Review of Adult Salmon and Steelhead Straying with an Emphasis on Columbia River Populations. Prepared for the U.S. Army Corps of Engineers, Walla Walla District, by Department of Fish and Wildlife Resources, College of Natural Resources, University of Idaho.

E X E CUT IV E SUMMARY
Context for review – Management of the Federal Columbia River Power System (FCRPS) includes collection of juvenile salmonids at dams followed by downstream transport on barges or trucks. Evidence from tagging studies indicate higher straying rates in adults that were transported as juveniles compared to those that migrated in river, potentially hindering salmon and steelhead recovery efforts. A clear understanding of the patterns of straying across populations and the underlying mechanisms affecting upstream migration behavior, route selection, and homing to (or straying from) natal habitats is critical to evaluating the effects of "natural" versus human-induced straying on salmon and steelhead populations. A comprehensive review and analysis of available literature and data is currently lacking for the Columbia River-Snake River system.

This literature review presented here is intended to provide managers with an overview of available information on the many inter-related mechanisms associated with juvenile imprinting and emigration and subsequent homing and straying behaviors by returning adults. The review includes a synthesis of published straying data from the Columbia River basin, with additional comparison data from representative studies outside of the Columbia system. Topics covered in the review and data synthesis were developed in consultation with U.S. Army Corps of Engineers (USACE) biologists as part of a coordinated effort to identify critical knowledge gaps and to provide a context for prioritizing research and management needs. In the review, we identified potentially important demographic and genetic factors affecting both donor populations (populations strayed from) and recipient populations (populations receiving strays).

Snake River steelhead straying model – This review also includes results from a Snake River modeling exercise that was developed in parallel with the literature review. The model estimates the number of adult steelhead strays for donor and recipient populations across a range of adult straying rates, smolt abundance at Lower Granite Dam, transportation rate from the Snake River, and smolt-to-adult returns (SARs) for hatchery, wild, in-river, and barged populations. Model outputs indicate that transported hatchery steelhead contribute the largest number of strays in
most simulations. The absolute number of strays also tended to increase with smolt abundance, as SAR's increased, and as transport proportion increased. As part of the modeling exercise, we developed a simple numerical model to show the proportion of strays in a wild recipient population (i.e., relative abundance) in relation to donor population size, recipient population size, and donor stray rate. This model shows that strays from large donor populations can numerically overwhelm native fish in small recipient populations, even at low (~1%) stray rates.

We developed the model into a spreadsheet-based tool provided as a product of this project. This tool allows users to input a variety of data on Snake River steelhead juveniles and adults that are then used to estimate adult Snake River steelhead straying. The tool allows users to estimate total steelhead stray abundance and to estimate the number of strays that enter individual recipient populations (e.g., into the John Day River) using combinations of empirical values from recent years (i.e., from the Fish Passage Center) or user-specified values. The straying model is ultimately designed to help evaluate the potential effectiveness of different management efforts to reduce straying by barged fish.

Key conclusions – The content of the review has direct management implications for those working with adult salmon and steelhead straying in the Columbia River basin. Key findings include:
- adult straying is a desirable and 'natural' component of salmonid metapopulation biology in unmanipulated systems, and is critical to genetic resilience, demographic stability, and range expansion into unexploited habitats;
- adult straying rates differ among salmonid species;
- adult straying rates differ among populations and among life history types within species;

- most strays enter sites that are geographically close to natal sties; transported fish, however, often stray into more distant rivers;
- the effects of straying differ between the donor and recipient populations. Strays can have positive, negative, or neutral effects on recipient populations, depending on the source and relative abundance of the strays, effects on donor populations depend on straying rate and donor population size;
- adult straying is often associated with juvenile behavior and physiology – and especially olfactory imprinting – but migratory and reproductive behaviors of adults also influence homing outcomes;
- transportation of juvenile salmon and steelhead can increase adult straying behaviors, likely by negatively affecting sequential olfactory imprinting;
- hatchery rearing can contribute to adult straying, although there have been few spatially- and temporally-controlled studies of straying by closely-related hatchery and wile populations;
- in the Columbia River basin, many adults stray from the Snake River and enter mid-Columbia River tributaries especially the Deschutes and John Day rivers; straying rates are higher for adults that were transported as juveniles; additional straying occurs at a variety of spatial scales basin-wide;

Critical uncertainties – The review identified several uncertainties related to managing 'undesirable' (i.e., human influenced) adult straying in the Columbia River basin. These include:
- the specific mechanisms of impaired imprinting for transported juveniles remain unknown; candidate hypotheses include chronological effects (i.e., transport is too rapid), spatial effects (i.e., barges are in inappropriate habitats), and in-barge effects (i.e., stress, contaminants, etc.);
- potential interactive or cumulative of effects of hatchery rearing and juvenile transport are poorly understood;
- evidence suggests that strays may outnumber natives in small recipient populations; it is unknown how the impact of straying differs across donor and recipient population sizes;
- accounting for hatchery- and transport-related strays in the Columbia River system is far from complete because strays are not routinely identified or monitored in most sub-basins;
- it is not known how many strays successfully breed in most recipient populations;
- adult strays appear to preferentially enter some recipient river systems, but not others; the mechanisms affecting this selective behavior are largely unknown;
- genetic, fitness, and other population-level impacts of strays (i.e., outbreeding depression, introgression, hybridization, domestication effects, reduced productivity, etc.) have not been addressed for most Columbia River populations

Keefer, M. L. and C. C. Caudill (2014). "Homing and straying by anadromous salmonids: a review of mechanisms and rates." Reviews in Fish Biology and Fisheries 24(1): 333-368.

There is a long research history addressing olfactory imprinting, natal homing, and non-natal straying by anadromous salmon and trout (Salmonidae). In undisturbed populations, adult straying is a fundamental component of metapopulation biology, facilitating genetic resilience, demographic stability, recolonization, and range expansion into unexploited habitats.

Unfortunately, salmonid hatcheries and other human actions worldwide have affected straying in ways that can negatively affect wild populations through competitive interactions, reduced productivity and resiliency, hybridization and domestication effects, and outbreeding depression. Reduced adult straying is therefore an objective for many managed populations. Currently, there is considerable uncertainty about the range of 'natural' stray rates and about which mechanisms precipitate straying in either wild or human-influenced fish. Research in several disciplines indicates that adult straying is affected by endocrine physiology and neurological processes in juveniles, incomplete or interrupted imprinting during rearing and emigration, and by complex interactions among adult maturation processes, reproductive behaviors, olfactory memory, environmental conditions during migration, and senescence physiology. Reported salmonid stray rates indicate that the behavior varies among species, among life-history types, and among populations within species. Most strays enter sites near natal areas, but long-distance straying also occurs, especially in hatchery populations that were outplanted or transported as juveniles. A majority of past studies has estimated straying as demographic losses from donor populations, but some have estimated straying into recipient populations. Most recipient-based estimates have substantiated concerns that wild populations are vulnerable to swamping by abundant hatchery and farm-raised strays.

Keefer, M. L., G. A. Taylor, D. F. Garletts, C. K. Helms, G. A. Gauthier, T. M. Pierce and C. C. Caudill (2013). "HIGH-HEAD DAMS AFFECT DOWNSTREAM FISH PASSAGE TIMING AND SURVIVAL IN THE MIDDLE FORK WILLAMETTE RIVER." River Research and Applications 29(4): 483-492.

Many high-head dams in Oregon's Willamette River basin were constructed without fish passage facilities for downstream migrants. Instead, fish pass dams via hydroelectric turbines, surface spillways or deep-water regulating outlets. The availability of these routes varies seasonally with dam operations and reservoir depth, which can fluctuate by tens of meters. To assess how dam and reservoir operations affect fish movement timing and survival, we used rotary screw traps below three Willamette basin dams and at two riverine sites above reservoirs. Traps were operated 2950days over 8years, and >195000 fish were collected. Samples above reservoirs were primarily native salmonids (Oncorhynchus spp.), daces (Rhinichthys spp.) and sculpins (Cottus spp.), while those below dams were often dominated by non-native Centrarchidae. Capture rates at riverine sites were highest from late winter to early summer, coincident with juvenile Chinook salmon emigration. Conversely, collection below dams was largely restricted to late fall and winter when reservoirs were drawn down to annual lows and discharge was high. We hypothesize that winter operations facilitated fish access to dam turbines and regulating outlets, whereas springsummer operations entrapped fish in reservoirs and restricted volitional downstream passage. Total fish mortality was 2% at riverine sites and was 3669% below dams. Estimates were highest for non-native species and juvenile Chinook salmon. Fatal injuries were consistent with traumas related to pressure, shear and contact and there were size-related and morphology-related risk differences. Mitigation opportunities include fish bypass system development, retrofits for existing routes and

seasonally appropriate reservoir draw down to allow fish passage. Copyright (c) 2012 John Wiley & Sons, Ltd.

Kendall, N. W., J. R. McMillan, M. R. Sloat, T. W. Buehrens, T. P. Quinn, G. R. Pess, K. V. Kuzishchin, M. M. McClure and R. W. Zabel (2015). "Anadromy and residency in steelhead and rainbow trout (Oncorhynchus mykiss): a review of the processes and patterns." Canadian Journal of Fisheries and Aquatic Sciences 72(3): 319-342.

Oncorhynchus mykiss form partially migratory populations with anadromous fish that undergo marine migrations and residents that complete their life cycle in fresh water. Many populations' anadromous components are threatened or endangered, prompting interest in understanding ecological and evolutionary processes underlying anadromy and residency. In this paper, we synthesize information to better understand genetic and environmental influences on O. mykiss life histories, identify critical knowledge gaps, and suggest next steps. Anadromy and residency appear to reflect interactions among genetics, individual condition, and environmental influences. First, an increasing body of literature suggests that anadromous and resident individuals differ in the expression of genes related to growth, smoltification, and metabolism. Second, the literature supports the conditional strategy theory, where individuals adopt a life history pattern based on their conditional status relative to genetic thresholds along with ultimate effects of size and age at maturation and iteroparity. However, except for a generally positive association between residency and high lipid content plus a large attainable size in fresh water, the effects of body size and growth are inconsistent. Thus, individuals can exhibit plasticity in variable environments. Finally, patterns in anadromy and residency among and within populations suggested a wide range of possible environmental influences at different life stages, from freshwater temperature to marine survival. Although we document a number of interesting correlations, direct tests of mechanisms are scarce and little data exist on the extent of residency and anadromy. Consequently, we identified as many data gaps as conclusions, leaving ample room for future research.

Kilduff, D. P., L. W. Botsford and S. L. H. Teo (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 71(7): 1671-1682.

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. Shortterm 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.

Kilduff, D. P., E. Di Lorenzo, L. W. Botsford and S. L. H. Teo (2015). "Changing central Pacific El Ninos reduce stability of North American salmon survival rates." Proceedings of the National Academy of Sciences of the United States of America 112(35): 10962-10966.

Pacific salmon are a dominant component of the northeast Pacific ecosystem. Their status is of concern because salmon abundance is highly variable-including protected stocks, a recently closed fishery, and actively managed fisheries that provide substantial ecosystem services. Variable ocean conditions, such as the Pacific Decadal Oscillation (PDO), have influenced these fisheries, while diminished diversity of freshwater habitats have increased variability via the portfolio effect. We address the question of how recent changes in ocean conditions will affect populations of two salmon species. Since the 1980s, El Nino Southern Oscillation (ENSO) events have been more frequently associated with central tropical Pacific warming (CPW) rather than the canonical eastern Pacific warming ENSO (EPW). CPW is linked to the North Pacific Gyre Oscillation (NPGO), whereas EPW is linked to the PDO, different indicators of northeast Pacific Ocean ecosystem productivity. Here we show that both coho and Chinook salmon survival rates along western North America indicate that the NPGO, rather than the PDO, explains salmon survival since the 1980s. The observed increase in NPGO variance in recent decades was accompanied by an increase in coherence of local survival rates of these two species, increasing salmon variability via the portfolio effect. Such increases in coherence among salmon stocks are usually attributed to controllable freshwater influences such as hatcheries and habitat degradation, but the unknown mechanism underlying the ocean climate effect identified here is not directly subject to management actions.

Kovach, R. P., J. E. Joyce, J. D. Echave, M. S. Lindberg and D. A. Tallmon (2013). "Earlier Migration Timing, Decreasing Phenotypic Variation, and Biocomplexity in Multiple Salmonid Species." Plos One 8(1).

Lennox, R. J., J. M. Chapman, C. M. Souliere, C. Tudorache, M. Wikelski, J. D. Metcalfe and S. J. Cooke (2016). "Conservation physiology of animal migration." Conservation Physiology 4.

Migration is a widespread phenomenon among many taxa. This complex behaviour enables animals to exploit many temporally productive and spatially discrete habitats to accrue various fitness benefits (e.g. growth, reproduction, predator avoidance). Human activities and global environmental change represent potential threats to migrating animals (from individuals to species), and research is underway to understand mechanisms that control migration and how migration responds to modern challenges. Focusing on behavioural and physiological aspects of migration can help to provide better understanding, management and conservation of migratory populations. Here, we highlight different physiological, behavioural and biomechanical aspects of animal migration that will help us to understand how migratory animals interact with current and future anthropogenic threats. We are in the early stages of a changing planet, and our understanding of how physiology is linked to the persistence of migratory animals is still developing; therefore, we regard the following questions as being central to the conservation physiology of animal migrations. Will climate change influence the energetic costs of migration? Will shifting temperatures change the annual clocks of migrating animals? Will anthropogenic influences have an effect on orientation during migration? Will increased anthropogenic alteration of migration stopover sites/migration corridors affect the stress physiology of migrating animals? Can physiological knowledge be used to identify strategies for facilitating the movement of animals? Our synthesis reveals that given the inherent challenges of migration, additional stressors derived from altered environments (e.g. climate change, physical habitat alteration, light pollution) or interaction with human infrastructure (e.g. wind or hydrokinetic turbines, dams) or activities (e.g. fisheries) could lead to long-term changes to migratory phenotypes. However, uncertainty remains because of the complexity of biological systems, the inherently dynamic nature of the environment and the scale at which many migrations occur and associated threats operate, necessitating improved integration of physiological approaches to the conservation of migratory animals.

Lusardi, R. A. and P. B. Moyle (2017). "Two-Way Trap and Haul as a Conservation Strategy for Anadromous Salmonids." Fisheries 42(9): 478-487.

Dams are ubiquitous in the United States and have disconnected migratory fishes from important historical habitat. Trapping fish and moving them around dams (trap and haul) is a common strategy to manage Pacific coast salmonids. Usually, juveniles or adults are moved in one direction, but there is growing interest in two-way trap and haul (TH2), where both adults and out-migrating juveniles are captured and transported over dams. Despite recent technological advances, no TH2 program is an unequivocal success. Our review indicates that uncertainties associated with TH2 programs exist and include delayed effects from transportation, maintenance of above-dam populations, out-migrant capture efficiency, and the role of hatchery supplementation. Two-way trap and haul programs should (1) clearly define measurable and objective success metrics, such as the 10 we provide; (2) proceed experimentally under an adaptive management framework to determine risk-benefit trade-offs; and (3) be part of comprehensive conservation strategies that consider the entire life cycle of each species. Two-way trap and haul is proposed as a high-priority recovery strategy for

Chinook Salmon Oncorhynchus tshawytscha populations in California. Our findings indicate that any such TH2 program should proceed with extreme caution.

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

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

Magie, R. J., M. S. Morris, J. P. Bender, B. F. Jonasson, B. P. Sandford and R. D. Ledgerwood (2015). Development of a passive integrated transponder (PIT) detection system for adult salmonids in the lower Columbia River, 2013, Report by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington.

For the third year, we deployed a new system to detect adult salmon tagged with passive integrated transponder (PIT) tags in the tidal freshwater portion of the Columbia River estuary. The system was installed in the river along a pile dike near river kilometer (rkm) 70, with above-water components at the terminal piling. It was designed to detect adult salmonids for estimates of survival and travel time to upstream sites, but juvenile salmonids and other PIT-tagged fish were also detected.

In 2013, we replaced the system transceiver with a new model that promised greater read range. Based on capability of the new transceiver, we built new submersible antennas that covered four times the area of antennas used in the prototype system (2.4 × 6.1 m). We initially installed three of the larger antennas housed in 10-cm-diameter rigid PVC pipe. However, after several weeks of operation, stress fractures developed in two of these antennas. We replaced these antennas, and constructed new antennas using 1.9-cm-diameter flexible PVC tubing.

By late August, we had replaced all but one of the rigid antennas with antennas housed with small-diameter flexible tubing. We also expanded the site to include two additional flexible antennas placed further inshore along the pile dike. The new transceiver worked well for these antennas, which were installed 55 m and 76 m from the
power source. Except for interruptions to replace antennas, and some brief solar-power shortages late in the season, the system remained operational from March through July (3 antennas) and from August to October (5 antennas).

To evaluate fish behavior near the system, we periodically used a DIDSON acoustic camera. Camera observations confirmed that fish passed more readily through the enlarged antennas, which nearly eliminated the avoidance behavior observed in previous years.

During 2013, the pile dike system detected 375 adult and jack salmonids, representing 1.6% of all PIT-tagged adult and jack salmonids passing Bonneville Dam in 2013. For spring, summer, and fall Chinook, as well as steelhead, these detections were sufficient for estimates of survival and travel time to Bonneville Dam (Table 1). Most detections of adult and jack salmonids came from a single 2.4- by 6.1-m antenna located on the terminus of the pike dike.

Only two adult Chinook salmon detected on the pile dike system were destined for Willamette Falls Dam. However, the system detected 620 juvenile salmonids comprised of 464 Chinook salmon, 98 steelhead, 53 coho salmon, 4 sockeye, and 1 cutthroat trout. Ten white sturgeon adults and 1 northern pikeminnow were also detected in 2013.

Although we will continue development and testing of the pile dike system, its performance has already shown proof of concept for potential expansion to other large riverine habitats. The ability to deploy large, submerged antennas at long distances from a power source (>75 m) represents a significant advance to instream PIT-tag monitoring
technology. Site selection for such deployments will rely on many of the methods established for existing instream monitoring, such as evaluation of ambient EMI (electromagnetic interference). However, flexible antennas can be built and potentially deployed at a much lower cost than the rigid antenna arrays used in our prototype system (and presently deployed in most instream PIT-tag monitoring applications).

Expanded deployment of flexible antenna systems in the estuary can maximize detections of adult salmonids, augmenting the accuracy of survival and travel time estimates and helping to pinpoint problems in specific reaches. Such estimates can provide insight into mortality from pinniped predation and fishing pressure as well as stock-specific run timing in tidal freshwater reaches. As a next step, we plan to adopt the flexible antenna for use in a mobile application that can target juvenile or adult salmonids in a variety of riverine or reservoir conditions.

Malick, M. J., S. P. Cox, R. M. Peterman, T. C. Wainwright and W. T. Peterson (2015). "Accounting for multiple pathways in the connections among climate variability, ocean

processes, and coho salmon recruitment in the Northern California Current." Canadian Journal of Fisheries and Aquatic Sciences 72(10): 1552-1564.

Pathways linking climate to population dynamics of higher-trophic-level fish species such as Pacific salmon often involve a hierarchy in which regional-scale physical and biological processes mediate the effects of large-scale climate variability. We used probabilistic networks to investigate 17 potential ecological pathways linking climate to Oregon coho salmon (Oncorhynchus kisutch) recruitment. We found that pathways originating with the Pacific Decadal Oscillation were the most influential on recruitment, with the net effect being two to four times greater than for pathways originating with the North Pacific Gyre Oscillation or the Oceanic Niño Index. Among all environmental variables, sea surface temperature and an index of juvenile salmon prey biomass had the greatest effects on recruitment, with a 76% chance of recruitment being equal to or below average given that ocean temperatures were above average and a 34% chance of recruitment being below average given that prey biomass was above average. Our results provide evidence that shifts in climate patterns could strongly influence recruitment simultaneously through multiple ecological pathways and highlight the importance of quantifying cumulative effects of these pathways on higher-trophic-level species.

Mann, M. E. and P. H. Gleick (2015). "Climate change and California drought in the 21st century." Proceedings of the National Academy of Sciences of the United States of America 112(13): 3858-3859.

Marsh, D. M., W. D. Muir, B. P. Sandford, S. G. Smith and D. Elliott (2012). Alternative barging strategies to improve survival of salmonids transported from Lower Granite Dam: final report from the 2006–2008 spring/summer Chinook salmon and steelhead juvenile migrations, National Marine Fisheries Service, Seattle, Washington.

Marsh, T. M., W. D. Muir, B. P. Sandford, S. G. Smith and D. Elliott (2015). Alternative Barging Strategies to Improve Survival of Salmonids Transported from Lower Granite Dam: Final Report from the 2006-2008 Spring/Summer Chinook Salmon and Steelhead Juvenile Migrations, Report by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, Washington, and the Western Fisheries Research Center, U.S. Geological Survey, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

In 2011, the final year class of adult salmon Oncorhynchus spp. returned from smolt groups released for a multi-year study to evaluate an alternate release site for transported fish. Smolts were collected and tagged at Lower Granite Dam, transported, and released at the alternate

site near Astoria, Oregon (river kilometer 10) or at the traditional release site near Skamania Landing (rkm 225) just downstream of Bonneville Dam.

Study fish were juvenile steelhead O. mykiss and yearling spring/summer Chinook salmon O. tshawytscha, and our evaluation was based on comparisons of smolt-to-adult return rates (SARs) between replicate paired groups. Our hypothesis was that moving the traditional barge-release site 215 km downstream could increase adult returns by decreasing smolt mortality due to predation by piscivorous fish and birds. Paired groups were released weekly over 6 weeks during the migration seasons of 2006, 2007, and 2008. The last adult steelhead from these releases returned in May 2011 (2-ocean), and the last adult Chinook salmon in August 2011 (3-ocean).

In each study year, we collected river-run yearling spring/summer Chinook salmon and steelhead at the Lower Granite Dam juvenile fish facility. All study fish were tagged with passive integrated transponder (PIT) tags. Both hatchery and wild fish were collected on six consecutive Sundays from mid-April to late May. In 2007, only five paired study groups were released because the first release of the migration season was blocked by a legal challenge from regional agencies and tribes.

Each week, paired groups were loaded to barges, with one group transported to Astoria and a second to Skamania. Between 2006 and 2008, total annual release numbers ranged 28,766-47,791 for yearling Chinook and 53,939-71,585 for steelhead.

Avian predation—To reduce predation from colonies of Caspian terns Hydroprogne caspia and double-crested cormorants Phalacrocorax auritas on East Sand Island, all Astoria groups were released after dark on an outgoing tide. After the nesting season, vacant bird colonies were scanned to detect PIT tags from fish released for this study and others. We used these data to estimate minimum predation rates.

For Chinook salmon, estimates of minimum predation ranged 3.1-7.1% for releases at Skamania Landing and 0.8-1.1% for releases at Astoria (Table E1). For steelhead, we found larger differences in estimated predation between study groups, with estimates ranging 16.7-26.1% for Skamania vs. 2.2-4.9% for Astoria releases (Table E1).

For Astoria and Skamania release groups, we converted estimates of mortality from predation (PA and PS) to express relative survival. For each paired group, we subtracted the rate of predation from 1 to obtain rates of predator avoidance (1 − PA) and (1 − PS). We then estimated relative survival of the two groups by calculating predator avoidance ratios: (1 − PA)/(1 − PS).

These results show that releasing fish farther downstream, at night, and on an outgoing tide had the predicted effect of substantially reducing avian predation, particularly for steelhead, the species most vulnerable to avian predation. However, these survival benefits were largely offset by impaired homing during the adult migration.

Effect of fish pathogens—To further investigate causes of mortality, we evaluated pathogen loads in individual study fish to determine whether levels of infection affected vulnerability to avian predators. We collected nearly 1,800 non-lethal gill clip samples over each season and evaluated them for Renibacterium salmoninarum and Nucleospora salmonis. We found no evidence from any study year that infection with one or both pathogens influenced rates of avian predation. However, infection levels of R. salmoninarum were low in the majority of test fish during all 3 years, and therefore statistical power to detect an effect was low.

Smolt-to-adult returns (SARs)—For pooled groups of hatchery and wild steelhead from releases over all years and at both locations, the number of adults returning to Lower Granite Dam ranged 1,015-1,787 (Table E2). Pooled hatchery and wild steelhead from all groups had annual SARs ranging 1.74-2.82% for releases at Astoria (TA) and 1.32-2.25% for releases at Skamania Landing (TS; Table E2).

We tested the null hypothesis that SARs were equal for Astoria and Skamania release groups, against the two-sided alternative hypothesis that SARs were not equal. For these tests, we first calculated the SAR ratio (TA/TS) for each paired release. We then calculated the geometric mean and corresponding variance of each estimate by year.

To compare SARs between paired study groups, we conducted a Student's t-test between mean SARs transformed on the logarithmic scale. We repeated these tests for all paired releases across the 3 study years with $\alpha = 0.05$.

For paired releases of wild steelhead, mean TA/TS across the 3 years was 1.04, and mean SARs did not differ significantly between release locations within or across years.

For hatchery steelhead, we found a significant difference in 2006, with Astoria releases having a 22% higher mean SAR ($P = 0.02$). Across the 3 years, mean SAR for hatchery steelhead released at Astoria was 14% higher than for those released at Skamania, but the difference was not significant at the 0.05 level ($P = 0.14$). Relative SARs for the two release locations did not show temporal trends within years (seasons).

For pooled groups of hatchery and wild Chinook salmon from releases over all years and at both release locations, the number of adults returning to Lower Granite Dam ranged 190-739 (Table E2). Pooled hatchery and wild Chinook from all groups had annual SARs ranging 0.33-1.55% for releases at Astoria (TA) and 0.57-1.54% for releases at Skamania Landing (TS; Table E2).

For wild Chinook salmon, relative SARs varied widely across years, with mean TA/TS ratios ranging 0.48-1.80. Because adult return numbers were low, no differences between release groups were significant. For wild Chinook, mean SARs were similar between release locations over the 3 years, with a mean TA/TS ratio of 1.04 ($P = 0.92$).

For hatchery Chinook salmon, mean SAR ratios were less than 1.0 within all 3 years, meaning Astoria groups had lower survival than Skamania groups. However, none of the within-year differences was significant (P values were 0.41, 0.51, and 0.81). Across the 3 years, Astoria SARs averaged only 76% of Skamania SARs (P = 0.25).

Adult conversion rates—For Chinook salmon, average adult conversion rates from Bonneville to Lower Granite Dam were 10% lower for groups released at Astoria than for those released at Skamania over the 3 study years (Table E3). However, the difference was not statistically significant (P = 0.12). In contrast, for steelhead, the difference in average conversion rates between release sites was greater and was highly significant (P < 0.01), both across years and within each study year. The magnitude of the difference was consistent as well: the rate at which adult steelhead successfully completed migration from Bonneville to Lower Granite Dam was 20-22% lower for fish released at Astoria than for those released at Skamania Landing. This lower rate was a result of higher rates of straying and wandering, which likely increased exposure to fisheries, both sport and commercial.

Adult straying rates—To evaluate rates of straying, we examined numbers of returning adults detected at sites other than Bonneville, McNary, Ice Harbor, and Lower Granite Dams. For fish identified as strays in this way, we also distinguished between temporary and permanent straying. Fish that were eventually detected at Lower Granite Dam were considered temporary strays, or "wanderers." Those that were never detected at Lower Granite Dam were permanent strays, or "lost."

Very few adult spring/summer Chinook salmon from this study strayed (only 37 of 1,660 hatchery and wild adults from both release sites). Straying rates for pooled hatchery and wild adult Chinook from all study years were 2.6% for Astoria releases and 2.0% for Skamania releases (P = 0.46). Only one of the 37 Chinook salmon strays was later detected at Lower Granite Dam; all others were lost.

Rates of straying were higher for steelhead than for Chinook salmon and higher for fish released at Astoria than those released at Skamania. Across the 3 study years, straying was 28% greater for wild steelhead released at Astoria (P = 0.16) and 47% greater for hatchery steelhead released at Astoria (P = 0.003).

Wild steelhead released at Astoria had an average straying rate to the John Day and Deschutes Rivers that was 52% higher than that of their cohorts released at Skamania (P = 0.06). To these same rivers, hatchery steelhead released at Astoria had an average straying rate 54% higher than their cohorts released at Skamania (P = 0.003).

Release from Astoria was also associated with an increased probability of permanent straying. Averaged across the 3 study years, wild steelhead released at Astoria were 64% more likely to become permanent strays than their counterparts released at Skamania (P = 0.03). For hatchery steelhead, the increase in permanent straying for releases from Astoria averaged 51% (P < 0.001).

Conclusions—We found no evidence of a consistent difference in SARs for fish released at the two barge-release locations. Data were not sufficient to evaluate the effects of fish pathogens on avian predation. There was clear evidence that fish of both species released at Astoria were less vulnerable to avian predators than those released at the customary site at Skamania Landing. Unfortunately, this survival benefit did not translate to higher SARs, as it was offset by higher rates of straying by fish released from Astoria. This was likely a result of greater impairment to homing ability for fish released at Astoria.

Marsh, T. M., S. G. Smith and B. P. Sandford (*In progress*). A Study to Evaluate Latent Mortality Associated with Passage Through Snake River Dams, 2005-2011.

Martins, E. G., S. G. Hinch, S. J. Cooke and D. A. Patterson (2012). "Climate effects on growth, phenology, and survival of sockeye salmon (Oncorhynchus nerka): a synthesis of the current state of knowledge and future research directions." Reviews in Fish Biology and Fisheries 22(4): 887-914.

Sockeye salmon (Oncorhynchus nerka) is one of the most iconic and valued species of Pacific salmon. Various studies have examined the potential effects of future climate change on sockeye salmon, but there is currently no synthesis of the documented effects of climate on this species. In this paper, we present a synthesis of 80 peer-reviewed publications in the English language evaluating the effects of climate on sockeye salmon growth, phenology, and survival. The great majority of studies examined have been conducted with stocks from North America (90 % of studies). Survival (55 %) has been the most frequently studied aspect of the sockeye salmon life history in relation to climate, followed by growth (45 %) and phenology (30 %), with temperature (83.4 %) being the climate-related variable most frequently examined in such studies. Across life stages, the effects of climate-related variables have been most frequently studied on fry (36.3 %) and least studied on spawners (7.5 %). Our synthesis revealed that associations between temperature and growth, phenology, or survival have been uncovered for all the life stages of sockeye salmon, whereas relationships with other climate-related variables have been sparse. There is substantial evidence that sockeye salmon are influenced by thermal conditions experienced at regional, rather than ocean- or continental-wide scales, and that responses to temperature vary among and within stocks. The mechanisms by which climate affect sockeye salmon during the early stages in freshwater and while at sea are still poorly understood and warrant future research. More research on the effects of non-temperature, climate-related variables (e.g. stream flow, ocean pH), inter-generational and carryover effects of climate, interaction between climate and non-climate stressors, and adaptation to climate change are also needed. Such information will be critical to advance our understanding of how sockeye salmon stocks will fare with future climate change.

McCann, J., B. Chockley, E. Cooper, T. Garrison, H. Schaller, S. Haeseker, R. Lessard, C. Petrosky, T. Copeland, E. Tinus, E. Van Dyke, R. Ehlke and M. DeHart (2016). Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye, Prepared by the Fish Passage Center, the U.S. Fish and Wildlife Service, the Columbia River Inter-Tribal Fish Commission, Idaho Department of Fish and Game, Oregon Department of Fish and Wildlife, and Washington Department of Fish and Wildlife.

The 2016 Comparative Survival Study Annual Report continues to update the historical time series life-cycle monitoring data and includes enhancements to analyses based upon review comments and recommendations from the fishery management agencies, tribes, and the Northwest Power and Conservation Council's Independent Scientific Advisory Board (ISAB). This report includes complete return data for wild and hatchery Chinook salmon and steelhead (all Snake River returns are to Lower Granite Dam). For wild and hatchery spring/summer Chinook, 3-salt returns from smolt migration year 2013, and 2-salt returns from smolt migration year 2014 are included in this Annual Report. For fall Chinook, 3-salt returns from smolt migration year 2012, and 2-salt returns from smolt migration year 2013 are included in this Annual Report. For wild and hatchery steelhead, 2-salt returns from migration year 2013 are included in this Annual Report. Finally, for Snake River hatchery sockeye, 2-salt returns from smolt migration year 2014 are included in this Annual Report.

Mark groups in 2016 were consistent with groups utilized in 2015. In addition to overall smolt-to-adult return rates (SARs) for aggregate Snake River wild steelhead and Chinook salmon, the CSS has continued to pursue the development of SAR and life cycle metrics at the Major Population Group (MPG) level when sample size was adequate. These MPG-level SARs are provided for both Lower Granite to Lower Granite and Lower Granite to Bonneville, with and without jacks (1-salt) for Chinook salmon. In addition, Chapter 4 now includes estimates of overall SARs (RRE-to-BOA and MCN-to-BOA) for Okanogan River sockeye and wild summer Chinook from above Wells Dam. The CSS continues to strive to improve life cycle monitoring metrics for wild populations of salmon and steelhead, and continues to work with fishery managers to improve tagging coverage of wild populations from tributary traps.

The long-term CSS objective of linking stages of the salmon life cycle, the factors influencing survival at each life stage, and understanding how each factor affects survival at later life stages, continues. The retrospective analyses of past years provided the foundation for the development and inclusion of prospective analyses in the 2016 report. The analyses presented in Chapter 2 utilize the life cycle model to predict the long-term effects of four experimental spill alternatives on population recovery. The experimental spill levels are defined in terms of the limits of total dissolved gas (TDG) produced at each project. The prospective analyses considered the relative benefit in adult returns and smolt-to-adult returns of four operational scenarios, the Biological Opinion (BiOp), 115%/120%, 120%, and 125% spill levels under high, average and low flow conditions. The analyses do not predict absolute SARs but rather examine the relative change among the four scenarios with increasing spill for fish passage. This analysis predicts that higher SARs and long-term abundance increases can be achieved by increasing spill levels, and that the benefits of spill are sensitive to flows. The immediate benefits of

increased flow levels, combined with the long-term benefits of habitat actions predict potential recovery of populations to up to three fold increases in abundance above levels predicted by BiOp level spill.

The time series analyses of juvenile fish passage characteristics, fish travel time, instantaneous mortality, and reach survival probability relative to environmental variables was updated to include the 2015 outmigration. Multiple regression analyses, mixed effect model structures and multimodel inference methods were utilized to evaluate juvenile fish passage characteristics relative to environmental variables. This time series of data incorporates within and across-year variation and demonstrates a high degree of contrast in reach survival probability over this timeframe. Overall, conclusions from the 2016 analyses are consistent with past years findings, that across river reaches and species, water travel time, spill, and Julian date are important variables in predicting reach survival probability. In addition, the number of dams with surface spillway structures was somewhat important for steelhead and subyearling Chinook but not important for spring/summer Chinook. It is important to note that although water transit times in 2015 were similar to 2001, a record low flow year, estimates of mean fish travel time, instantaneous mortality and reach survival probabilities were not dramatically different than recent years and showed substantial improvements over the fish survival and travel time estimates from 2001. The primary difference in the outmigration conditions between 2001 and 2015 was the provision of spill for fish passage. In addition, the instantaneous mortality rates tended to be lower under conditions of higher spill levels.

Overall SARs are the net effect of SARs for the different routes of in-river passage and juvenile transportation. Overall SAR and route of passage SARs are consistent with past year's findings. None of the passage routes have resulted in SARs that met the NPCC SAR objectives for Snake River wild spring/summer Chinook and steelhead. The relative effectiveness of transportation has been observed to decline as in-river conditions and survival rates improve. PIT-tag SARs for Middle Columbia wild spring Chinook and wild steelhead generally fell within the 2%–6% range of the NPCC SAR objectives. Incorporating the 2015 adult returns in this Annual Report shows that the trends seen in all but two past years of CSS monitoring continue. The overall SARs for Upper Columbia and Snake River populations of salmon and steelhead are not meeting the 2%–6% regional goal, while middle Columbia populations are meeting the regional SAR goals in most years.

In this report, the analyses of SARs relative to estimates of population productivity which began in the 2015 CSS Annual Report has been expanded and is presented in Chapter 5. This represents the continuation of a longer-term effort, which will incorporate effects of density dependence on observed productivity to evaluate population responses relative to SAR rates. Analyses in this Chapter support objectives of the Columbia River Basin Fish and Wildlife Program (NPCC 2014), encouraging a regional review of the NPCC SAR objectives relative the survival of populations needed to achieve salmon and steelhead recovery and harvest goals. New to the 2016 Annual Report are the comparisons of Snake River SARs and steelhead population productivity for Fish Creek (Clearwater Major Population Group (MPG)) and Rapid River (Salmon MPG), which complement those for Snake River spring/summer Chinook.

Analyses in this report include spring/summer chinook population data from the Middle Fork Salmon River MPG that is primarily in wilderness and has little potential for improvement to tributary habitat or survival during the egg-to-smolt life stage. Major population declines of Snake River wild spring/summer Chinook were associated with SARs less than 1% and increased life-cycle productivity occurred when SARs exceeded 2%. Snake River wild steelhead population declines were associated with brood year SARs less than 1%, and increased life-cycle productivity occurred in the years that brood year SARs exceeded 2%. Pre-harvest SARs in the range of 4% to 6% are associated with historical levels of productivity for Snake River wild spring/summer Chinook. Although there are fewer SAR estimates for John Day River spring Chinook, historical levels of productivity appear to be achieved with pre-harvest SARs in the range of 4%-7%

Results of analyses of smolt to adult return, TIR, and delayed mortality for fall Chinook were consistent with past year's analyses. These results indicate that the smolt transportation program for juvenile fall Chinook salmon does not adequately mitigate for the adverse effects of development and operation of the Snake and Columbia rivers hydropower projects on fall Chinook juvenile survival and adult returns. Consistent with past years analyses, overall SARs of fall Chinook salmon were low compared to SARs for spring/summer Chinook salmon and steelhead. As in past years, the need to increase marking of fall chinook in order to address the entire passage distribution and population is needed. The CSS continues to work with the Nez Perce Tribe to improve fall Chinook marking coverage.

This report presents an update of the bypass effects analyses presented in the 2010 CSS Annual Report. This analysis examined the effect of juvenile salmon and steelhead powerhouse passage encounters on smolt to adult return rates. The juvenile downstream migration history of juvenile salmon and steelhead detected at Bonneville Dam was analyzed relative to their adult return to Bonneville Dam. This analysis showed that juvenile salmon and steelhead that had powerhouse bypass collection system encounters had lower smolt to adult return rates. At all dams, logit SARs were 12-13% lower at each dam for Chinook smolts encountering juvenile bypass system compared to those fish that avoided the bypass system. These 12-13% differences imply that the odds of survival from BON to BOA decreased by 11-12% for each of the juvenile bypass systems between John Day and Lower Granite Dam. For steelhead, logit SARs were 9-13% lower at each dam, implying 8% to 12% reductions in the odds of survival from BON to BOA for each of the juvenile bypass systems between John Day and Lower Granite dams.

The Draft CSS Annual Report for 2016 included an update of previous analyses of age at maturity. The ISAB provided extensive comments and recommendations on the draft chapter which will require some time to complete. In order to meet reporting deadlines, Chapter 8 Age at Maturity is not included in the final CSS Annual Report for 2016. AN addendum to the report, addressing the ISAB comments and recommendations will be completed in January 2017 and posted with the Final Annual Report.

McCann, J., B. Chockley, E. Cooper, B. Hsu, H. Schaller, S. Haeseker, R. Lessard, C. Petrosky, E. Tinus, E. Van Dyke, A. Storch, D. Rawding and M. DeHart (2017). Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye DRAFT, Prepared by the Fish Passage Center, the U.S. Fish and Wildlife Service, the Columbia River Inter-Tribal Fish Commission, Idaho Department of Fish and Game, Oregon Department of Fish and Wildlife, and Washington Department of Fish and Wildlife.

McMichael, G. A., A. C. Hanson, R. A. Harnish and D. M. Trott (2013). "Juvenile salmonid migratory behavior at the mouth of the Columbia River and within the plume." Animal Biotelemetry 2013: 1-14.

Background: Early ocean experience is a critical time period that affects juvenile salmonid survival. Understanding juvenile salmonid behavior in nearshore marine environments and how oceanic conditions (such as dynamic river plume habitats) affect salmonid migration will contribute to salmonid survival studies and conservation and management efforts. Relatively few studies have been conducted on juvenile salmonid behavior as they migrate out the mouth of the Columbia River and some studies suggest that juvenile salmonids typically migrate north immediately upon entry into the ocean from the Columbia River. We present findings from a study that used acoustic telemetry to determine the migratory direction, residence time, and travel rate of juvenile salmonids as they left the Columbia River and entered the marine environment.

Results: A total of 8,159 acoustic-tagged salmonid smolts were detected at the mouth of the Columbia River. Of the fish detected at the mouth, an estimated 16% of yearling Chinook salmon, 10% of steelhead, and 26% of subyearling Chinook salmon were detected on a sparse array deployed outside the mouth of the Columbia River in the vicinity of the plume. The travel rate of Chinook salmon smolts decreased as they left the river and entered the marine environment, whereas the travel rate of steelhead increased. Chinook salmon also spent more time in the transitional area between the river mouth and plume compared to steelhead. In early spring, yearling Chinook salmon and steelhead were predominately detected on the plume array towards the edge of the shelf and to the south. Later in the season, yearling Chinook salmon and steelhead smolts were more often detected north of the river mouth. Subyearling Chinook salmon were most often detected on the portion of the plume array to the north of the river mouth.

Conclusions: Our study showed that salmonid smolt migration out of the river into the nearshore marine environment appears to vary across species, season, and age class, and may be influenced by local environmental conditions. Direction of movement upon ocean entry cannot be assumed and is likely influenced by oceanic conditions such as wind and currents. We also present, for the first time, the utility of the Juvenile Salmon Acoustic Telemetry System (JSATS) to monitor the behavior of juvenile fish in the marine environment. Our results will help

inform future studies using telemetry and hydroacoustics as well as trawl surveys to assess nearshore ocean juvenile salmonid distribution, behavior, and survival.

McMichael, G. A., J. R. Skalski and K. A. Deters (2011). "Survival of Juvenile Chinook Salmon during Barge Transport." North American Journal of Fisheries Management 31(6): 1187-1196.

To estimate survival during barge transport over a distance of 470 km from Lower Granite Dam on the Snake River to a release area downstream of Bonneville Dam (the lowermost dam on the ColumbiaRiver),we used a novel adaptation of a release–recapture model with 1,494 acoustic-tagged yearling Chinook salmon Oncorhynchus tshawytscha smolts. Smolts were collected at Lower Granite Dam, received surgically implanted acoustic transmitters, and were divided into three groups: (1) a barge group (RB) that was released into the raceway with fish that were later loaded into transportation barges (general barge population); (2) a control group (RA) that was held in a net-pen suspended within the barge hold containing the general barge population until 5–6 h prior to barge evacuation (i.e., fish release into the river), at which time they were confirmed to be alive and then released into the barge hold; and (3) a dead group (RD) that was euthanized and then released into the barge hold 5–6 h prior to barge evacuation in order to validate a model assumption. Six replicates of each group were loaded onto fish transport barges that departed from Lower Granite Dam between 29 April and 13 May 2010. Detections on acoustic receiver arrays between 70 and 220 km downstream of the barge evacuation site served as the basis for estimation of survival within the barge. The ratio of RB : RA survival from release to river kilometer 153 provided the estimate of within-barge survival. The replicate survival estimates ranged from 0.9503 (SE = 0.0253) to 1.0003 (SE = 0.0155). The weighted average of the replicate estimates of survival during the barge transportation experience was 0.9833 (SE = 0.0062). This study provides the first active telemetry documentation that the assumed survival rate of 98% during the barge transportation experience appears to be justified for yearling Chinook salmon smolts.

McNatt, R. A., D. L. Bottom and S. A. Hinton (2016). "Residency and Movement of Juvenile Chinook Salmon at Multiple Spatial Scales in a Tidal Marsh of the Columbia River Estuary." Transactions of the American Fisheries Society 145(4): 774-785.

Use of the Columbia River estuary by juvenile Pacific salmon Oncorhynchus spp. is garnering more attention as managers look to improve salmon survival through estuary restoration. Studies have shown that juvenile salmon are abundant in shallow-water habitats within the Columbia River estuary, but information on how juveniles exploit specific estuarine habitats is lacking. We used a combination of physical marks and PIT tag technology to record residence time, movement, and growth of juvenile Chinook Salmon O. tshawytscha, particularly subyearlings, within an emergent marsh of the Columbia River estuary during 2005, 2006, and 2008. We documented marsh-scale residency and movement within the marsh complex and channel-scale residency and movement within two small secondary channels. Many juvenile Chinook Salmon remained in the marsh for 2-4 weeks and increased in FL by 10-20 mm, with an

average growth rate of 0.53 mm/ d. Chinook Salmon entered secondary channels most frequently in late afternoon and occasionally did so against the tide. Our results indicate that subyearling Chinook Salmon take advantage of shallow estuarine habitat in the Columbia River to a greater extent than previously documented.

Mesa, M. G. and J. J. Warren (1997). "Predator avoidance ability of juvenile chinook salmon (*Oncorhynchus tshawytscha*) subjected to sublethal exposures of gas-supersaturated water." Canadian Journal of Fisheries and Aquatic Sciences 54(4): 757-764.

To assess the effects of gas bubble trauma (GBT) on the predator avoidance ability of juvenile chinook salmon (Oncorhynchus tshawytscha), we created groups of fish that differed in prevalence and severity of gas emboli in their lateral lines, fins, and gills by exposing them to 112% total dissolved gas (TDG) for 13 days, 120% TDG for 8 h, or 130% TDG for 3.5 h. We subjected exposed and unexposed control fish simultaneously to predation by northern squawfish (Ptychocheilus oregonensis) in water of normal gas saturation in 6, 18, and 10 tests using prey exposed to 112, 120, and 130% TDG, respectively. Only fish exposed to 130% TDG showed a significant increase in vulnerability to predation. The signs of GBT exhibited by fish sampled just prior to predator exposure were generally more severe in fish exposed to 130% TDG, which had the most extensive occlusion of the lateral line and gill filaments with gas emboli. Fish exposed to 112% TDG had the most severe signs of GBT in the fins. Our results suggest that fish showing GBT signs similar to those of our fish exposed to 130% TDG, regardless of their precise exposure history, may be more vulnerable to predation.

Midwood, J. D., M. H. Larsen, M. Boel, K. Aarestrup and S. J. Cooke (2015). "An Experimental Field Evaluation of Winter Carryover Effects in Semi-Anadromous Brown Trout (Salmo trutta)." Journal of Experimental Zoology Part a-Ecological Genetics and Physiology 323(9): 645-654.

For semi-anadromous brown trout, the decision whether or not to smoltify and migrate to the sea is believed to be made at the end of the preceding summer in response to both local environmental conditions and individual physiological status. Stressors experienced during the fall may therefore influence their propensity to migrate as well as carry over into the winter resulting in mortality when fish face challenging environmental conditions. To evaluate this possibility, we artificially elevated cortisol levels in juvenile trout (via intracoelomic injection of cortisol in the fall) and used passive integrated transponder tags to compare their overwinter and spring survival, growth, and migration success relative to a control group. Results suggest that overwinter mortality is high for individuals in this population regardless of treatment. However, survival rates were 2.5 times lower for cortisol-treated fish and they experienced significantly greater loss in mass. In addition, less than half as many cortisol-treated individuals made it downstream to a stationary antenna over the winter and also during the spring migration compared to the control treatment. These results suggest that a fall stressor can reduce overwinter survival of juvenile brown trout, negatively impact growth of individuals that

survive, and ultimately result in a reduction in the number of migratory trout. Carryover effects such as those documented here reveal the cryptic manner in which natural and anthropogenic stressors can influence fish populations.

Miller, J. A., D. J. Teel, A. Baptista and C. A. Morgan (2013). "Disentangling bottom-up and top-down effects on survival during early ocean residence in a population of Chinook salmon (Oncorhynchus tshawytscha)." Canadian Journal of Fisheries and Aquatic Sciences 70(4): 617-629.

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

Miller, J. A., D. J. Teel, W. T. Peterson and A. M. Baptista (2014). "Assessing the Relative Importance of Local and Regional Processes on the Survival of a Threatened Salmon Population." Plos One 9(6).

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.

Miller, K. M., A. Teffer, S. Tucker, S. R. Li, A. D. Schulze, M. Trudel, F. Juanes, A. Tabata, K. H. Kaukinen, N. G. Ginther, T. J. Ming, S. J. Cooke, J. M. Hipfner, D. A. Patterson and S. G. Hinch (2014). "Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines." Evolutionary Applications 7(7): 812-855.

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.

Morita, K., T. Tamate, M. Kuroki and T. Nagasawa (2014). "Temperature-dependent variation in alternative migratory tactics and its implications for fitness and population dynamics in a salmonid fish." Journal of Animal Ecology 83(6): 1268-1278.

1. Temperature-driven life-history modifications by adaptation occur in ectotherms, and therefore, life-history modifications by adaptation need to be taken into consideration when predicting population responses to the climate change.

2. Partial migration is a common form of life-history diversity in which a population contains both migratory and resident behaviours. Salmonid fish exhibit a wide range of life-history diversity and, in particular, partial migration. We evaluated the effect of temperature-driven life-history modifications on population dynamics in partially migratory masu salmon (Oncorhynchus masou) by field observations and theoretical models.
3. Field observations revealed that spatial patterns of alternative migratory tactics were associated with temperature gradients. The occurrence of resident males increased, whereas the proportion of migrant males and the proportion of delayed migrants including both sexes decreased with increasing temperature and, thereby, with improved early growth conditions.
4. The expected fitness for each migratory tactic was computed in a life-history model with early growth conditions as a function. Individual fitness was maximized by adopting resident tactics under favourable early growth conditions, early migrant tactics under intermediate early growth conditions and delayed migrant tactics under unfavourable early growth conditions. The results suggest that individuals exhibited a status-dependent conditional strategy, that is, the adoption of alternative migratory tactics is influenced by the status of individuals to make the best of a situation.
5. A simulation model suggests that increased residency by males to increased temperature leads to a substantial decrease in the number of migrants. Moreover, the decrease in the number of delayed (older) migrants with increasing temperature magnified fluctuations in abundance. Our findings indicate the importance of temperature-driven life-history modifications for predicting dynamics of natural populations under climate warming.

Morris, M. S., A. J. Borsky, P. J. Bentley and L. N. Webb (2017). Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2016.

In 2016, we continued a multi-year study in the Columbia River estuary to detect juvenile Pacific salmon Oncorhynchus spp. marked with passive integrated transponder (PIT) tags. Fish were detected using a surface pair trawl with a matrix of rectangular detection antennas fitted into the cod-end. The matrix was configured with three parallel antennas in front and three in the rear for a total of six individual antennas.

This configuration relied on trawl net wings to guide fish toward the cod end of the trawl, where they would come within detection range of the antennas. Entrained fish were able to exit the trawl safely, without capture or handling. We deployed the trawl in the Columbia River navigation channel between river kilometer (rkm) 66 and 84 and sampled for a total of 829 h.

During this period, we detected 12,165 PIT-tagged juvenile salmon, of which 16% were wild, 4% were unknown, and 80% were of hatchery origin. Species composition of detected fish was 43% spring/summer Chinook, 3% fall Chinook, 43% steelhead, 2% sockeye, 6% coho, less than 1% cutthroat trout, and 3% unknown.

Our sampling schedule began with a single daytime shift operating 3-5 d/week. We began sampling on 24 March to coincide with arrival in the estuary of spring-migrating juvenile salmon

and steelhead. As numbers of juvenile migrants increased, we intensified the sample effort with two daily shifts: one operating 7 d/week during daylight and a second operating 6 d/week during darkness. Intensive sampling continued from 1 May through 9 June, when we returned to a single daytime shift. We ended sampling on 5 July after most spring migrants had passed.

During the intensive sample period, average hourly detections of yearling Chinook were significantly higher in darkness than daylight hours (11 vs. 5 fish/h; $P < 0.001$). Conversely, average hourly detections of steelhead were higher during daylight than darkness hours (11 vs. 4 fish/h; $P < 0.001$). During intensive sampling, the trawl was deployed for an average of 15 h/d, the same as in 2015. Also during the intensive sampling period, we detected 2.0% of the yearling Chinook salmon and 3.4% of the steelhead detected at Bonneville Dam. These proportions were lower than those in 2015, when we detected 3.3% of the yearling Chinook and 4.6% of the steelhead detected at Bonneville Dam.

In 2016, we continued development of a flexible antenna array that could be towed behind two small vessels to detect juvenile salmon without a net. Objectives of this development effort are to simplify logistics, increase sample efficiency, and reduce the cost of sampling PIT-tagged fish in the estuary.

For these tests, the flexible antenna array was configured with six rectangular antennas each housed in 1.9-cm diameter flexible PVC hose. The flexible antenna system can utilize up to 12 antennas, but six were used because of limited resources. Sampling cruises to test the flexible antenna array were conducted simultaneously with deployments of the matrix trawl system. We compared detection efficiency between the two systems to evaluate the feasibility of transitioning entirely to the flexible system in future years.

The flexible antenna system detected a total of 549 fish across 21 d of operation in 2016 (78.2 h total). Of these total detections, 14% were Chinook, 79% steelhead, 4% coho, less than 1% sockeye, and 3% unknown species. We sampled the flexible and matrix systems simultaneously on 10 d. Daily ratios of mean detection rate (fish/h) between the two systems were calculated for each concurrent deployment. Over the 10 d of simultaneous deployment, the overall mean ratio of detection rates for the flexible vs. the matrix trawl systems was 60%.

Juvenile steelhead were detected in disproportionately high numbers in the flexible antenna system, comprising 78% of total detections—more than double the proportion of steelhead detected in the matrix trawl (35%). This discrepancy was likely due to the shallow sample depth of the flexible antenna system compared to the matrix trawl system (3.0 vs. 5.0 m). We concluded that the relatively shallow sample depth of the flexible antenna system likely allowed Chinook salmon to pass below the array without being detected.

After the spring migration season, we tested multiple orientations and configurations of a six-antenna flexible array with the objective of increasing sample depth. Testing confirmed the feasibility of re-configuring antennas to obtain a sample depth of 6.0 m without sacrificing

electronic performance. We plan to use the new configuration in 2017 sampling and expect that it will increase detections of Chinook salmon.

As in previous study years, we examined PIT-tag detection data collected in 2016 to evaluate potential factors related to detection probability and to compare passage performance metrics among fish groups by species, rearing type (hatchery or wild), and migration history (transported vs. inriver).

For yearling Chinook salmon, we found a significant effect of migration history and arrival date on detection rate ($P = 0.013$ and $P < 0.001$, respectively), but no significant interaction between date and migration history ($P = 0.957$). We detected inriver migrants at a higher rate than transported fish, with detection rates for both groups increasing through the season.

Similarly, for steelhead, there were significant effects of migration history and date-squared on detection rate ($P = 0.029$ and $P = 0.021$, respectively), but no interaction between date and migration rate ($P = 0.429$). As with Chinook salmon, we detected inriver migrant steelhead at a higher rate than transported steelhead. Detection rates for both steelhead groups increased through the season but began to decrease in early June.

Over the years, we have observed an inverse relationship between river flow and detection rates in the trawl. Mean flow volumes at Bonneville Dam were 23% higher during the two-shift sample period of 2016 than during the two-shift period of 2015 (6,953 vs. 5,333 m3/s). However, mean flows during this period in 2016 were still 18% lower than the 14-year average for 2000-2014 (8,296 m3/s, excluding 2001). Mean daily river flows were above average for the first two weeks of the intensive sampling season (1-14 May 2016). After mid-May, flows decreased to drought-like conditions and remained low through the end of the season.

From the total combined species detected with the trawl system in 2016, 17% had been transported, while 20% had been detected passing Bonneville Dam. The remaining 63% had neither been transported nor detected at Bonneville Dam, although at least 94% of total detections had originated upstream from Bonneville. Mean migration rate to the estuary (rkm 75) was significantly faster for yearling Chinook salmon detected at Bonneville Dam than for those released from barges just below the dam (82 vs. 73 km/d, $P < 0.001$). Similar differences were noted for steelhead, with travel rates of 92 km/d for inriver migrants vs. 86 km/d for transported fish ($P < 0.001$).

This trend was repeated in observations of mean migration rate between inriver migrant and transported sockeye (95 vs. 78 km/d) and subyearling Chinook salmon (72 vs. 58 km/d). However, for both species, detection numbers were insufficient for meaningful statistical analysis. Between Bonneville Dam and the sample reach overall, migration rates for both inriver and transported fish were faster in 2016 than in 2015 across all species. This was likely a function of high flow volumes during the first half of May.

Trawl detections of subyearling Chinook salmon have decreased in recent years, commensurate with reduced tagging effort for these fish. In 2016, we detected 278 subyearling fall Chinook, with the majority of detections occurring from mid-May through the end of the sampling season. Of these 278 fish, 214 originated from the Snake River basin (63 inriver migrants and 151 transported). The remaining 64 were inriver migrants from Columbia River stocks, with 12 released above McNary Dam, 40 released between McNary and Bonneville Dam and 12 released below Bonneville Dam. We did not detect holdover subyearlings in 2016 (holdovers overwinter in freshwater and resume downstream migration in spring).

Of the 234 sockeye salmon detected in the trawl, 47% had been released into the Snake River, 53% into the upper Columbia River above McNary Dam, and less than 1% into the middle Columbia River between McNary and Bonneville Dam. Of sockeye detected in 2016, 35% were hatchery, 12% were wild, and 53% were of unknown origin. Migration history of detected sockeye was 79% inriver migrant and 21% transported.

As in previous years, detection data from the trawl in 2016 were essential for calculating annual survival probabilities to the tailrace of Bonneville Dam, the last dam encountered by migrating juvenile salmonids. Operation of a detection system in the estuary has provided data for estimates of survival to Bonneville Dam since 1998. These estimates are critical to research and management programs for endangered salmonids in the Snake and Columbia River basin and in other basins of the Pacific Northwest.

Trawl detections also contribute data for estimates of travel time, migration rate, and other performance metrics between juvenile fish groups of differing migration history, origin, rearing type, and species. Annual releases of PIT-tagged fish in the Columbia River basin have been near 2 million for the past several years. Detections of these fish as they pass through the estuary continue to increase our understanding of behavior and survival during the critical smolt transition period.

Morris, M. S., R. J. Magie, J. P. Bender, B. P. Sandford and R. D. Ledgerwood (2014). Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary Using a Pair-Trawl, 2013, Report of research by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington, for the Division of Fish and Wildlife, Bonneville Power Administration, U.S. Department of Energy, Portland, Oregon.

In 2013, we continued a multi-year study to detect juvenile anadromous salmonids Oncorhynchus spp. implanted with passive integrated transponder (PIT) tags using a surface pair-trawl fitted with a PIT-tag detection system. We sampled along the navigation channel in the upper Columbia River estuary between river kilometers (rkm) 61 and 83. We deployed the trawl for a total of 889 h between 25 March and 25 July and detected a total of 22,879 PIT-tagged juvenile salmonids. These detections were comprised of 19% wild and 79% hatchery-reared fish (2% were of unknown origin). The species composition of all PIT-tagged fish

detected in the trawl during 2013 was 45% spring/summer Chinook salmon, 5% fall Chinook salmon, 41% steelhead, 4% sockeye, 3% coho, less than 1% cutthroat trout, and 1% unknown species.

In 2013, sampling was conducted with our matrix-antenna PIT-tag detection system used since 2008. This system was composed of a 122-m-long surface pair-trawl that funneled fish through a 2.6-m wide by 3.0-m tall fish-passage opening. The fish-passage structure was constructed with separate front and rear components, with each component consisting of 3 parallel antenna coils. The trawl sampled from the surface to a depth of about 5.0 m and was towed into the current while we maintained a distance of 91.5 m between the forward wings of the trawl.

Sampling began on 25 March with a single daily shift operating 3-5 d week^{-1} to coincide with the anticipated arrival of early migrating juvenile PIT-tagged salmon and steelhead in the estuary. As numbers of migrating juvenile salmonids in the estuary increased, sample effort was increased to two daily shifts operating 7 d week^{-1} during daylight and 6 d week^{-1} during darkness. This intensive sampling period began on 29 April and continued through 6 June. During this period we averaged 13 detections h^{-1} during daylight and 23 detections h-1 during darkness for yearling Chinook salmon ($P = 0.02$). During the same period for steelhead the trend was opposite, with 21 detections h^{-1} during daylight and 7 detections h^{-1} during darkness ($P < 0.001$). Sampling continued with a single daily shift through 25 July when sampling ended as numbers of PIT-tagged fish in the sampling reach declined.

During the intensive sampling period, the trawl was deployed for an average of 14 h d^{-1} and we detected 2.7% of the yearling Chinook and 3.8% of the steelhead previously detected at Bonneville Dam. By comparison, during intensive sampling in 2012, the trawl was deployed for an average of 14 h d^{-1} and detected 1.7% of the yearling Chinook and 2.6% of the steelhead detected at Bonneville Dam. We also detected 1.9% of the yearling Chinook salmon and 3.7% of the steelhead transported and released below Bonneville Dam in 2013. These rates were higher for transported fish than in 2012, when we detected 1.3% of the yearling Chinook and 3.5% of the steelhead. However, the detection rate of barged steelhead in 2012 was exceptionally high compared to flow volume due to an apparent shift of their peak availability from mid-day to mid-morning. Under lower flow conditions, as in 2013, the peak detection rate of steelhead has tended to occur towards mid-day, and our afternoon refueling period has generally reduced their overall detection rate. Flow volume at Bonneville Dam was below average in 2013 (8,013 m^3 s^{-1}) while in 2012 it was above average (9,912 m^3 s^{-1}). Detection rates in the trawl are typically inversely correlated with flow, where rates are higher in low to moderate flow years.

In 2013, 19% of the PIT-tagged fish detected with the trawl system had been transported, while 10% had been detected in the juvenile bypass system or corner collector at the Bonneville Dam Second Powerhouse. There is no PIT-tag detection capability at the First Powerhouse bypass or Spillway. The remaining 71% of fish detected with the trawl had not been transported or detected at Bonneville Dam, although 99% of them had originated upstream from Bonneville.

In 2013, estimated survival from Lower Granite to Bonneville Dam tailrace was 61.9% for combined wild and hatchery Snake River yearling Chinook (Table 1). This was slightly lower than the 63.4% estimated for these fish in 2012.

Estimated survival through this same reach for combined wild and hatchery Snake River steelhead was 51.5%, which was lower than the 59.7% estimated for these fish in 2012. For Snake River sockeye, estimated survival through the same reach was 53.6% in 2013, which was higher than the 47.2% estimated in 2012. Estimated survival from McNary to Bonneville Dam tailrace was similar in 2013 and 2012 for combined wild and hatchery Snake River yearling Chinook (79.6 vs. 80.2%). In the same reach for combined wild and hatchery upper Columbia River yearling Chinook, survival was higher in 2013 than in 2012, both for groups released above the confluence of the Yakima River (102.5 vs. 84.5%) and for those released in the Yakima River (76.0 vs. 55.8%). For mixed wild and hatchery Snake River steelhead, estimated survival through this reach was lower in 2013 than in 2012 (79.8 vs. 85.6%). For combined wild and hatchery steelhead from the upper Columbia River, estimated survival was 91.0% in 2013 vs. 106.9% in 2012. Due to low rates of detection for upper Columbia River sockeye salmon, estimates of survival from McNary to Bonneville Dam were imprecise in both years, at 65.8% (±21.7) in 2013 and 84.0% (±40.5) in 2012.

Seasonal mean travel speed to Jones Beach was significantly faster for yearling Chinook salmon detected passing Bonneville Dam (96 km d^{-1}) than for those released from barges just below the dam (71 km d-1, $P \leq 0.001$). Similar differences in travel speed between inriver-migrant and barged fish were noted for steelhead (100 vs. 93 km d^{-1}, $P < 0.001$). There was not a significant difference in travel speed between sockeye salmon passing Bonneville Dam (103 km d^{-1}) and those released from barges below the dam (106 km d^{-1}, $P < 0.10$), although low inriver detections may have contributed to this (n = 78). There were insufficient detections of subyearling Chinook salmon in 2013 for meaningful comparisons of travel speed.

We detected a total of 477 subyearling fall Chinook salmon in 2013, with detections occurring after the intensive sample period. Of these 477 fish, 216 originated in the Snake River basin (201 inriver migrants and 15 transported). The remaining 261 subyearling fish were Columbia River stocks. We also detected 54 fall Chinook salmon from the Snake River basin that had been released as subyearlings in 2012. Of these 54 fish, 31 had overwintered in either the Snake or Columbia River above Bonneville Dam, and 23 had not been detected in 2013 prior to being detected in the estuary.

In 2013, we detected 1,023 sockeye salmon; 83% of these fish had been released into the Snake River and 17% into the Columbia River. Of these 1,023 fish, 89% were hatchery reared, 2% were wild, and the remaining 9% were of unknown origin. Fish migrating inriver made up 55% of the total sockeye detections (563), while the other 45% were fish that had been transported (460).

In late 2012, we began developing a stationary PIT-tag detection system featuring the larger antennas now possible due to a new transceiver (model IS1001 MTS). The new system was installed along a pile dike in the lower estuary during spring 2013. The antennas we deployed

measured 2.4 by 6.1 m and were housed with 10.2-cm-diameter, rigid PVC pipe. In June, we also briefly tested this new system by towing it behind a modified trawl. These tests showed significant stress on the PVC frame, and the large, rigid antenna frame required complicated logistics for deployment and retrieval. As a result, we developed an antenna of similar dimensions but housed using a flexible light-weight hose. This design was much easier to deploy and was more resistant to vibration and stress when under tow. In October, we conducted preliminary testing of this flexible antenna attached to a rope-frame for added strength. While results were promising, more testing of the flexible design is needed to reduce vibration and to develop a larger matrix of multiple antenna coils.

Myrvold, K. M. and B. P. Kennedy (2015). "Density dependence and its impact on individual growth rates in an age-structured stream salmonid population." Ecosphere 6(12).

In organisms with flexible and indeterminate growth, demographic density dependence can affect both individual fitness and population dynamics. Recent work in stream salmonids suggests that individual growth rates can be depressed even at low population densities, which warrants examination of populations previously assumed to be below carrying capacity. We investigated the effects of population density on individual growth rates in a threatened population of steelhead (Oncorhynchus mykiss) in a tributary to the Clearwater River in Idaho, USA. We followed a mark-recapture design where we visited 16 study sites on average five times per year from 2010 to 2012. The 95% confidence interval for average growth rates (% change in body mass per day) for subyearlings were [0.82, 1.0]) and [0.16, 0.30] for yearling steelhead. Variance decomposition showed that the variation in growth rates could be attributed equally to individual-and visit-level factors in subyearlings, whereas almost two-thirds of the variance in yearling growth rates could be attributed to individual-level factors. Growth rates in the subyearling age class were negatively related to the densities of yearling steelhead, but not vice versa. Yearling growth rates showed no evidence of density dependence. Finally, density in interaction with water temperature did not affect growth rates of either age class. Our results demonstrate that density dependence can pose constraints on individual growth rates at low population densities (<1 fish m(-2)) in stream salmonids, and underscore the importance of considering age classes separately when studying density dependence in age-structured populations.

National Marine Fisheries Service (NMFS). (2016). 2016 5-Year Review: Summary & Evaluation of Snake River Sockeye, Snake River Spring-Summer Chinook, Snake River Fall-Run Chinook, Snake River Basin Steelhead. Published by the National Marine Fisheries Service, West Coast Region, Portland, Oregon of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

National Oceanic and Atmospheric Administration (NOAA). (2014). Endangered Species Act Section 7(a)(2) Supplemental Biological Opinion, Consulatation on Remand for Operation of the Federal Columbia River Power System. Portland, Oregon, NOAA Fisheries.

Nieland, J. L., T. F. Sheehan and R. Saunders (2015). "Assessing demographic effects of dams on diadromous fish: a case study for Atlantic salmon in the Penobscot River, Maine." Ices Journal of Marine Science 72(8): 2423-2437.

Dams are a major contributor to the historic decline and current low abundance of diadromous fish. We developed a population viability analysis to assess demographic effects of dams on diadromous fish within a river system and demonstrated an application of the model with Atlantic salmon in the Penobscot River, Maine. We used abundance and distribution of wild- and hatchery-origin adult salmon throughout the watershed as performance metrics. Salmon abundance, distribution to upper reaches of the Penobscot watershed, and the number and proportion of wild-origin fish in the upper reaches of the Penobscot watershed increased when dams, particularly mainstem dams, were removed or passage efficiency was increased. Salmon abundance decreased as indirect latent mortality per dam was increased. Salmon abundance increased as marine or freshwater survival rates were increased, but the increase in abundance was larger when marine survival was increased than when freshwater survival was increased. Without hatchery supplementation, salmon abundance equalled zero with low marine and freshwater survival but increased when marine and freshwater survival rates were increased. Models, such as this one, that incorporate biological, environmental, and functional parameters can be used to predict ecological responses of fish populations and can help evaluate and prioritize management and restoration actions for diadromous fish.

Northwest Fisheries Science Center (NWFSC). (2015). Status Review Update for Pacific Salmon and Steelhead Listed Under the Endangered Species: Pacific Northwest Seattle, Washington, Northwest Fisheries Science Center, NOAA Fisheries.

Northwest Power & Conservation Council (NPCC). (2014). Columbia River Basin Fish and Wildlife Program. Council Document 2014-12.
http://www.nwcouncil.org/media/7148624/2014-12.pdf.

O'Connor, C. M. and S. J. Cooke (2015). "Ecological carryover effects complicate conservation." Ambio 44(6): 582-591.

Ecological carryover effects occur when an individual's previous history and experiences explain their current performance. It is becoming clear that ecological carryover effects are a common phenomenon across taxa, and have the potential to play an important role in governing individual fitness and population dynamics. Carryover effects may reduce the success of conservation efforts aimed at slowing or reversing biodiversity loss. Failure to consider carryover effects might lead to erroneous conclusions about the effectiveness of conservation measures. We suggest that carryover effects are considered explicitly in threat assessment and conservation planning, in order to understand the long-term consequences of stressors, target efforts more effectively, and ensure that the success or failure of conservation efforts is tracked more accurately. We encourage proactive research focused on the proximate mechanisms underlying carryover effects, so that predictive measures of carryover effects in wild populations can be developed and refined. Finally, we suggest that in some cases, positive carryover effects could be exploited for conservation benefit. We conclude that the failure to consider carryover effects in conservation science and practice may put imperiled populations at further risk.

O'Connor, C. M., D. R. Norris, G. T. Crossin and S. J. Cooke (2014). "Biological carryover effects: linking common concepts and mechanisms in ecology and evolution." Ecosphere 5(3): 11.

The term 'carryover effect' originally arose from repeated measures clinical experiments. However, the term has more recently been applied to ecological and evolutionary studies, often in migratory systems, which has led to an emphasis on non-lethal effects across seasons. In this article, we suggest that ecological carryover effects can also occur between life-history stages, developmental stages, physiological states, or social situations, and each will be associated with a discrete time-scale. Therefore, we propose the working definition: In an ecological context, carryover effects occur in any situation in which an individual's previous history and experience explains their current performance in a given situation. This concept of carryover effects provides an explicit but highly flexible context for examining the mechanisms that drive non-lethal interactions between distinct periods of an organism's lifetime, and unites the currently disparate fields investigating these effects in ecological systems. Greater communication among research fields and identifying mechanisms of carryover effects at different time scales will ultimately lead to a better understanding of the factors influencing variation in individual fitness.

Osterback, A. M. K., D. M. Frechette, S. A. Hayes, M. H. Bond, S. A. Shaffer and J. W. Moore (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.

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.

Osterback, A. M. K., D. M. Frechette, A. O. Shelton, S. A. Hayes, M. H. Bond, S. A. Shaffer and J. W. Moore (2013). "High predation on small populations: avian predation on imperiled salmonids." Ecosphere 4(9).

Generalist predators can contribute to extinction risk of imperiled prey populations even through incidental predation. Quantifying predation on small populations is important to manage their recovery, however predation is often challenging to observe directly. Recovery of prey tags at predator colonies can indirectly provide minimum estimates of predation, however overall predation rates often remain unquantifiable because an unknown proportion of tags are deposited off-colony. Here, we estimated overall predation rates on threatened wild juvenile steelhead (Oncorhynchus mykiss) by generalist adult Western Gulls (Larus occidentalis) in six central California (USA) watersheds. We estimated predation rates by gulls from the recapture of PIT (passive integrated transponder) tags that were originally inserted into steelhead and were subsequently deposited at a Western Gull breeding colony, A no Nuevo Island (ANI). We combined three independent datasets to isolate different processes: (1) the probability a tagged steelhead was consumed during predation, (2) the probability a consumed tag was transported to ANI, and (3) the probability a transported tag was detected at ANI. Together, these datasets parameterized a hierarchical Bayesian model to quantify overall predation rates while accounting for tag loss between when prey were tagged and subsequent tag detection at ANI. Results from the model suggest that low recovery rates of PIT tags from steelhead at ANI were mostly driven by low probabilities of transportation (<= 0.167) of consumed tags to ANI. Low transportation probabilities equate to high per-capita probabilities of predation (<= 0.306/yr) at the three watersheds in closest proximity to ANI, whereas predation rates were uncertain at watersheds farther from ANI due to very low transportation rates. This study provides the first overall estimate of Western Gull predation rates on threatened wild juvenile steelhead and suggests gull predation on salmonids is a larger source of mortality than was previously estimated from minimum predation rates. This study thus represents an important example of high rates of incidental predation by a generalist consumer on an imperiled prey and provides a

quantitative framework to inform robust estimates of predation rates on small populations that can be applied to other systems where direct observation of predation is not feasible.

Otero, J., J. H. L'Abee-Lund, T. Castro-Santos, K. Leonardsson, G. O. Storvik, B. Jonsson, B. Dempson, I. C. Russell, A. J. Jensen, J.-L. Bagliniere, M. Dionne, J. D. Armstrong, A. Romakkaniemi, B. H. Letcher, J. F. Kocik, J. Erkinaro, R. Poole, G. Rogan, H. Lundqvist, J. C. MacLean, E. Jokikokko, J. V. Arnekleiv, R. J. Kennedy, E. Niemela, P. Caballero, P. A. Music, T. Antonsson, S. Gudjonsson, A. E. Veselov, A. Lamberg, S. Groom, B. H. Taylor, M. Taberner, M. Dillane, F. Arnason, G. Horton, N. A. Hvidsten, I. R. Jonsson, N. Jonsson, S. McKelvey, T. F. Naesje, O. Skaala, G. W. Smith, H. Saegrov, N. C. Stenseth and L. A. Vollestad (2014). "Basin-scale phenology and effects of climate variability on global timing of initial seaward migration of Atlantic salmon (Salmo salar)." Global Change Biology 20(1): 61-75.

Migrations between different habitats are key events in the lives of many organisms. Such movements involve annually recurring travel over long distances usually triggered by seasonal changes in the environment. Often, the migration is associated with travel to or from reproduction areas to regions of growth. Young anadromous Atlantic salmon (Salmo salar) emigrate from freshwater nursery areas during spring and early summer to feed and grow in the North Atlantic Ocean. The transition from the freshwater ('parr') stage to the migratory stage where they descend streams and enter salt water ('smolt') is characterized by morphological, physiological and behavioural changes where the timing of this parr-smolt transition is cued by photoperiod and water temperature. Environmental conditions in the freshwater habitat control the downstream migration and contribute to within- and among-river variation in migratory timing. Moreover, the timing of the freshwater emigration has likely evolved to meet environmental conditions in the ocean as these affect growth and survival of the post-smolts. Using generalized additive mixed-effects modelling, we analysed spatio-temporal variations in the dates of downstream smolt migration in 67 rivers throughout the North Atlantic during the last five decades and found that migrations were earlier in populations in the east than the west. After accounting for this spatial effect, the initiation of the downstream migration among rivers was positively associated with freshwater temperatures, up to about 10 °C and levelling off at higher values, and with sea-surface temperatures. Earlier migration occurred when river discharge levels were low but increasing. On average, the initiation of the smolt seaward migration has occurred 2.5 days earlier per decade throughout the basin of the North Atlantic. This shift in phenology matches changes in air, river, and ocean temperatures, suggesting that Atlantic salmon emigration is responding to the current global climate changes.

Peterson, W. T., J. L. Fisher, J. O. Peterson, C. A. Morgan, B. J. Burke and K. L. Fresh (2014). "Applied Fisheries Oceanography Ecosystem Indicators of Ocean Condition Inform Fisheries Management in the California Current." Oceanography 27(4): 80-89.

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

Phillis, C. C., J. W. Moore, M. Buoro, S. A. Hayes, J. C. Garza and D. E. Pearse (2016). "Shifting Thresholds: Rapid Evolution of Migratory Life Histories in Steelhead/Rainbow Trout, Oncorhynchus mykiss." Journal of Heredity 107(1): 51-60.

Expression of phenotypic plasticity depends on reaction norms adapted to historic selective regimes; anthropogenic changes in these selection regimes necessitate contemporary evolution or declines in productivity and possibly extinction. Adaptation of conditional strategies following a change in the selection regime requires evolution of either the environmentally influenced cue (e. g., size-at-age) or the state (e. g., size threshold) at which an individual switches between alternative tactics. Using a population of steelhead (Oncorhynchus mykiss) introduced above a barrier waterfall in 1910, we evaluate how the conditional strategy to migrate evolves in response to selection against migration. We created 9 families and 917 offspring from 14 parents collected from the above-and below-barrier populations. After 1 year of common garden-rearing above-barrier offspring were 11% smaller and 32% lighter than below-barrier offspring. Using a novel analytical approach, we estimate that the mean size at which above-barrier fish switch between the resident and migrant tactic is 43% larger than below-barrier fish. As a result, above-barrier fish were 26% less likely to express the migratory tactic. Our results demonstrate how rapid and opposing changes in size-at-age and threshold size contribute to the contemporary evolution of a conditional strategy and indicate that migratory barriers may elicit rapid evolution toward the resident life history on timescales relevant for conservation and management of conditionally migratory species.

Plumb, J. M., W. P. Connor, K. F. Tiffan, C. M. Moffitt, R. Perry and N. S. Adams (2012). "Estimating and Predicting Collection Probability of Fish at Dams Using Multistate Modeling." Transactions of the American Fisheries Society 141(5): 1364-1373.

Dams can be equipped with a bypass that routes a portion of the fish that enter the turbine intakes away from the powerhouse into flumes, where they can be counted. Daily passage abundance can be estimated by dividing the number of fish counted in the bypass by the sampling rate and then dividing the resulting quotient by the collection probability (i.e., the proportion of the fish population passing the dam that is bypassed). We used multistate mark-recapture modeling to evaluate six candidate models for predicting the collection probabilities of radio-tagged subyearling fall Chinook salmon (n = 3,852) as a function of 1-2-d time periods (general model), four different combinations of outflow (i.e., the total volume of water passing

the dam) and turbine allocation (i.e., the proportion of outflow directed through the turbines), and a null (intercept only) model. The best-fit model was the additive combination of turbine allocation and outflow, which explained 71% of the null deviance. Cross validation of the best-fit model accounted for the variation that may arise from different data sets and the ensuing parameter values on the collection probability estimates and yielded a standard error of 0.613 that can be used to construct approximate 95% prediction intervals in nonstudy years. Such estimates have been unavailable and will be useful anywhere estimates of daily passage abundance at dams with bypasses are needed to manage migratory fishes.

Poletto, J. B., D. E. Cocherell, S. E. Baird, T. X. Nguyen, V. Cabrera-Stagno, A. P. Farrell and N. A. Fangue (2017). "Unusual aerobic performance at high temperatures in juvenile Chinook salmon, Oncorhynchus tshawytscha." Conservation Physiology 5.

Understanding how the current warming trends affect fish populations is crucial for effective conservation and management. To help define suitable thermal habitat for juvenile Chinook salmon, the thermal performance of juvenile Chinook salmon acclimated to either 15 or 19 degrees C was tested across a range of environmentally relevant acute temperature changes (from 12 to 26 degrees C). Swim tunnel respirometers were used to measure routine oxygen uptake as a measure of routine metabolic rate (RMR) and oxygen uptake when swimming maximally as a measure of maximal metabolic rate (MMR) at each test temperature. We estimated absolute aerobic scope (AAS = MMR - RMR), the capacity to supply oxygen beyond routine needs, as well as factorial aerobic scope (FAS = MMR/RMR). All fish swam at a test temperature of 23 degrees C regardless of acclimation temperature, but some mortality occurred at 25 degrees C during MMR measurements. Overall, RMR and MMR increased with acute warming, but aerobic capacity was unaffected by test temperatures up to 23 degrees C in both acclimation groups. The mean AAS for fish acclimated and tested at 15 degrees C (7.06 +/- 1.76 mg O-2 kg(-1) h(-1)) was similar to that measured for fish acclimated and tested at 19 degrees C (8.80 +/- 1.42 mg O-2 kg(- 1) h(- 1)). Over the entire acute test temperature range, while MMR and AAS were similar for the two acclimation groups, RMR was significantly lower and FAS consequently higher at the lower test temperatures for the fish acclimated at 19 degrees C. Thus, this stock of juvenile Chinook salmon shows an impressive aerobic capacity when acutely warmed to temperatures close to their upper thermal tolerance limit, regardless of the acclimation temperature. These results are compared with those for other salmonids, and the implications of our findings for informing management actions are discussed.

Quinn, T. P., P. McGinnity and T. E. Reed (2016). "The paradox of "premature migration" by adult anadromous salmonid fishes: patterns and hypotheses." Canadian Journal of Fisheries and Aquatic Sciences 73(7): 1015-1030.

In several groups of anadromous fishes, but especially the salmonids, some populations migrate from the ocean to fresh water many months prior to spawning. This "premature migration" reduces growth opportunities at sea, compels them to occupy much less productive freshwater

habitats, and exposes them to extremes of flow and temperature, disease, and predation. We first review migration in salmonids and find great variation in timing patterns among and within species, relative to the timing of reproduction. Premature migration is widely distributed among species but not in all populations, and we propose two hypotheses to explain it. First, the fish may be making "the best of a bad situation" by entering early because access to suitable breeding sites is constrained seasonally by flow or temperature regimes, so they sacrifice growing opportunities at sea. Alternatively or additionally, some populations may be "balancing risks and benefits" as they trade off the benefits of growth at sea against the risk of mortality there. In this model, the reduced risk of mortality at sea must be balanced against the risk of mortality in freshwater habitats from thermal stress, disease, and predators. Premature migration may be favored where temperatures and flows are moderate or where lakes provide safety from predators and reduce energetic expenditure. Consistent with this hypothesis, early return is characteristic of larger, older salmonids (that would benefit less from additional time at sea to grow than would smaller fish). Finally, we consider the vulnerability of premature migrants to climate change and selective fisheries. Migration timing is an important part of the portfolio of phenotypic diversity that conveys resilience to species, population complexes, and the fisheries that depend on them. The premature migrants are often especially valued in fisheries and also often of particular conservation concern, and the phenomenon merits further research.

Railsback, S. F., B. C. Harvey and J. L. White (2014). "Facultative anadromy in salmonids: linking habitat, individual life history decisions, and population-level consequences." Canadian Journal of Fisheries and Aquatic Sciences 71(8): 1270-1278.

Modeling and management of facultative anadromous salmonids is complicated by their ability to select anadromous or resident life histories. Conventional theory for this behavior assumes individuals select the strategy offering highest expected reproductive success but does not predict how population-level consequences such as a stream's smolt production emerge from the anadromy decision and habitat conditions. Our individual-based population model represents juvenile growth, survival, and anadromy decisions as outcomes of habitat and competition. In simulation experiments that varied stream growth and survival conditions, we examined how many simulated juveniles selected anadromy versus residence and how many of those choosing anadromy survived until smolting. Owing to variation in habitat and among individuals, the within-population frequency of anadromy changed gradually with growth and survival conditions instead of switching abruptly. Higher predation risk caused more juveniles to select anadromy, but fewer survived long enough to smolt. Improving growth appears a much safer way to increase smolt production compared with reducing freshwater survival. Smolt production peaked at high growth and moderately high survival, conditions that also produced many residents.

Rechisky, E. L., D. W. Welch and A. D. Porter (2013). "Reply to Haeseker: Value of controlled scientific experiments to resolve critical uncertainties regarding Snake River salmon survival."

Proceedings of the National Academy of Sciences of the United States of America 110(37): E3465-E3465.

Rechisky, E. L., D. W. Welch, A. D. Porter, J. E. Hess and S. R. Narum (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-U436.

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 inriver migrating Snake and mid-Columbia River yearlings was indistinguishable. We found mixed results for our transportation study, with no support for transport-DM in 2010, and weak support in 2011. Our study provides further evidence that freshwater management strategies may not increase the rate of Chinook salmon returning to the Snake River if prior freshwater experience has no substantial influence on subsequent survival in the ocean.

Rechisky, E. L., D. W. Welch, A. D. Porter, M. C. Jacobs-Scott and P. M. Winchell (2013). "Influence of multiple dam passage on survival of juvenile Chinook salmon in the Columbia River estuary and coastal ocean." Proceedings of the National Academy of Sciences of the United States of America 110(17): 6883-6888.

Multiple dam passage during seaward migration is thought to reduce the subsequent survival of Snake River Chinook salmon. This hypothesis developed because juvenile Chinook salmon from the Snake River, the Columbia River's largest tributary, migrate >700 km through eight hydropower dams and have lower adult return rates than downstream populations that migrate through only 3 or 4 dams. Using a large-scale telemetry array, we tested whether survival of hatchery-reared juvenile Snake River spring Chinook salmon is reduced in the estuary and coastal ocean relative to a downstream, hatchery-reared population from the Yakima River. During the initial 750-km, 1-mo-long migration through the estuary and coastal

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

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

Many juvenile Snake River Chinook salmon are transported downriver to avoid hydroelectric dams in the Columbia River basin. As mortality to the final dam is similar to 50%, transported fish should return as adults at roughly double the rate of nontransported fish; however, the benefit of transportation has not been realized consistently. "Delayed'' mortality caused by transportation-induced stress is one hypothesis to explain reduced returns of transported fish. Differential timing of ocean entry is another. We used a large-scale acoustic telemetry array to test whether survival of transported juvenile spring Chinook is reduced relative to in-river migrant control groups after synchronizing ocean entry timing. During the initial 750 km, 1 month long migration after release, we found no evidence of decreased estuarine or ocean survival of transported groups; therefore, decreased survival to adulthood for transported Chinook is likely caused by factors other than delayed effects of transportation, such as earlier ocean entry.

Richins, S. M. (2017). Influence of Juvenile and Adult Experiences on Tributary Overshoot and Fallback by Steelhead in the Columbia River Basin. School of Aquatic and Fishery Sciences. Seattle, Washington, University of Washington. Master of Science.

Tributary overshoot occurs when adult fishes homing to natal sites continue upstream past the mouth of their natal stream. Using multistate release-recapture models, I examined the prevalence of overshooting and fallback to home by 37,806 PIT-tagged steelhead from 14 tributaries of the Columbia River basin in the years 2005—2015. For stocks that overshot at rates > 5%, I used generalized linear models and conditional inference trees to examine the influence of juvenile and adult experiences on overshooting and fallback to home. More than 40% of adult John Day, Umatilla, Walla Walla, Wenatchee, and Tucannon river steelhead overshot upstream dams. Average annual fallback rates to home ranged from 17.8% (SE 1.9%) for Walla Walla hatchery steelhead to 75.0% (SE 2.6%) for Umatilla wild steelhead. Overshooting was associated with factors related to the reservoir environment. Incorrect shoreline orientation within 24 rkm of the natal stream resulted in increased overshooting. Steelhead were also more likely to overshoot when water temperatures were higher (significant in 5 of 7 tributaries, $P < 0.05$). In contrast with adult experiences, juvenile experiences linked to imprinting disruption did not consistently increase overshooting. Hatchery steelhead were more likely to overshoot and less likely to fall back home than their wild counterparts. However, overshooting was only elevated in hatchery stocks reared

upstream of release sites. Attraction to upstream areas was decreased with endemic broodstock and long-term acclimation. Juvenile barging was found to decrease overshooting relative to inriver out-migration. Longer ocean residency was associated with increased overshooting, but effects were biologically small. Finally, there was some evidence that spill during March increased fallback to home. A significant positive effect of spill during March was found for hatchery ($\chi 2_{8} = 15.82$, P = 0.032) but not for wild steelhead ($\chi 2_{10} = 12.87$, P = 0.231).

Roby, D. D., K. Collis, P. J. Loschl, Y. Suzuki, D. Lyons, T. J. Lawes, K. S. Bixler, B. Caillouet, B. Underwood, A. Evans, B. Cramer, A. Turecek, Q. Payton and M. Hawbecker (2017). Avian Predation on Juvenile Salmonids: Evaluation of the Caspian Tern Management Plan in the Columbia River Estuary, U.S. Geological Survey, Oregon State University, and Real Time Research, Inc.: 83.

The primary objectives of this study in 2016 were to monitor, evaluate, and adaptively manage initiatives implemented to reduce the number of Caspian tern (Hydroprogne caspia) nesting on East Sand Island and, therefore, reduce tern predation rates on ESA-listed juvenile salmonids (Oncorhynchus spp.) in the Columbia River estuary. First, with guidance from resource managers, we prepared 1 acre of tern nesting habitat for terns to use on East Sand Island and attempted to prevent nesting by terns outside that designated nesting area. Second, we monitored tern nesting activity on East Sand Island and evaluated their predation rates on ESA-listed juvenile salmonids. Third, we evaluated movement rates of previously color-banded Caspian terns to and from the East Sand Island colony to assess the efficacy of management initiatives implemented to relocate nesting terns to sites outside the Columbia River basin. Lastly, we monitored the effects of Caspian tern management actions implemented on East Sand Island on the other colonial waterbirds that nest and roost on the island.

The management plan entitled, Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary was first implemented in 2008, and implementation continued in 2016. The objective of this plan is to reduce the size of Caspian tern colony on East Sand Island to 3,125 - 4,375 breeding pairs, while preventing Caspian terns from colonizing other sites in the Columbia River estuary. As part of this plan, we prepared 1.0 acre of suitable nesting habitat for Caspian terns on East Sand Island prior to the 2016 nesting season, the same area of nesting habitat that was provided for terns in 2015, and an 80% reduction in what was provided for terns on East Sand Island prior to implementation of the management plan. The estimate of Caspian tern colony size on the 1.0-acre designated colony area in 2016 was 5,215 breeding pairs (95% c.i. = 5,000 – 5,430 pairs), slightly lower than the colony size in 2015 (5,430 breeding pairs; 95% c.i. = 5,200 – 5,660 pairs), and about a 50% reduction from the peak size of the tern colony on East Sand Island (ca. 10,670 pairs), which occurred in 2008.

We attempted to limit tern nesting on East Sand Island to the 1.0-acre designated colony area using passive dissuasion (stakes, rope, and flagging) and active dissuasion (human hazing). A total of 5.1 acres of passive dissuasion was installed on East Sand Island prior to the 2016 nesting season, 2.4 acres of which was installed on the east end of the island near the Caspian

tern colony. Intensive human hazing was implemented in areas where terns prospected for nest sites. Despite these efforts, two satellite tern colonies formed late in the 2016 nesting season, one adjacent to the main colony area on the upper beach and the other adjacent to a ring-billed gull (Larus delawarensis) colony at the northeast tip of the island. Combined, these two satellite tern colonies consisted of an additional 700 breeding pairs, when the size of the satellite colonies was at its peak. Thus, the estimated total number of Caspian terns that attempted to nest on East Sand Island in 2016 was 5,915 pairs (95% c.i. = 5,410 – 6,425 pairs), which was slightly lower than the total number of Caspian terns nesting on East Sand Island in 2015 (6,240 pairs).

In 2016, the average nesting density of Caspian terns in the 1-acre designated colony area on East Sand Island was 1.36 nests/m2, similar to the average nesting density in 2015 (1.32 nests/m2), and the highest average nesting density ever recorded for Caspian terns nesting on East Sand Island. The peak nesting density on the tern colony in 2016 was 1.50 nests/m2, the same as in 2015. These results suggest that Caspian tern nesting density on the designated colony area is approaching the maximum. Given the more than 30-year history of Caspian terns nesting in the Columbia River estuary, it is expected that some, perhaps most, terns will initially adapt to reductions in suitable nesting habitat on East Sand Island by nesting at higher densities and/or attempting to nest in other, sometimes marginal, nesting habitat on East Sand Island (e.g., upper beaches) and elsewhere in the Columbia River estuary (e.g., Rice Island). Efforts to reduce Caspian tern predation rates on juvenile salmonids in the Columbia River estuary to levels stipulated in the management plan will likely require that all Caspian terns nesting in the Columbia River estuary be restricted to just the designated colony area on East Sand Island, and that the area of designated Caspian tern nesting habitat be reduced to about two-thirds of an acre, thereby forcing terns displaced from East Sand Island to relocate to alternative colony sites outside the Columbia River estuary.

As was the case in 2015, Caspian terns nesting on East Sand Island in 2016 were relatively resilient to disturbances by bald eagles (Haliaeetus leucocephalus) and associated gull (Larus spp.) depredation of tern eggs and chicks. These limiting factors caused the Caspian tern colony on East Sand Island to fail or nearly fail during 2010-2012. In 2016, the Caspian tern colony on the 1-acre designated colony site produced about 2,870 fledglings (average of about 0.55 young raised/breeding pair; 95% c.i. = 0.38 – 0.61), similar to the average productivity during 2015 (0.63 young raised/breeding pair).

To assess the efficacy of management implemented to disperse Caspian terns from nest sites within the Columbia River basin to alternative colony sites outside the basin, we monitored Caspian tern movements by re-sighting terns previously banded with field-readable leg bands at colonies both inside and outside the basin. Most resighted Caspian terns exhibited site fidelity to the colony on East Sand Island in 2016, although some banded individuals dispersed to colonies in the Columbia Plateau region and in the Salish Sea region. Estimated numbers of Caspian terns that moved from the Corps-constructed alternative colony sites in interior Oregon and northeastern California to the Columbia River estuary and to the Columbia Plateau region were high in 2016, probably due to continued severe drought that has negatively

affected tern nesting and foraging habitat in interior Oregon and northeastern California during 2014-2016.

Predation rates on specific populations of anadromous salmonids (ESUs/DPSs) by Caspian terns nesting on East Sand Island in 2016 were some of the lowest ever recorded, particularly predation rates on steelhead (O. mykiss) populations. For example, predation rates on Snake River steelhead in 2016 were 6.1% (95% credible interval = 4.8 – 8.8), compared with an average of 22.2% (95% CI = 20.3 – 24.8) observed prior to implementation of management to reduce the size of the tern colony on East Sand Island. Reductions in tern predation rates were commensurate with reductions in tern colony size, indicating that Caspian tern management actions to reduce tern nesting habitat on East Sand Island are resulting in lower average annual predation rates on salmonid smolts. Like predation rates measured in previous years, Caspian tern predation rates in 2016 were significantly higher on populations of steelhead (6.1 – 8.8%, depending on DPS) compared with populations of salmon (0.7 – 1.4%, depending on ESU). An investigation of variation in predation rates based on fish rear-type (hatchery, wild), out-migration history (in-river, transported), run-timing, and smolt abundance (density) indicated that multiple factors influence a fish's susceptibility to tern predation; reflecting dynamic and complex predator-prey interactions in the Columbia River estuary.

To further reduce predation rates by Caspian terns nesting at East Sand Island on salmonid smolts in the Columbia River estuary, more Caspian terns will need to be relocated to colonies outside the estuary. Based on the size of the East Sand Island colony in 2016 (5,915 breeding pairs) relative to the target colony size stipulated in the Management Plan (3,125 – 4,375 breeding pairs), an additional 1,500 – 2,800 breeding pairs will need to be relocated outside the estuary. This will likely require an increased effort to prevent Caspian terns from nesting outside the designated 1-acre designated colony area on East Sand Island. The potential for the formation of satellite tern colonies on East Sand Island can be reduced by (1) installing pre-season passive dissuasion more strategically, (2) move the designated tern nesting habitat further from the beach, and (3) collect a limited number of tern eggs (under permit) at incipient satellite colonies. In addition, the designated colony area will need to be reduced to less than 1 acre of nesting habitat (ca. 0.67 acres) to meet the management objective for colony size stipulated in the Plan.

Roegner, G. C., E. A. Daly and R. D. Brodeur (2013). "Surface distribution of brachyuran megalopae and ichthyoplankton in the Columbia River plume during transition from downwelling to upwelling conditions." Continental Shelf Research 60: 70-86.

In the California Current coastal boundary zone, the spring transition between downwelling and upwelling conditions, along with the fluctuating structure of the Columbia River plume, creates highly dynamic interactions. In this study, we investigated whether the surface distribution of brachyuran larvae and ichthyoplankton would track the dynamics of the Columbia River plume. By happenstance, the cruise period coincided with the spring transition from downwelling to sustained upwelling conditions in 2010, a year when the transition was delayed and Columbia

River flow was substantially higher than average. We used time series of wind and freshwater input to evaluate the influence of physical forcing on oceanographic patterns, and sampled hydrography and surface plankton concentrations within a 182 km(2) grid off Willapa Bay, WA. Additionally, two longer transects, one cross-shelf and the other along-shore, were made to discern the extent of plume influence on larval crab and fish abundance. We found that plume waters that were trapped in a northward-flowing coastal-boundary current during downwelling conditions were advected offshore after several days of upwelling-favorable winds. Neustonic collections of brachyuran larvae and ichthyoplankton varied in response to this large seaward advective event. Megalopae of cancrid crabs exhibited patterns of both offshore transport (Cancer oregonensis/productus) and nearshore retention (C. magister). Additionally, abundant numbers of large juvenile widow (Sebastes entomelas) and yellowtail (S. flavidus) rockfish of a size appropriate for settlement were sampled during a period when ocean conditions favored high recruitment success. These results demonstrated that the response of planktonic crab larvae and ichthyoplankton to large-scale advection varied by species, with larger and more vagile fish exhibiting less evidence of passive transport than smaller crab larvae. Importantly, portions of the planktonic fish and crab community were able to maintain nearshore distributions in favorable settlement habitat, despite physical advection offshore.

Roegner, G. C., L. A. Weitkamp and D. J. Teel (2016). "Comparative Use of Shallow and Deepwater Habitats by Juvenile Pacific Salmon in the Columbia River Estuary Prior to Ocean Entry." Marine and Coastal Fisheries 8(1): 536-552.

The degree to which fine-scale habitat use by salmonid species and stocks varies within habitat types such as estuaries is not fully resolved.We sampled shallow shoreline and deeper main-stem channel habitats in the Columbia River estuary over 3 years to compare salmon species composition, migration timing, density, size, and production type (hatchery or natural). Results indicated a high degree of spatial heterogeneity in habitat occupancy by the five salmonid species that are native to the basin. Salmonid communities at two channel habitat sites were much more similar to each other than to the community at a shoreline site. Salmonids sampled at the shoreline site were primarily subyearling Chinook Salmon Oncorhynchus tshawytscha and Chum Salmon O. keta and yearling Coho Salmon O. kisutch, with few other salmonids present. In contrast, channel habitat contained a higher diversity of salmon species, with samples representing all species of anadromous salmonids, including Sockeye Salmon O. nerka and steelhead O. mykiss. Salmonids in deeper channel habitat were generally larger than salmonids found along the shore, and the proportion of hatchery-origin salmon was also higher in deep channel habitats. On a per-area basis, we also found much higher densities of salmon along the shoreline than in channel habitats. For Chinook Salmon, habitat use also differed by genetic stock of origin: upper-river stocks primarily used deeper channels, while lower-river populations used both channel and shoreline areas. We concluded that sampling at both habitat types is required to fully encompass the migration patterns of all salmon evolutionarily significant units in the Columbia River basin. These spatial and temporal variations in salmon timing and density have ramifications for feeding, growth, and competitive interactions. This study provides information that is relevant for conservation efforts targeting specific fish

populations and efforts to evaluate the potential impacts of in-water activities in the Columbia River estuary.

Rupp, D. E., T. C. Wainwright, P. W. Lawson and W. T. Peterson (2012). "Marine environment-based forecasting of coho salmon (Oncorhynchus kisutch) adult recruitment." Fisheries Oceanography 21(1): 1-19.

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

Russell, I. C., M. W. Aprahamian, J. Barry, I. C. Davidson, P. Fiske, A. T. Ibbotson, R. J. Kennedy, J. C. Maclean, A. Moore, J. Otero, T. Potter and C. D. Todd (2012). "The influence of the freshwater environment and the biological characteristics of Atlantic salmon smolts on their subsequent marine survival." Ices Journal of Marine Science 69(9): 1563-1573.

Atlantic salmon have declined markedly in the past 20–30 years throughout their range. Much of the focus for this decline has been on increased mortality during the marine phase of the life cycle. However, marine mortality does not operate independently of factors acting in freshwater and the biological characteristics of smolts migrating to sea. Over recent decades, juvenile salmon in many rivers have grown faster and migrated to sea at a younger age, so have been typically smaller than earlier. This has shortened the generation time for many individuals and may dampen the impact of increased marine mortality, assuming that expected higher in-river survival prior to smolting is not outweighed by increased mortality of smaller smolts at sea. Over the same period, smolt run-timing across the geographic range has been earlier, at an average rate of almost 3 d per decade. This has given rise to growing concerns about smolts potentially missing the optimum environmental migration “window”, the timing of which may also be changing. Contaminants and other factors operating in freshwater also impact smolt quality with adverse consequences for their physiological readiness for life at sea. Given that managers have very limited ability to influence the broad scale factors limiting salmon survival

at sea, it is vital that freshwater habitats are managed to both maximize the smolt output and to minimize the impact of factors acting in freshwater that may compromise salmon once they migrate to sea.

Ruzicka, J. J., E. A. Daly and R. D. Brodeur (2016). "Evidence that summer jellyfish blooms impact Pacific Northwest salmon production." Ecosphere 7(4).

Interannual variability in salmon (Oncorhynchus spp.) production in the northeast Pacific is understood to be driven by oceanographic variability and bottom-up processes affecting prey availability to juvenile salmon. Scyphozoan jellyfish have an important role in shaping the pathways of energy flow through pelagic food webs. While jellyfish obtain high production rates and biomasses as major consumers of zooplankton production, they have few predators and may divert plankton production away from higher trophic levels. Although jellyfish are planktivorous and juvenile coho (O. kisutch) and Chinook (O. tshawytscha) salmon are mainly piscivorous, they may be indirect competitors for plankton production. Ecosystem model simulations suggested that among all trophic interactions within the Pacific Northwest coastal food web, juvenile salmon are particularly sensitive to jellyfish blooms, and that salmon production will be suppressed in years of high summer jellyfish biomass. Pelagic surveys off Oregon and Washington (1999–2012) were used to examine the interannual relationship between salmon production and the dominant jellyfish species, the sea nettle Chrysaora fuscescens, off the Pacific Northwest coast. There was a significant, negative correlation between sea nettle biomass and the strength of adult coho and Chinook salmon returns to the Columbia River. Examination of spatial distributions across years showed a positive association between sea nettles and salmon. Within individual years, significant differences between the distribution of sea nettles and yearling coho and Chinook salmon generally occurred during cooler ocean summers, perhaps due to the greater expanse of optimal salmon habitat resulting from more upwelling. Whether the association is behavioral or a product of oceanographic processes, association enhances the opportunity for indirect competition. Examination of feeding incidence in September showed that salmon stomachs were less full at locations with higher sea nettle biomass.

Sabal, M. C., D. D. Huff, M. J. Henderson, J. Fiechter, J. A. Harding and S. A. Hayes (2016). "Contrasting patterns in growth and survival of Central Valley fall run Chinook salmon related to hatchery and ocean conditions." Environmental Biology of Fishes 99(12): 949-967.

The objective of this study was to determine important ocean and hatchery covariates influencing early growth and survival of Central Valley fall run Chinook salmon. We used a dataset of recaptured coded wire tagged hatchery Chinook salmon to estimate early growth and cohort survival. Ocean conditions during the period of early ocean entry were based on output from a coupled physical-biogeochemical model configured for the broader California Current region. We built generalized additive and generalized linear models to describe growth and survival and used Akaike Information Criterion (AICc) model selection to determine which

hatchery and ocean covariates related best to response variables. With regards to hatchery covariates, growth was best explained by release location, while survival was best explained by release weight and hatchery of origin. The ocean conditions included in the best models for both growth and survival included diatoms, predatory zooplankton, temperature, and currents. We observed the highest rates of salmon survival when in situ physical ocean conditions were indicative of relaxation events. For all four ocean covariates, the response curves illustrated opposite patterns between growth and survival models. This result implies that during periods of low survival, juvenile salmon were either 1) growing at a faster rate, or 2) growth appeared to increase because smaller fish had a higher mortality rate than larger fish. The first explanation would imply density-dependence, whereas the second explanation would imply size-selective mortality. These alternatives have implications on hatchery practices including salmon size at release and number of salmon in release groups.

Samhouri, J. F., K. S. Andrews, G. Fay, C. J. Harvey, E. L. Hazen, S. M. Hennessey, K. Holsman, M. E. Hunsicker, S. I. Large, K. N. Marshall, A. C. Stier, J. C. Tam and S. G. Zador (2017). "Defining ecosystem thresholds for human activities and environmental pressures in the California Current." Ecosphere 8(6): Article e01860.

The oceans are changing more rapidly than ever before. Unprecedented climatic variability is interacting with unmistakable long-term trends, all against a backdrop of intensifying human activities. What remains unclear, however, is how to evaluate whether conditions have changed sufficiently to provoke major responses of species, habitats, and communities. We developed a framework based on multimodel inference to define ecosystem-based thresholds for human and environmental pressures in the California Current marine ecosystem. To demonstrate how to apply the framework, we explored two decades of data using gradient forest and generalized additive model analyses, screening for nonlinearities and potential threshold responses of ecosystem states (n = 9) across environmental (n = 6) and human (n = 10) pressures. These analyses identified the existence of threshold responses of five ecosystem states to four environmental and two human pressures. Both methods agreed on threshold relationships in two cases: (1) the winter copepod anomaly and habitat modification, and (2) sea lion pup production and the summer mode of the Pacific Decadal Oscillation (PDO). Considered collectively, however, these alternative analytical approaches imply that as many as five of the nine ecosystem states may exhibit threshold changes in response to negative PDO values in the summer (copepods, scavengers, groundfish, and marine mammals). This result is consistent with the idea that the influence of the PDO extends across multiple trophic levels, but extends current knowledge by defining the nonlinear nature of these responses. This research provides a new way to interpret changes in the intensities of human and environmental pressures as they relate to the ecological integrity of the California Current ecosystem. These insights can be used to make more informed assessments of when and under what conditions intervention, preparation, and mitigation may enhance progress toward ecosystem-based management goals.

Sandford, B. P., R. W. Zabel, L. G. Gilbreath and S. G. Smith (2012). "Exploring Latent Mortality of Juvenile Salmonids Related to Migration through the Columbia River Hydropower System." Transactions of the American Fisheries Society 141(2): 343-352.

The ability to manage anthropogenic actions that affect the dynamics of animal populations requires the identification and understanding of life-stage-specific mortality. This understanding can be confounded when the expression of mortality is removed, in time or space, from its cause. For years, researchers studying endangered Snake River spring-summer Chinook salmon Oncorhynchus tshawytscha have debated the magnitude of mortality that is related to-but expressed after-passage through the Snake and Columbia River hydropower system ("latent" mortality). We conducted experiments with Chinook salmon to assess the magnitude of latent mortality from two sources: passage through juvenile bypass structures at dams, and transportation with larger juvenile steelhead O. mykiss present in the barge holds. Nearly 129,000 juvenile Chinook salmon (passive integrated transponder tagged) were exposed to different treatment conditions during downstream migration. Study fish were then held in seawater tanks for up to 223 d, and time to mortality was noted for each individual that died. We analyzed survival patterns by using statistical procedures for time-to-event data (i.e., survival analysis). Differential survival between treatment groups was taken to indicate latent mortality caused by the specific treatment. We used a nonparametric Kaplan-Meier analysis to visualize survival patterns and a parametric logistic regression analysis to model the effects of multiple factors. Chinook salmon that were transported with steelhead had significantly lower survival than those that were transported alone. However, there was little evidence for differential latent mortality between Chinook salmon that were not detected at the bypass systems of five dams along the migration route and those that were detected at two to five bypass systems. Our application of survival analyses to individuals subjected to various treatments and held for extended periods produced an effective combination that can be used to test for latent mortality; these results may serve as an initial assessment for further conservation investigations and as a guide to more-targeted research.

Sather, N. K., G. E. Johnson, D. J. Teel, A. J. Storch, J. R. Skalski and V. I. Cullinan (2016). "Shallow Tidal Freshwater Habitats of the Columbia River: Spatial and Temporal Variability of Fish Communities and Density, Size, and Genetic Stock Composition of Juvenile Chinook Salmon." Transactions of the American Fisheries Society 145(4): 734-753.

We investigated the spatial and temporal variability of the fish community and the density, size, and genetic stock composition of juvenile Chinook Salmon Oncorhynchus tshawytscha in shallow tidal freshwater habitats of the Columbia River. We sought to address data gaps related to juvenile Chinook Salmon in this portion of the Columbia River and thereby inform habitat restoration efforts. We examined fish communities, juvenile salmon life history characteristics, and relationships between salmon density and habitat conditions by using beach seine data collected over a 63-month period (2007-2012) from two tidal freshwater areas: the Sandy River delta (river kilometer [rkm] 188-202) and the lower river reach (rkm 110-141). We found few differences in the fish community across the two study areas. Fish community patterns were

largely attributable to seasonal changes as opposed to spatial gradients and habitat types. Juvenile Chinook Salmon were the most common salmon species in our catches; this species was the only salmonid encountered during all four seasons. Chinook Salmon density differed among three distinct habitat strata (main channel, off-channel, and wetland channel), but FL and genetic stock composition did not. Across all habitat strata, environmental covariates (mean percent tree cover, dissolved oxygen level, and mean percent emergent vegetation) were positively associated with juvenile Chinook Salmon density. Although comparisons of environmental metrics and salmon density helped to establish a quantitative relationship between biotic and abiotic conditions, we found that juvenile salmon occupied a range of habitats. Our findings support a strategy that involves restoring a diversity of shallow tidal freshwater habitats to facilitate the recovery of threatened and endangered salmon populations in the Columbia River basin.

Satterthwaite, W. H., M. P. Beakes, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard and M. Mangel (2010). "State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley." Evolutionary Applications 3(3): 221-243.

We use a state dependent life history model to predict the life history strategies of female steelhead trout (Oncorhynchus mykiss) in altered environments. As a case study of a broadly applicable approach, we applied this model to the American and Mokelumne Rivers in central California, where steelhead are listed as threatened. Both rivers have been drastically altered, with highly regulated flows and translocations that may have diluted local adaptation. Nevertheless, evolutionary optimization models could successfully predict the life history displayed by fish on the American River (all anadromous, with young smolts) and on the Mokelumne River (a mix of anadromy and residency). The similar fitness of the two strategies for the Mokelumne suggested that a mixed strategy could be favored in a variable environment. We advance the management utility of this framework by explicitly modeling growth as a function of environmental conditions and using sensitivity analyses to predict likely evolutionary endpoints under changed environments. We conclude that the greatest management concern with respect to preserving anadromy is reduced survival of emigrating smolts, although large changes in freshwater survival or growth rates are potentially also important. We also demonstrate the importance of considering asymptotic size along with maximum growth rate.

Satterthwaite, W. H., S. M. Carlson, S. D. Allen-Moran, S. Vincenzi, S. J. Bograd and B. K. Wells (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.

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.

Satterthwaite, W. H., S. M. Carlson and A. Criss (2017). "Ocean Size and Corresponding Life History Diversity among the Four Run Timings of California Central Valley Chinook Salmon." Transactions of the American Fisheries Society 146(4): 594-610.

We used coded wire tag data to compare spawner age structure and seasonal patterns of age-specific size at date among fish harvested in the ocean from the four seasonal run timings (fall, late-fall, winter, and spring) of Chinook Salmon Oncorhynchus tshawytscha from the Central Valley, California, and we examined differences between the fall-run fish (the most abundant run) from the Sacramento and San Joaquin River basins. The runs varied in their ocean size at a common age and date, and within each run, monthly mean ocean sizes appeared to stop increasing when spawners began to return to freshwater. Despite support for multiple hypotheses, no single factor explained all of the variation among and within runs. Ocean size at a common date was well explained by a "juvenile head-start" hypothesis, predicting larger sizes for the spring and fall runs due to earlier ocean entry. Month of spawner return was well explained by a "premature adult migration" hypothesis, predicting earlier returns (within years, regardless of age) by winter-and spring-run fish spawning further upstream. However, neither release timing nor spawning elevation could fully explain observed patterns in spawner age structure, such as an unusually high occurrence of age-2 San Joaquin River fall-run spawners and the near absence of age-4 or older spawners in the winter run. Larger smolt size might explain earlier maturation by the San Joaquin versus Sacramen to River fall run, but smolt size could not explain patterns in age structure across runs. Metabolic costs of holding upstream with large size might explain the lack of older spawners among the winter run but are inconsistent with the late-fall run having the highest frequency of age-4 and older spawners. Our results demonstrate multiple pathways by which differences both within and among the runs may contribute to differences in their fishery vulnerability and demographic decoupling, which could contribute to a stabilizing portfolio effect.

Satterthwaite, W. H., S. A. Hayes, J. E. Merz, S. M. Sogard, D. M. Frechette and M. Mangel (2012). "State-Dependent Migration Timing and Use of Multiple Habitat Types in Anadromous Salmonids." Transactions of the American Fisheries Society 141(3): 781-794.

Anadromous salmonids vary considerably in their age at ocean entry, their timing of ocean entry within a year, and the extent to which they use multiple habitat types within freshwater. To better understand habitat use and movement timing, we developed a broadly applicable model of state-dependent movements among multiple habitats, which was parameterized based on a case study of steelhead Oncorhynchus mykiss in a California coastal watershed with a seasonally closed lagoonal estuary. The model correctly predicted population-level patterns, including predominance of anadromy and a dominant smolt age of 2 years. In addition, the new model predicted the occurrence of small, lagoon-rearing fish (displaying smoltlike migratory behavior) that returned upstream and did not enter the ocean until the next year, whereas large fish emigrated from the lagoon into the ocean. The new model predicted all-or-nothing habitat use for fish of a given size, but we observed a mix of strategies for fish of the same size. Our modeling suggests that a mortality-growth rate tradeoff can explain much of the life history variation, but this tradeoff alone cannot drive a mixture of habitat use strategies by fish of a similar state (i.e., length). We predicted that a mixed strategy may develop as a consequence of density-dependent reduction in growth rates, arising as more individuals recruit to the originally preferable habitat. Higher risk in the higher-growth habitat may halt recruitment to the high-growth habitat even before growth rates are equalized. Uncertainty in rewards associated with the higher-growth habitat may also favor a mixed strategy in which only some fish accept the higher risk associated with increased growth opportunity. This model framework can be used to predict movement timing and use of multiple habitats for other salmonids and in other systems.

Schaller, H. A., C. E. Petrosky and E. S. Tinus (2013). "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.

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.

Scheuerell, M. D., R. W. Zabel and B. P. Sandford (2009). "Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (Oncorhynchus spp.)." Journal of Applied Ecology 46(5): 983-990.

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

Senner, N. R., J. R. Conklin and T. Piersma (2015). "An ontogenetic perspective on individual differences." Proceedings of the Royal Society B-Biological Sciences 282(1814): 5-13.

Phenotypic differences among individuals can arise during any stage of life. Although several distinct processes underlying individual differences have been defined and studied (e.g.

parental effects, senescence), we lack an explicit, unified perspective for understanding how these processes contribute separately and synergistically to observed variation in functional traits. We propose a conceptual framework based on a developmental view of life-history variation, linking each ontogenetic stage with the types of individual differences originating during that period. In our view, the salient differences among these types are encapsulated by three key criteria: timing of onset, when fitness consequences are realized, and potential for reversibility. To fill a critical gap in this framework, we formulate a new term to refer to individual differences generated during adulthood reversible state effects. We define these as 'reversible changes in a functional trait resulting from life-history trade-offs during adulthood that affect fitness', highlighting how the adult phenotype can be repeatedly altered in response to environmental variation. Defining individual differences in terms of trade-offs allows explicit predictions regarding when and where fitness consequences should be expected. Moreover, viewing individual differences in a developmental context highlights how different processes can work in concert to shape phenotype and fitness, and lays a foundation for research linking individual differences to ecological and evolutionary theory.

Sharma, R., L. A. Velez-Espino, A. C. Wertheimer, N. Mantua and R. C. Francis (2013). "Relating spatial and temporal scales of climate and ocean variability to survival of Pacific Northwest Chinook salmon (Oncorhynchus tshawytscha)." Fisheries Oceanography 22(1): 14-31.

Pacific Northwest Chinook, Oncorhynchus tshawytscha, have exhibited a high degree of variability in smolt-to-adult survival over the past three decades. This variability is summarized for 22 Pacific Northwest stocks and analyzed using generalized linear modeling techniques. Results indicate that survival can be grouped into eight distinct regional clusters: (1) Alaska, Northern BC and North Georgia Strait; (2) Georgia Strait; (3) Lower Fraser River and West Coast Vancouver Island; (4) Puget Sound and Hood Canal; (5) Lower Columbia Tules; (6) Columbia Upriver Brights, Willamette and Cowlitz; (7) Oregon and Washington Coastal; and (8) Klamath River and Columbia River Summers. Further analysis for stocks within each of the eight regions indicates that local ocean conditions following the outmigration of smolts from freshwater to marine areas had a significant effect on survival for the majority of the stock groups analyzed. Our analyses of the data indicate that Pacific Northwest Chinook survival covaries on a spatial scale of 350450 km. Lagged time series models are presented that link large-scale tropical Pacific conditions, intermediate-basin scale northeastern Pacific conditions, and local sea surface temperatures to survival of Pacific Northwest stocks.

Skalski, J. R., M. B. Eppard, G. R. Ploskey, M. A. Weiland, T. J. Carlson and R. L. Townsend (2014). "Assessment of Subyearling Chinook Salmon Survival through the Federal Hydropower Projects in the Main-Stem Columbia River." North American Journal of Fisheries Management 34(4): 741-752.

High survival through hydropower projects is an essential element in the recovery of Pacific salmon Oncorhynchus spp. populations in the Columbia River. High dam passage survival is also a regulatory requirement under the 2008 Biological Opinion (BiOp; established under the Endangered Species Act) on Federal Columbia River Power System operation. The BiOp requires dam passage survival to be at least 0.96 and at least 0.93 for spring and summer out-migrating juvenile salmonids, respectively, and to be estimated with an SE of 0.015 or lower. An innovative virtual/paired-release design was used to estimate dam passage survival, which was defined as survival from the upstream face of a dam to the tailrace mixing zone. A coordinated four-dam study was conducted during the 2012 summer out-migration using 14,026 subyearling Chinook Salmon O. tshawytscha out-migrants with surgically implanted acoustic micro-transmitter tags. The release-recapture design consisted of 9 different release locations and 14 different detection arrays. Each of the four estimates of dam passage survival exceeded BiOp requirements, with values ranging from 0.9414 to 0.9747 (SE = 0.0031-0.0114). The virtual/paired-release design illustrated here has potential applicability wherever dam passage survival of migrant juvenile fish stocks must be estimated.

Skalski, J. R., M. A. Weiland, K. D. Ham, G. R. Ploskey, G. A. McMichael, A. H. Colotelo, T. J. Carlson, C. M. Woodley, M. B. Eppard and E. E. Hockersmith (2016). "Status after 5 Years of Survival Compliance Testing in the Federal Columbia River Power System (FCRPS)." North American Journal of Fisheries Management 36(4): 720-730.

Survival studies of juvenile Pacific salmon Oncorhynchus spp. implanted with acoustic tags have been conducted at hydroelectric dams within the Federal Columbia River Power System in the Columbia and Snake rivers between 2010 and 2014 to assess compliance with the dam passage survival standards stipulated in the 2008 Biological Opinion. For juvenile yearling Chinook Salmon O. tshawytscha and steelhead O. mykiss that migrate downstream in the spring, dam passage survival (defined as survival from the upstream dam face to the tailrace mixing zone) must be >= 96%, and for subyearling Chinook Salmon that migrate downstream in summer, dam passage survival must be >= 93%. Precision requirement stipulates a standard error <= 1.5% (i.e., a 95% confidence interval of +/- 3%). A total of 29 compliance tests have been conducted at six of eight main-stem dams in the Federal Columbia River Power System, using over 109,000 acoustic-tagged salmonid smolts. Of these 29 compliance studies, 23 met the survival standards and 26 met the precision requirements. Of the six dams evaluated to date, individual survival estimates range from 0.9597 to 0.9868 for yearling Chinook Salmon, from 0.9534 to 0.9952 for steelhead, and from 0.9076 to 0.9789 for subyearling Chinook Salmon. Averages across the six dams exceed the survival standards for all three migrant populations.

Sloat, M. R. and G. H. Reeves (2014). "Individual condition, standard metabolic rate, and rearing temperature influence steelhead and rainbow trout (Oncorhynchus mykiss) life histories." Canadian Journal of Fisheries and Aquatic Sciences 71(4): 491-501.

We reared juvenile Oncorhychus mykiss with low and high standard metabolic rates (SMR) under alternative thermal regimes to determine how these proximate factors influence life histories in a partially migratory salmonid fish. High SMR significantly decreased rates of freshwater maturation and increased rates of smoltification in females, but not males, after 1 year of rearing. Warmer water temperatures significantly decreased rates of freshwater maturation and increased rates of smoltification in both sexes. Variation in individual growth influenced the probability of adopting anadromy or freshwater residency as life histories, but produced paradoxical results. Individuals with the highest growth performance within their respective temperature treatments had a higher probability of freshwater maturation, but warmer temperatures decreased freshwater maturation despite significantly increasing somatic growth. Whole-body lipid content was significantly lower for fish reared in the warm temperature treatment, which may explain the decreased probability of freshwater maturation for individuals exposed to warmer temperatures. Our results indicate that changes in somatic growth induced by altered thermal regimes can influence the relationship between body size and the probability of maturation. Accordingly, somatic growth may not be a robust predictor of shifts in the prevalence of anadromy and residency in partially migratory salmonids when compared across thermal regimes.

Smith, S. G., D. M. Marsh, R. L. Emmett, W. D. Muir and R. W. Zabel (2013). A Study to Determine Seasonal Effects of Transporting Fish from the Snake River to Optimize a Transportation Strategy. Report by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, for the Walla Walla District, Northwestern Division, U.S. Army Corps of Engineers. : 218 pp.

• This report provides analyses of within-season patterns of smolt-to-adult return rates (SARs) relative to in-season juvenile migration timing and changing environmental conditions. SARs of juvenile fish that were transported from Lower Granite Dam (LGR) were compared to SARs of those that were bypassed at Lower Granite Dam and continued in-river migration through the lower Snake and Columbia Rivers in the years 1998 – 2009.
• This report does not include within-season analysis of fish transported from Little Goose or Lower Monumental Dams. Future reports from this study will include such analysis where it is possible given available data. This report does include analysis of annual data (pooling data across the entire migration season rather than analyzing patterns within the season) for Little Goose and Lower Monumental Dams, as well as the corresponding annual Lower Granite Dam data.
• To study seasonal SAR patterns, known dates of juvenile passage are required. Therefore, in-river migrant groups were formed from PIT-tagged fish that passed Lower Granite Dam via the juvenile bypass system (i.e., “bypassed” fish), the only passage route in which PITtagged fish were detected. However, during periods when non-tagged fish that enter the juvenile bypass system are collected and transported, in-river migrants among the non-tagged run-at-large are mostly fish that pass via non-bypass routes. There is evidence that SARs for bypassed fish are generally lower than those for the aggregate of fish that pass the collector projects via non-bypass (i.e. non-detection) routes. Thus, inference based on bypassed PITtagged fish might be

biased if applied to the in-river run at large might be biased. This report addresses the potential bias by carefully considering standards for assessment of SARs for transported fish relative to bypassed fish, adjusting standards appropriately to reflect the likely degree of difference between bypassed fish and the non-bypassed, non-detected, run at large.

• Historically, the measure for assessing the benefit of transport relative to in-river migration has often been called the transport-to-inriver ratio (T/I) or transport-to-migrant ratio (T:M). Here, we introduce the term "T:B ratio," so that it is clear that we are comparing [T]ransported and [B]ypassed fish.

• The T:B ratio is defined as the ratio of SAR for transported fish to the SAR for bypassed fish for corresponding groups. Statistical models produced estimated values for the SARs of the two groups for each day of the migration season for which there was data, and the T:B for each day was estimated from the SAR estimates.

• With respect to transportation from LGR, the SAR analysis in the report is an update of an analysis completed in 2009 (NOAA Fisheries 2010). We have added recent adult return data, extended the family of statistical models used to describe in-season patterns of SARs, and investigated environmental covariates to explain the observed patterns in SARs. A final difference between the analysis in this report and the previous one is the use of model averaging, a statistical technique based in information theoretic multi-model inference. The previous report showed only the "best-fit" models. The estimates of SAR and T:B reported here account for uncertainty in the selection of models, not just uncertainty in fitting a single selected model.

• Over the years, fish have been PIT tagged both upstream from LGR and at LGR. Tagging location was included as a potential factor in the models of SAR. In some cases where data were available from both tagging locations, SARs were not substantially different between tagging locations. In other cases, SARs differed substantially but relative SARs between transported and bypassed fish were very similar. In still others, both SARs and T:B differed depending on tagging location. Differences between tagging locations in annual SARs and T:B are quantified in a section on annual data.

• The basic unit of data on which the analyses were based was the estimated SAR for a daily group of fish. Independent analyses were conducted for each combination of species (yearling Chinook salmon or steelhead), rearing type (wild or hatchery), and migration year (1998-2009 for Chinook, 1998-2008 for steelhead). Each analysis included as many of the following four categories as were available: fish tagged upstream of LGR and transported from LGR; fish tagged upstream of LGR and detected and returned to river at LGR; fish tagged at LGR and transported from LGR; fish tagged at LGR and released in the tailrace of LGR. Although analyses were based on SARs for daily groups, there was too much sampling variability in the daily points for effective visual display. Instead, for illustration, we pooled daily groups into weekly periods and plotted estimated SARs for the weekly groups. Weekly points, with relatively less "noise," effectively summarized the daily data and provided a clearer picture.

• We used a statistical regression method (Poisson log-linear regression) to fit curves to the daily SAR data points, and to assess the fits statistically. Two phases of regression analysis were conducted using two sets of models: (1) descriptive models, with which patterns of SARs were traced through time; (2) explanatory models, with which we explored the potential to explain the temporal patterns using environmental variables. As with any regression method, the

resulting curves represent a “smoothing” of the data points, in this case the estimated daily SARs, and the data points themselves were “scattered” around the smoothed line.
• In the descriptive phase of the analysis, potential factors to explain SARs were migration group (transported or bypassed), tagging location, and date of passage (day of year). A quadratic term (“date squared”) was included to potentially fit SAR patterns that did not monotonically increase or decrease through time. Two- and three-way interactions among factors were also considered. Each of a pre-defined set of models was fit and informationtheoretic (AIC-based) methods were used to model-average the estimates of SARs and T:B.
• In the explanatory phase of the analysis, which is to be considered a pilot study, selected details of river and ocean environment were included as potential factors to explain the temporal patterns in SARs. From a suite of potential factors for which we have compiled data, for this analysis we selected the following: flow, spill percentage, water temperature, smolt passage index (an index of smolt abundance), and coastal upwelling. The full suite of factors is detailed in Appendix A. In future analyses, we will consider additional factors from this suite.
• In the explanatory phase, each of a pre-defined set of models was fit to the daily SAR data and resulting predicted SARs and T:B were model-averaged. The set of models included both covariate models and selected purely descriptive temporal models. If the temporal patterns were driven by the covariates, then we expect that the weight of the covariate models would be greater than the descriptive models.
• Daily T:B ratios estimated from the fitted SAR curves were assessed relative to two different “standards.” T:B greater than 1.0 indicated that among fish in the bypass system, those that were transported returned at a higher rate than those that were returned to the river. The second standard, designed for inference to the run at large, was based on a correction factor calculated to compensate for the overall difference in SARs between bypassed and neverbypassed fish. These correction factors “raised the bar” to a standard higher than a T:B of 1.0. The estimated bypass effect varied by year, species, and rearing type. The resulting annual alternative standards ranged from 1.01 to 1.03 for wild Chinook, and 1.03 to 1.12 for wild steelhead. For hatchery fish, the alternative standards ranged from 1.07 to 1.14 for Chinook and from 1.09 to 1.25 for steelhead. The alternative standards were devised so that T:B greater than the standard indicated that transported fish in the run at large returned at a higher rate than in-river migrants in the run at large.
• Regression results for each species/rearing-type/year were illustrated with a three-panel figure: one small panel for each tagging location showing point estimates of SAR for weekly pooled groups, with standard errors, and the model-averaged SAR curves from the regression for transported and bypassed fish; and one large panel showing the curves for T:B through the season derived from model-averaged SAR curves, along with 95% confidence “envelopes” around the T:B curves. Appendix B includes 46 such sets of figures for descriptive models, and Appendix C includes 46 such sets of figures for explanatory models. For comparison across years, we also produced figures that included a full set of (simplified) annual T:B panels, reduced in size so that all 11 or 12 years for a species/rearing-type combination would fit in one figure.
• The estimated curves for T:B ratios were summarized, relative to the 1.0 standard and the alternative standard, in a series of color-coded figures (Figures 6-9 and 19-22). Each horizontal

line in the figures represents one migration season for a species/rearingtype/tagging location combination, with a series of color-coded boxes representing days in the migration season. The color coding indicates on which days the estimated T:B was less than the standard, which days the estimated T:B was greater than the standard, and whether the difference between estimated T:B and standard was significant.

• A wide variety of patterns in SARs was observed. Though there are exceptions, for wild and hatchery Chinook salmon that were bypassed at LGR and migrated in the river, a common pattern was that SAR decreased from the beginning of the season (earliest fish to arrive at LGR) until the end (latest to arrive). The latest arriving bypassed fish (late May) almost always had the lowest SARs of the season. Transported Chinook salmon were more likely than bypassed fish to show a peak SAR sometime in the middle of the season, most commonly occurring in the second week of May. For transported Chinook salmon, the lowest SAR of the season was often for those that were transported earliest. Similar SAR patterns were seen for steelhead, though mid-season peaks were observed less often.

• For both wild and hatchery Chinook salmon, the estimated T:B ratio was usually nearly constant throughout the season or steadily increasing. In several years, the T:B ratio increased late in the season while SARs for both groups of fish were decreasing, indicating that the decline for bypassed fish was steeper than for transported. For wild steelhead, estimated T:B ratios were relatively constant throughout the season for 8 of the 10 migration years we could model. Hatchery steelhead exhibited more variation in patterns of T:B.

• For both species and both rearing types in all migration years before 2006, the estimated T:B ratio almost always exceeded the alternative standard (i.e., exceeded the “higher bar” and so therefore also exceeded the 1.0 standard) for fish that arrived at LGR on May 1 or later, and the difference was often statistically significant.

• The years deserving the greatest focus are the recent years (2006 – 2009) when the spill and transport program continued through the entire season regardless of flow conditions. Analyses of these recent migration years did not indicate radical departures from the patterns in temporal T:B ratios observed in earlier years. However, T:B ratios of hatchery steelhead may have changed – the only instances of significantly lower returns for transported hatchery steelhead occurred in the early parts of the 2007 and 2008 migration seasons (T:B increased through the season and exceeded standards by May 10 in both years).

• In migration years 2006-2009 there have been some exceptions to the post-May 1 pattern: estimated T:B still usually increased through the season, but there were instances when the estimate did not exceed the standards until later in May. It is difficult to determine at this point whether altered spill operations and returning all bypassed smolts to the river during the early part of the migrations in 2006-2009 have resulted in changed T:B ratios compared to earlier years. Estimated T:B ratios for some groups at LGR were apparently lower, at least early in the season. Adult returns are incomplete for some of these migration years, and final results cannot be evaluated for another year or two.

• The analysis of the relationship of SARs with selected explanatory covariates was not consistent across data sets. For about half of all data sets, models including at least one covariate were better than strictly descriptive models. For all species and rearing types, water temperature was most strongly associated with SAR among the covariates we investigated. Rankings among the other covariates varied between species and rearing types. With respect to

T:B standards, the explanatory models gave temporal results similar to those for descriptive models. Because the covariates are variable from day to day, the estimated SARs and T:B ratios are more variable in explanatory models.

• Average (geometric mean) annual estimates of T:B ratios for fish tagged upstream of LGR, based on pooling data across the entire migration season, were greater than 1.0 for both species and both rearing types from all dams. Including the 2001 migration year, the means ranged from 1.49 (wild Chinook salmon from Lower Granite Dam) to 3.62 (hatchery steelhead from Lower Granite Dam. Excluding 2001, the range was 1.28 (wild Chinook salmon from Lower Granite Dam) to 3.02 (wild steelhead from Little Goose Dam).

• The analysis of annual SARs and T:B ratios included comparisons based on tagging location. SARs for fish tagged at LGR tended to be lower than those for fish tagged upstream. This was true for both transported and bypassed fish, but the difference was greater for bypassed fish. The T:B ratios estimated from fish tagged at LGR tended to be higher (greater estimated benefit of transportation) than those estimated from fish tagged upstream. Across all species, rearing types, and dams, the average T:B from fish tagged at LGR was 19% higher than from fish tagged upstream. A probable cause for these observed differences are effects of handling and tagging at LGR (handling and tagging effects on fish tagged upstream have likely been expressed by the time fish arrive at LGR). Another probable factor contributiong to differences is that the mix of populations represented in the samples is different; fish tagged at LGR are a representative sample of the run at large passing the dam, while fish tagged at various upstream locations are not tagged in numbers proportional to the untagged populations.

• Just as this report for the 2011 study year includes data from multiple past years, future reports from this research project build and expand on these analyses. In this sense, this report represents a “living” document. To begin with, we will routinely update the analysis with additional adult return data as it becomes available. We will add within-season analyses of data from fish transported or bypassed from the juvenile bypass system at Little Goose Dam, and possibly at Lower Monumental Dam. The area of major novel research will be in expanding the pilot study of explanatory variables into a full-blown analysis of correlative factors and corresponding assessment of methods for using the results for in-season management based on quantitative environmental factors.

• The analyses presented in the report do not provide a complete basis for determining when to transport and when not. We direct readers to the 2008 Independent Scientific Advisory Board (ISAB) Report on transportation for more details about this subject. For example, the ISAB felt it was premature to select a management alternative based on historic data prior to conducting a thorough evaluation of the recent structural and operational modifications made to benefit in-river migrants, if this management decision precluded acquiring additional information on the in-river strategy.

Smith, S. G., T. M. Marsh and W. P. Connor (2017). Responses of Snake River Fall Chinook Salmon to Dam Passage Strategies and Experiences - DRAFT. Report for U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington, by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, Washington, and the Idaho Fishery Resource Office, U.S. Fish and Wildlife Service, Orofino, Idaho.

Snow, C. G. (2016). "Survival of Age-0 Hatchery Summer-Run Chinook Salmon is Enhanced by Early Release." North American Journal of Aquaculture 78(1): 45-51.

Subyearling (age-0) hatchery summer-run Chinook Salmon Oncorhynchus tshawytscha have been released into the Columbia River in mid-June from Wells Fish Hatchery, Washington, since 1993, but release-to-adult survival (SAR) under this strategy has been low. I used paired releases of four broods of coded-wire-tagged age-0 Chinook Salmon released in mid-May (early release [ER] group) and mid-June (late release [LR] group) to evaluate whether advancing the release date could improve SAR. Additionally, passive integrated transponder tags implanted in a subsample of each release group were used to estimate emigration rate and release-to-McNary Dam survival of juvenile fish. Mean migration rate from release to McNary Dam was significantly faster for LR fish than for ER fish. No among-year difference in mean survival from release to McNary Dam was observed between ER and LR groups, although differences were observed within years. Mean overall SAR was significantly greater for ER fish than for LR fish. These results suggest that altering the release date of age-0 Chinook Salmon at Wells Hatchery would enhance return survival.

Sorel, M. H., A. G. Hansen, K. A. Connelly and D. A. Beauchamp (2016). "Trophic Feasibility of Reintroducing Anadromous Salmonids in Three Reservoirs on the North Fork Lewis River, Washington: Prey Supply and Consumption Demand of Resident Fishes." Transactions of the American Fisheries Society 145(6): 1331-1347.

The reintroduction of anadromous salmonids in reservoirs is being proposed with increasing frequency, requiring baseline studies to evaluate feasibility and estimate the capacity of reservoir food webs to support reintroduced populations. Using three reservoirs on the north fork Lewis River as a case study, we demonstrate a method to determine juvenile salmonid smolt rearing capacities for lakes and reservoirs. To determine if the Lewis River reservoirs can support reintroduced populations of juvenile stream-type Chinook Salmon Oncorhynchus tshawytscha, we evaluated the monthly production of daphnia Daphnia spp. (the primary zooplankton consumed by resident salmonids in the system) and used bioenergetics to model the consumption demand of resident fishes in each reservoir. To estimate the surplus of Daphnia prey available for reintroduced salmonids, we assumed a maximum sustainable exploitation rate and accounted for the consumption demand of resident fishes. The number of smolts that could have been supported was estimated by dividing any surplus Daphnia production by the simulated consumption demand of an individual Chinook Salmon fry rearing in the reservoir to successful smolt size. In all three reservoirs, densities of Daphnia were highest in the epilimnion, but warm epilimnetic temperatures and the vertical distribution of planktivores suggested that access to abundant epilimnetic prey was limited. By comparing accessible prey supply and demand on a monthly basis, we were able to identify potential prey supply bottlenecks that could limit smolt production and growth. These results demonstrate

that a bioenergetics approach can be a valuable method of examining constraints on lake and reservoir rearing capacity, such as thermal structure and temporal food supply. This method enables numerical estimation of rearing capacity, which is a useful metric for managers evaluating the feasibility of reintroducing Pacific salmon Oncorhynchus spp. in lentic systems.

Stich, D. S., M. M. Bailey, C. M. Holbrook, M. T. Kinnison and J. D. Zydlewski (2015). "Catchment-wide survival of wild- and hatchery-reared Atlantic salmon smolts in a changing system." Canadian Journal of Fisheries and Aquatic Sciences 72(9): 1352-1365.

We developed a hierarchical multistate model to estimate survival of Atlantic salmon (Salmo salar) smolts in the Penobscot River, USA, over a decade during which two mainstem dams were removed from the catchment. We investigated effects of (i) environmental factors, (ii) rearing history, and (iii) management actions, including dam removal, turbine shutdown, and installation of new powerhouses. Mean +/- SD smolt survival per kilometre was higher through free-flowing reaches of the catchment (0.995 +/- 0.004.km(-1)) than through reaches containing dams that remain in the system (0.970 +/- 0.019.km(-1)). We observed maximum survival between 12 and 17 degrees C and at intermediate discharges (1200 m(3).s(-1)). Smolt survival increased concurrent with dam removal and decreased following increases in hydropower generation. The greatest increase in smolt survival followed seasonal turbine shutdowns at a dam located on the largest tributary to the Penobscot River, while other shutdowns had little influence. Our model provides a useful tool for assessing changes to survival of migratory species and will be useful for informing stocking plans to maximize numbers of smolts leaving coastal systems.

Stich, D. S., M. T. Kinnison, J. F. Kocik and J. D. Zydlewski (2015). "Initiation of migration and movement rates of Atlantic salmon smolts in fresh water." Canadian Journal of Fisheries and Aquatic Sciences 72(9): 1339-1351.

Timing of ocean entry is critical for marine survival of both hatchery and wild Atlantic salmon (Salmo salar) smolts. Management practices and barriers to migration such as dams may constrain timing of smolt migrations resulting in suboptimal performance at saltwater entry. We modeled influences of stocking location, smolt development, and environmental conditions on (i) initiation of migration by hatchery-reared smolts and (ii) movement rate of hatchery-and wild-reared Atlantic salmon smolts in the Penobscot River, Maine, USA, from 2005 through 2014 using acoustic telemetry data. We also compared movement rates in free-flowing reaches with rates in reaches with hydropower dams and head ponds. We compared movement rates before and after (1) removal of two mainstem dams and (2) construction of new powerhouses. Initiation of movement by hatchery fish was influenced by smolt development, stocking location, and environmental conditions. Smolts with the greatest gill Na+, K+-ATPase (NKA) activity initiated migration 24 h sooner than fish with the lowest gill NKA activity. Fish with the greatest cumulative thermal experience initiated migration 5 days earlier than those with lowest cumulative thermal experience. Smolts released furthest from the ocean initiated

migration earlier than those released downstream, but movement rate increased by fivefold closer to the ocean, indicating behavioral trade-offs between initiation and movement rate. Dams had a strong effect on movement rate. Movement rate increased from 2.8 to 5.4 km.h(-1) in reaches where dams were removed, but decreased from 2.1 to 0.1 km.h(-1) in reaches where new powerhouses were constructed. Movement rate varied throughout the migratory period and was inversely related to temperature. Fish moved slower at extreme high or low discharge. Responses in fish movement rates to dam removal indicate the potential scope of recovery for these activities.

Stich, D. S., G. B. Zydlewski, J. F. Kocik and J. D. Zydlewski (2015). "Linking Behavior, Physiology, and Survival of Atlantic Salmon Smolts During Estuary Migration." Marine and Coastal Fisheries 7(1): 68-86.

Decreased marine survival is identified as a component driver of continued declines of Atlantic Salmon Salmo salar. However, estimates of marine mortality often incorporate loss incurred during estuary migration that may be mechanistically distinct from factors affecting marine mortality. We examined movements and survival of 941 smolts (141 wild and 800 hatchery-reared fish) released in freshwater during passage through the Penobscot River estuary, Maine, from 2005 to 2013. We related trends in estuary arrival date, movement rate, and survival to fish characteristics, migratory history, and environmental conditions in the estuary. Fish that experienced the warmest thermal history arrived in the estuary 8 d earlier than those experiencing the coolest thermal history during development. Estuary arrival date was 10 d later for fish experiencing high flow than for fish experiencing low flow. Fish released furthest upstream arrived in the estuary 3 d later than those stocked further downstream but moved 0.5 km/h faster through the estuary. Temporally, movement rate and survival in the estuary both peaked in mid-May. Spatially, movement rate and survival both decreased from freshwater to the ocean. Wild smolts arrived in the estuary later than hatchery fish, but we observed no change in movement rate or survival attributable to rearing history. Fish with the highest gill Na+, K+-ATPase activity incurred 25% lower mortality through the estuary than fish with the lowest gill Na+, K+-ATPase activity. Smolt survival decreased (by up to 40%) with the increasing number of dams passed (ranging from two to nine) during freshwater migration. These results underscore the importance of physiological preparedness on performance and the delayed, indirect effects of dams on survival of Atlantic Salmon smolts during estuary migration, ultimately affecting marine survival estimates.

Stich, D. S., G. B. Zydlewski and J. D. Zydlewski (2016). "Physiological preparedness and performance of Atlantic salmon Salmo salar smolts in relation to behavioural salinity preferences and thresholds." Journal of Fish Biology 88(2): 595-617.

This study investigated the relationships between behavioural responses of Atlantic salmon Salmo salar smolts to saltwater (SW) exposure and physiological characteristics of smolts in laboratory experiments. It concurrently described the behaviour of acoustically tagged smolts

with respect to SW and tidal cycles during estuary migration. Salmo salar smolts increased their use of SW relative to fresh water (FW) from April to June in laboratory experiments. Mean preference for SW never exceeded 50% of time in any group. Preference for SW increased throughout the course of smolt development. Maximum continuous time spent in SW was positively related to gill Na+, K+-ATPase (NKA) activity and osmoregulatory performance in full-strength SW (measured as change in gill NKA activity and plasma osmolality). Smolts decreased depth upon reaching areas of the Penobscot Estuary where SW was present, and all fish became more surface oriented during passage from head of tide to the ocean. Acoustically tagged, migrating smolts with low gill NKA activity moved faster in FW reaches of the estuary than those with higher gill NKA activity. There was no difference in movement rate through SW reaches of the estuary based on gill NKA activity. Migrating fish moved with tidal flow during the passage of the lower estuary based on the observed patterns in both vertical and horizontal movements. The results indicate that smolts select low-salinity water during estuary migration and use tidal currents to minimize energetic investment in seaward migration. Seasonal changes in osmoregulatory ability highlight the importance of the timing of stocking and estuary arrival.

Swain, D. L. (2015). "A tale of two California droughts: Lessons amidst record warmth and dryness in a region of complex physical and human geography." Geophysical Research Letters 42(22): 9999-10003.

The state of California has experienced the worst drought in its historical record during 2012-2015. Adverse effects of this multiyear event have been far from uniformly distributed across the region, ranging from remarkably mild in most of California's densely populated coastal cities to very severe in more rural, agricultural, and wildfire-prone regions. This duality of impacts has created a tale of two very different California droughts-highlighting enhanced susceptibility to climate stresses at the environmental and socioeconomic margins of California. From a geophysical perspective, the persistence of related atmospheric anomalies has raised a number of questions regarding the drought's origins-including the role of anthropogenic climate change. Recent investigations underscore the importance of understanding the underlying physical causes of extremes in the climate system, and the present California drought represents an excellent case study for such endeavors. Meanwhile, a powerful El Nino event in the Pacific Ocean offers the simultaneous prospect of partial drought relief but also an increased risk of flooding during the 2015-2016 winter-a situation illustrative of the complex hydroclimatic risks California and other regions are likely to face in a warming world.

Swain, D. L., M. Tsiang, M. Haugen, D. Singh, A. Charland, B. Rajaratnam and N. S. Diffenbaugh (2014). "The Extraordinary California Drought of 2013/14: Character, Context, and the Role of Climate Change." Bulletin of the American Meteorological Society 95(9): S3-S7.

California's driest 12-month period on record occurred during 2013/14, and although global warming has very likely increased the probability of certain large-scale atmospheric conditions, implications for extremely low precipitation in California remain uncertain.

Teel, D. J., B. J. Burke, D. R. Kuligowski, C. A. Morgan and D. M. Van Doornik (2015). "Genetic Identification of Chinook Salmon: Stock-Specific Distributions of Juveniles along the Washington and Oregon Coasts." Marine and Coastal Fisheries 7(1): 274-300.

Thompson, J. N. and D. A. Beauchamp (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.

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-selectivemortality (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 x 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.

Thompson, J. N. and D. A. Beauchamp (2016). "Growth of juvenile steelhead Oncorhynchus mykiss under size-selective pressure limited by seasonal bioenergetic and environmental constraints." Journal of Fish Biology 89(3): 1720-1739.

Increased freshwater growth of juvenile steelhead Oncorhynchus mykiss improved survival to smolt and adult stages, thus prompting an examination of factors affecting growth during critical periods that influenced survival through subsequent life stages. For three tributaries with contrasting thermal regimes, a bioenergetics model was used to evaluate how feeding rate and energy density of prey influenced seasonal growth and stage-specific survival of juvenile O. mykiss. Sensitivity analysis examined target levels for feeding rate and energy density of prey

during the growing season that improved survival to the smolt and adult stages in each tributary. Simulated daily growth was greatest during warmer months (1 July to 30 September), whereas substantial body mass was lost during cooler months (1 December to 31 March). Incremental increases in annual feeding rate or energy density of prey during summer broadened the temperature range at which faster growth occurred and increased the growth of the average juvenile to match those that survived to smolt and adult stages. Survival to later life stages could be improved by increasing feeding rate or energy density of the diet during summer months, when warmer water temperatures accommodated increased growth potential. Higher growth during the summer period in each tributary could improve resiliency during subsequent colder periods that lead to metabolic stress and weight loss. As growth and corresponding survival rates in fresh water are altered by shifting abiotic regimes, it will be increasingly important for fisheries managers to better understand the mechanisms affecting growth limitations in rearing habitats and what measures might maintain or improve growth conditions and survival.

Thorstad, E. B., F. Whoriskey, I. Uglem, A. Moore, A. H. Rikardsen and B. Finstad (2012). "A critical life stage of the Atlantic salmon Salmo salar: behaviour and survival during the smolt and initial post-smolt migration." Journal of Fish Biology 81(2): 500-542.

The anadromous life cycle of Atlantic salmon Salmo salar involves long migrations to novel environments and challenging physiological transformations when moving between salt-free and salt-rich waters. In this article, (1) environmental factors affecting the migration behaviour and survival of smolts and post-smolts during the river, estuarine and early marine phases, (2) how behavioural patterns are linked to survival and (3) how anthropogenic factors affect migration and survival are synthesized and reviewed based on published literature. The timing of the smolt migration is important in determining marine survival. The timing varies among rivers, most likely as a consequence of local adaptations, to ensure sea entry during optimal periods. Smolts and post-smolts swim actively and fast during migration, but in areas with strong currents, their own movements may be overridden by current-induced transport. Progression rates during the early marine migration vary between 0.4 and 3.0 body lengths s-1 relative to the ground. Reported mortality is 0.37.0% (median 2.3) km^{-1} during downriver migration, 0.636% (median 6.0) km^{-1} in estuaries and 0.33.4% (median 1.4) km^{-1} in coastal areas. Estuaries and river mouths are the sites of the highest mortalities, with predation being a common cause. The mortality rates varied more among studies in estuaries than in rivers and marine areas, which probably reflects the huge variation among estuaries in their characteristics. Behaviour and survival during migration may also be affected by pollution, fish farming, sea lice Lepeophtheirus salmonis, hydropower development and other anthropogenic activities that may be directly lethal, delay migration or have indirect effects by inhibiting migration. Total mortality reported during early marine migration (up to 5230 km from the river mouths) in the studies available to date varies between 8 and 71%. Hence, the early marine migration is a life stage with high mortalities, due to both natural and human influences. Factors affecting mortality during the smolt and post-smolt stages contribute to determine the abundance of spawner returns. With many S. salar populations in decline, increased mortality

at these stages may considerably contribute to limit S. salar production, and the consequences of human-induced mortality at this stage may be severe. Development of management actions to increase survival and fitness at the smolt and post-smolt stages is crucial to re-establish or conserve wild populations.

Tiffan, K. F., T. J. Kock, W. P. Connor, F. Mullins and R. K. Steinhorst (2012). "Downstream Movement of Fall Chinook Salmon Juveniles in the Lower Snake River Reservoirs during Winter and Early Spring." Transactions of the American Fisheries Society 141(2): 285-293.

We conducted a 3-year radiotelemetry study in the lower Snake River to (1) determine whether juvenile fall Chinook salmon Oncorhynchus tshawytscha pass dams during winter, when bypass systems and structures designed to prevent mortality are not operated; (2) determine whether downstream movement rate varies annually, seasonally, and from reservoir to reservoir; and (3) identify some of the factors that contribute to annual, seasonal, and spatial variation in downstream movement rate. Fall Chinook salmon juveniles moved downstream up to 169 km and at a sufficiently fast rate (7.5 km/d) such that large percentages (up to 93%) of the fish passed one or more dams during the winter. Mean downstream movement rate varied annually (9.2-11.3 km/d), increased from winter (7.5 km/d) to spring (16.4 km/d), and increased (from 6.9 to 16.8 km/d) as fish moved downstream from reservoir to reservoir. Fish condition factor at tagging explained some of the annual variation in downstream movement rate, whereas water particle velocity and temperature explained portions of the seasonal variation. An increase in migrational disposition as fish moved downstream helped to explain the spatial variation. The potential cost of winter movement might be reduced survival due to turbine passage at a time when the bypass systems and spillway passage structures are not operated. Efforts to understand and increase passage survival of winter migrants in large impoundments might help to rehabilitate some imperiled anadromous salmonid populations.

Tiffan, K. F., R. W. Perry, W. P. Connor, F. L. Mullins, C. D. Rabe and D. D. Nelson (2015). "Survival, Growth, and Tag Retention in Age-0 Chinook Salmon Implanted with 8-, 9-, and 12-mm PIT Tags." North American Journal of Fisheries Management 35(4): 845-852.

The ability to represent a population of migratory juvenile fish with PIT tags becomes difficult when the minimum tagging size is larger than the average size at which fish begin to move downstream. Tags that are smaller (e.g., 8 and 9 mm) than the commonly used 12-mm PIT tags are currently available, but their effects on survival, growth, and tag retention in small salmonid juveniles have received little study. We evaluated growth, survival, and tag retention in age-0 Chinook Salmon Oncorhynchus tshawytscha of three size-groups: 40-49-mm fish were implanted with 8- and 9-mm tags, and 50-59-mm and 60-69-mm fish were implanted with 8-, 9-, and 12-mm tags. Survival 28 d after tagging ranged from 97.8% to 100% across all trials, providing no strong evidence for a fish-size-related tagging effect or a tag size effect. No biologically significant effects of tagging on growth in FL (mm/d) or weight (g/d) were observed. Although FL growth in tagged fish was significantly reduced for the 40-49-mm and 50-59-mm

groups over the first 7 d, growth rates were not different thereafter, and all fish were similar in size by the end of the trials (day 28). Tag retention across all tests ranged from 93% to 99%. We acknowledge that actual implantation of 8- or 9-mm tags into small fish in the fieldwill pose additional challenges (e.g., capture and handling stress) beyond those observed in our laboratory. However, we conclude that experimental use of the smaller tags for small fish in the field is supported by our findings.

Todd, C. D., K. D. Friedland, J. C. MacLean, B. D. Whyte, I. C. Russell, M. E. Lonergan and M. B. Morrissey (2012). "Phenological and phenotypic changes in Atlantic salmon populations in response to a changing climate." Ices Journal of Marine Science 69(9): 1686-1698.

Atlantic salmon (Salmo salar) of southern European origin migrating to the Norwegian Sea currently encounter anomalously high seasurface temperatures, and returning adults are of low mean condition factor. For the River North Esk (Scotland), time-series changes in river age-structure of emigrant smolts and returning one-and two-sea-winter (1SW and 2SW) adults are assessed. A comparison of the river age-structure of returning adults (1977-1999) with that of their respective annual emigrant smolt cohorts shows no evidence of river age-related bias in survivorship at sea. Evidence is presented of a possible transgenerational, or maternal, influence (poor somatic condition of spawners) driving reduced quality of emigrant S2 smolts in the North Esk. This effect is concurrent with an influence of freshwater climate as indicated by the North Atlantic Oscillation Index (NAOI). The maternal influence and NAOI variation in the winter immediately prior to smolt migration jointly explain approximately 29 (S2) and 17% (S3), respectively, of the variation in the mean size of smolts over the period 1975-2010. Run-timing of 1SW adult cohorts returning to Scotland shows recent delays. Variation in river flow did influence mean return date for the River Tweed, but adult condition factor, which itself shows temporal trends likely to be associated with ocean climate change, was the primary significant explanatory variable for run-timing in the rivers North Esk and Tweed. Overall, in years of poorer adult condition, 1SW salmon stay at sea longer.

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

Early ocean residence is considered a critical period for juvenile salmon although specific survival mechanisms are often unidentified and may vary by species or life stage. Columbia River spring-run Chinook salmon Oncorhynchus tshawytscha abundance has declined dramatically since the early 1900s. To elucidate mechanisms of early marine survival, we tested the 'bigger-is-better' and 'stage-duration' aspects of the 'growth-mortality' hypothesis, which posits that size and growth rate are important for future abundance. We tested the 'match-mismatch' hypothesis to determine whether early marine growth was related to indices related to regional productivity, including spring transition timing and copepod community composition. We generated estimates of individual size at ocean entry and capture, marine

growth rate, early marine migration rate, and emigration timing using data from ocean surveys, genetic stock-assignment, and otolith analyses of juveniles collected across 8 yr between 1998 and 2008. Size at capture and marine growth rate after similar to 30 d marine residence were positively related to future adult returns, whereas size at marine entry was not. Growth rate was not significantly related to indices of secondary production, but size at capture was significantly greater when lipid-rich copepods dominated. Although future adult abundance was not related to emigration timing, juveniles migrated more slowly when copepod biomass was high, perhaps responding to foraging conditions. Overall, processes during early ocean residence appear to be more important for cohort size establishment than those at marine entry. Approaches that combine genetic and otolith analyses have great potential to provide information on stock-specific variation in survival mechanisms.

Trammell, J. L. J., D. E. Fast, D. R. Hatch, W. J. Bosch, R. Branstetter, A. L. Pierce, J. W. Blodgett and C. R. Frederiksen (2016). "Evaluating Steelhead Kelt Treatments to Increase Iteroparous Spawners in the Yakima River Basin." North American Journal of Fisheries Management 36(4): 876-887.

Steelhead Oncorhynchus mykiss are iteroparous, distinguishing them from Pacific salmon Oncorhynchus spp. that are semelparous. In this study we evaluated enhancement techniques that exploit this life history strategy to facilitate species restoration and recovery. In the Columbia River basin, where the natural ecosystem has been substantially altered over several decades due to human influence, all steelhead populations are listed as threatened or endangered under the U.S. Endangered Species Act. One factor believed to be limiting survival of Columbia River kelt (postspawned) steelhead is poor migration success to the ocean past several dams. We evaluated three treatments for kelts captured in the Yakima River basin from 2002 to 2011: (1) transport and release below Bonneville Dam (to provide unimpeded access to the ocean); (2) short-term reconditioning (holding and feeding in an artificial environment to facilitate gonad maturation) with transport; and (3) long-term reconditioning. These treatments were compared with an in-river migration control group to identify differences in the rate at which kelts survived and returned to Prosser Dam for potential repeat spawning (hereafter repeat spawners). The long-term reconditioning treatment exhibited the highest return rate of repeat spawners (range, 11.5-17.6%). The short-term reconditioning treatment with transport downstream from Bonneville Dam had a 3.2% return rate. The transport only treatment exhibited the lowest return rate (0.9%); this was only onethird of the control group's return rate (2.7%). Our results indicate that long-term steelhead kelt reconditioning is more successful than either transportation or in-river migration alternatives at increasing potential repeat spawner abundance and providing recovery benefits in river systems that have experienced substantial losses in natural productivity due to loss of habitat and habitat connectivity.

Tucker, S., J. M. Hipfner and M. Trudel (2016). "Size- and condition-dependent predation: a seabird disproportionately targets substandard individual juvenile salmon." Ecology 97(2): 461-471.

Selection of prey that are small and in poor body condition is a widespread phenomenon in terrestrial predator-prey systems and may benefit prey populations by removing substandard individuals. Similar selection is widely assumed to operate in aquatic systems. Indeed, size-selective predation is a longstanding and central tenet of aquatic food web theory. However, it is not known if aquatic predators select prey based on their condition or state, compared to their size. Surprisingly, no comparable information is available for marine systems because it is exceedingly difficult to make direct observations in this realm. Thus the role of body condition in regulating susceptibility to predation remains a black box in the marine environment. Here we have exploited an ideal model system to evaluate selective predation on pelagic marine fish: comparing characteristics (fork length, mass corrected for fork length) of fresh, whole, intact juvenile Pacific salmon delivered by a seabird to its single nestling with salmon collected concurrently in coastal trawl surveys. Three species of juvenile salmon (Oncorhynchus spp.) are consumed by provisioning Rhinoceros Auklets (Cerorhinca monocerata); an abundant, colonial, pursuit-diving seabird. Samples were collected from multiple colonies and fisheries surveys in coastal British Columbia in two years. As predicted, Auklets preyed on small individuals in poor condition and consistently selected them at levels higher than their relative availability. This is the first study to provide direct evidence for both size- and condition-selective predation on marine fish in the wild. We anticipate that our results will be a starting point in evaluating how selective predation may structure or influence marine fish populations and bridges a fundamental incongruity between ecological theory and application; although "bigger is better" is considered a fundamental tenet of marine food webs, marine predators are often assumed to consume indiscriminately.

Tucker, S., M. E. Thiess, J. F. T. Morris, D. Mackas, W. T. Peterson, J. R. Candy, T. D. Beacham, E. M. Iwamoto, D. J. Teel, M. Peterson and M. Trudel (2015). "Coastal Distribution and Consequent Factors Influencing Production of Endangered Snake River Sockeye Salmon." Transactions of the American Fisheries Society 144(1): 107-123.

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.

U.S. Army Corps of Engineers (USACE). (2015). Transportation of Juvenile Salmonids, Snake River, Washington, and Idaho, Configuration and Operations Plan, 2015 udpate. Walla Walla, Washington, USACE, Walla Walla District.

The US Army Corps of Engineers (Corps) has transported juvenile salmonids through the lower Snake and Columbia River system, releasing them below Bonneville Dam, for three decades to aid in increasing adult returns of fish found within the Columbia River Basin. Lower Granite, Little Goose, and Lower Monumental Dams are the only projects with collection and transport capability on the lower Snake and Columbia Rivers. Prior to 2006, the proportion of juvenile salmonids transported was high (70% to 90% of collected migrants), but the proportion of fish transported decreased substantially in 2006 because of court-mandated spill. Historically, fish transportation consistently produced higher smolt-to-adult returns (SARs) than fish migrating in-river. However, the degree of benefit obtained from transport has decreased as in-river survival has increased because of improvements to fish passage facilities at Federal dams on the Columbia and Snake Rivers. In recent years, there has been little benefit provided for wild spring Chinook salmon from transport. In addition, great variability exists in the data with respect to species, origin, timing and location of transport, and environmental conditions. Significant concerns regarding the uncertainty and unintended impacts of transportation exist, including effects to species not evaluated in transport research (e.g., Pacific lamprey), selectivity of bypass systems, elevated adult straying rates of transported juvenile salmonids, and unknown ecological and evolutionary impacts to ESA-listed fish. Addressing these uncertainties is important in assessing the use of fish transportation in meeting long-term management goals.

ES1 Key Recommendations for Lower Snake River Projects

ES1.1 Operational

• Spring
Four general operational alternatives were considered for managing the transport program for spring migrants at lower Snake River projects. These four alternatives are:
• Alternative 1 is a spread-the-risk strategy to collect and transport approximately 50% of juvenile salmonids in the Snake River. It is only recommended in situations where little or no data are available to inform fish managers, or where uncertainty of effects is high. It would

manage transportation similar to current operations, except transport would begin earlier in the season to achieve a 50% transport goal for Snake River migrants.

- Alternative 2 would eliminate transportation, transport infrastructure, and associated operation and maintenance (O&M) costs. Assuming current conditions, this strategy would almost certainly result in substantially fewer adult returns.
- Alternative 3 would allow transportation only under emergency conditions (e.g., powerhouse outages resulting in dissolved gas levels exceeding safe limits). Limited transportation infrastructure would remain at Lower Granite, Little Goose, and Lower Granite Dams. This alternative would require continued O&M, with reductions in adult return benefits in most years.
- Alternative 4 (Recommended) is a managed risk strategy that seasonally manipulates collection proportion goals, based on temporal data patterns and the degree of confidence associated with those data. It would result in a more focused and efficient transport program. Some operational changes would potentially be required, but transport operations at projects downstream of Lower Granite and Little Goose Dams would likely be reduced. This alternative is the recommended strategy for operation of the juvenile transportation program.

- Summer

More data is needed to determine any difference in the way summer-run migrants are managed. Therefore, a managed risk strategy similar to that recommended for Snake River spring-run migrants is used for summer transport operations as well. Summer-run operations will continue as proposed in Appendix B of the 2015 Fish Passage Plan.

ES1.2 Structural

There are dramatic differences between species in benefits derived from transport. Recent studies (Marsh et al., 2010) indicate only minor benefit for transporting wild Snake River spring/summer Chinook salmon. Benefits are positive, however, for transporting Snake River Basin steelhead. Therefore, it appears desirable to install a juvenile fish size separator at Lower Granite Dam, but the ability of a juvenile fish size separator to separate fish of different sizes from debris in a non-stressful manner needs to be demonstrated. At this time, a juvenile fish size separator is an optional item for the Lower Granite Juvenile Fish Facility Upgrade.

Alternative 4 will rely heavily on transporting large numbers of fish during specific temporal periods at Lower Granite Dam. Therefore, improved infrastructure is necessary to ensure direct loading can occur safely and reliably under a wide range of conditions. High priority direct barge-loading related improvements beyond separation could include new adult/trash separation (to improve debris and adult fish handling/kelt management); an improved barge-loading boom, fishway flumes, etc. (to reduce fish stress and injury), and a new downstream barge-loading dock (to improve reliability and safety). After specific operations are developed for Alternative 4, further investigation will determine if additional barges or raceways are warranted to augment capacity for greater operational flexibility and increased SARs.

ES3 Critical Uncertainties and Required Research

Critical uncertainties remain regarding the effects of transportation on ESA-listed fish. Further exploration and data are required to determine the most efficient and beneficial transportation program. It is recommended the following research be conducted through the Anadromous Fish Evaluation Program (AFEP) process:

- Seasonal effects of transporting steelhead and Chinook salmon
- Effects of transportation on straying rates of adult salmon and steelhead
- Selectivity of juvenile bypass systems
- Evaluating effects of transportation on other species of interest, particularly Pacific lamprey
- Evaluating ecological and evolutionary effects of transportation
- Determine additional adults returning each year, by species, due to transport

ES4 Configuration and Operation Plan Updates

It is recommended that this Configuration and Operation Plan (COP), mandated initially by the 2008 Federal Columbia River Power System Biological Opinion, be updated on a regular basis to include the most relevant transport data. In this way, adaptive management can be applied successfully to the transport program. A transport report, detailing specific collection and transport numbers, operation dates, constraints and challenges for the year, river conditions, and updated SAR and T:B [1] ratios, should be completed and distributed to regional fish managers annually.

[1] Ratio of the SAR of fish transported from a specific collector project relative to the SAR of fish collected and bypassed at a collector project.

U.S. Army Corps of Engineers (USACE). (2016). 2016 Fish Passage Plan, U.S. Army Corps of Engineers, Northwestern Division, Lower Columbia & Lower Snake River Hydropower Projects, CENWD-PDW-R.

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

The transition between freshwater and marine environments is associated with high mortality for juvenile anadromous salmonids, yet little is known about this critical period in many large rivers. To address this deficiency, we investigated the estuarine ecology of juvenile salmonids and their associated fish assemblage in open-water habitats of the lower Columbia River estuary during spring of 2007–10. For coho (Oncorhynchus kisutch), sockeye (O. nerka), chum (O. keta), and yearling (age 1.0) Chinook (O. tshawytscha) salmon, and steelhead (O. mykiss), we observed a consistent seasonal pattern characterized by extremely low abundances in mid-April, maximum abundances in May, and near absence by late June. Subyearling (age 0.0) Chinook salmon were most abundant in late June. Although we observed interannual variation in the presence, abundance, and size of juvenile salmonids, no single year was exceptional

across all species-and-age classes. We estimated that >90% of juvenile Chinook and coho salmon and steelhead were of hatchery origin, a rate higher than previously reported. In contrast to juvenile salmonids, the abundance and composition of the greater estuarine fish assemblage, of which juvenile salmon were minor members, were extremely variable and likely responding to dynamic physical conditions in the estuary. Comparisons with studies conducted 3 decades earlier suggest striking changes in the estuarine fish assemblage—changes that have unknown but potentially important consequences for juvenile salmon in the Columbia River estuary.

Weitkamp, L. A., T. P. Good, D. E. Lyons and D. D. Roby (2016). "The Infl uence of Environmental Variation on the Columbia River Estuarine Fish Community: Implications for Predation on Juvenile Salmonids." North Pacifi c Anadromous Fish Commission 6: 33-44.

Predation is often assumed to be the ultimate cause of mortality for juvenile salmonids in marine waters, but the specific biological or physical factors that influence predation are poorly understood. The Columbia River estuary is a useful model ecosystem to understand the relationship between avian predators, alternative prey, environmental variation, and predation on juvenile Pacific salmonids (Oncorhynchus spp.). Here, we explore the influence of a suite of local and ocean basin-scale environmental variables on the composition and abundance of the estuarine fish assemblage, an important determinant of avian predation on juvenile salmon in the Columbia River estuary. Multivariate analyses indicated that variables representing both freshwater (river flow) and marine (ocean temperature, upwelling, plume volume) conditions explained up to half of the variation in the fish assemblage. Many of the same environmental variables were related to the abundances of individual fish species. Our results also suggest that the estuarine fish assemblage in the future will be quite different from the current one, with likely repercussions for predator-prey interactions. Our results from estuarine habitats provide a useful model for understanding the dynamics of predation in marine habitats, which are much more logistically difficult to study.

Weitkamp, L. A., D. J. Teel, M. Liermann, S. A. Hinton, D. M. Van Doornik and P. J. Bentley (2015). "Stock-Specific Size and Timing at Ocean Entry of Columbia River Juvenile Chinook Salmon and Steelhead: Implications for Early Ocean Growth." Marine and Coastal Fisheries 7(1): 370-392.

Juvenile salmon transitioning from freshwater to marine environments experience high variation in growth and survival, yet the specific causes of this variation are poorly understood. Size at and timing of ocean entry may contribute to this variation because they influence both the availability of prey and vulnerability to predators. To explore this issue, we used stock assignments based on genetic stock identification and internal tags to document the stock-specific size and timing of juvenile hatchery and presumed wild Columbia River Chinook Salmon Oncorhynchus tshawytscha and steelhead O. mykiss at ocean entry during 2007–2011. We found that juvenile salmon and steelhead had consistent stock-specific capture dates, with

lower-river stocks typically having earlier timing than those originating farther upstream. Mean size also varied among stocks and was related to hatchery practices. Hatchery yearling Chinook Salmon and steelhead were consistently larger than wild fish from the same stocks, although timing in the estuary was similar. In contrast, hatchery subyearling Chinook Salmon were of similar size to wild fish but entered the ocean up to a month earlier. We evaluated the potential importance of these traits on early marine growth by estimating stock-specific growth rates for Chinook Salmon caught in estuarine and ocean habitats. Growth rates were related to relative ocean entry timing, with lower growth rates for stocks that had only recently arrived in marine waters. Our results demonstrate that stocks within a single basin can differ in their size and timing of ocean entry, life history traits that contribute to early marine growth and potentially to the survival of juvenile salmon. Our results also highlight the necessity of considering stock-specific variation in life history traits to understand salmon ecology and survival across the entire life cycle.

Wells, B. K., J. A. Santora, M. J. Henderson, P. Warzybok, J. Jahncke, R. W. Bradley, D. D. Huff, I. D. Schroeder, P. Nelson, J. C. Field and D. G. Ainley (2017). "Environmental conditions and prey-switching by a seabird predator impact juvenile salmon survival." Journal of Marine Systems 174: 54-63.

Due to spatio-temporal variability of lower trophic-level productivity along the California Current Ecosystem (CCE), predators must be capable of switching prey or foraging areas in response to changes in environmental conditions and available forage. The Gulf of the Farallones in central California represents a biodiversity hotspot and contains the largest common murre (Uria aalge) colonies along the CCE. During spring, one of the West Coast's most important Chinook salmon (Oncorhynchus tshawytscha) populations out-migrates into the Gulf of the Farallones. We quantify the effect of predation on juvenile Chinook salmon associated with ecosystem level variability by integrating long-term time series of environmental conditions (upwelling, river discharge), forage species abundance within central CCE, and population size, at-sea distribution, and diet of the common murre. Our results demonstrate common murres typically forage in the vicinity of their offshore breeding sites, but in years in which their primary prey, pelagic young-of-year rockfish (Sebastes spp.), are less available they forage for adult northern anchovies (Engraulis mordax) nearshore. Incidentally, while foraging inshore, common murre consumption of out-migrating juvenile Chinook salmon, which are collocated with northern anchovy, increases and population survival of the salmon is significantly reduced. Results support earlier findings that show timing and strength of upwelling, and the resultant forage fish assemblage, is related to Chinook salmon recruitment variability in the CCE, but we extend those results by demonstrating the significance of top-down impacts associated with these bottom-up dynamics. Our results demonstrate the complexity of ecosystem interactions and impacts between higher trophic-level predators and their prey, complexities necessary to quantify in order to parameterize ecosystem models and evaluate likely outcomes of ecosystem management options. Published by Elsevier B.V.

Williams, J. G., S. G. Smith, J. K. Fryer, M. D. Scheuerell, W. D. Muir, T. A. Flagg, R. W. Zabel, J. W. Ferguson and E. Casillas (2014). "Influence of ocean and freshwater conditions on Columbia River sockeye salmon Oncorhynchus nerka adult return rates." Fisheries Oceanography 23(3): 210-224.

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

Williams, R. N., P. A. Bisson, D. L. Bottom, L. D. Calvin, C. C. Coutant, C. A. Frissell, D. Goodman, D. Lettenmeier, J. A. Lichatowich, W. J. Liss, E. J. Loudenslager, W. E. McConnaha, L. L. McDonald, P. R. Mundy, M. S. Powell, B. E. Riddell, J. A. Stanford and R. R. Whitney (2006). Return to the River: Restoring Salmon to the Columbia River. San Diego, California, Elsevier Academic Press.

Williams, S., E. Winther and C. M. Barr (2017). Report on the Predation Index, Predator Control Fisheries, and Program Evaluation for the Coumbia River Basin Northern Pikeminnow Sport Reward Program, 2016 Annual Report. Report by the Pacific States Marine Fisheries Commission, the Washington Department of Fish and Wildlife, and the Oregon Department of Fish and Wildlife, for the Environment, Fish and Wildlife Program, Bonneville Power Administration, U.S. Department Energy, Portland, Oregon: 140 pp.

This report presents results for year twenty-six in the basin-wide Northern Pikeminnow Sport Reward Program designed to harvest Northern Pikeminnow1 (Ptychocheilus oregonensis) in the Columbia and Snake Rivers. This program was started in an effort to reduce predation by Northern Pikeminnow on juvenile salmonids during their emigration from natal streams to the

ocean. Earlier work in the Columbia River Basin suggested predation by Northern Pikeminnow on juvenile salmonids might account for most of the 10-20% mortality juvenile salmonids experience in each of eight Columbia River and Snake River reservoirs. Modeling simulations based on work in John Day Reservoir from 1982 through 1988 indicated that, if predator-size Northern Pikeminnow were exploited at a 10-20% rate, the resulting restructuring of their population could reduce their predation on juvenile salmonids by as much as 40%.

To test this hypothesis, we implemented a sport-reward angling fishery and a commercial long-line fishery in the John Day Pool in 1990. We also conducted a hook and line fishery in areas inaccessible to the public at four dams on the mainstem Columbia River and at Ice Harbor Dam on the Snake River. Based on the success of these limited efforts, we implemented three test fisheries on a system-wide scale in 1991 - a tribal long-line fishery above Bonneville Dam, a sport-reward fishery, and a dam-angling fishery. Low catch of target fish and high cost of implementation resulted in discontinuation of the tribal long-line fishery. However, the sport-reward and dam-angling fisheries were continued in 1992 and 1993. In 1992, we investigated the feasibility of implementing a commercial long-line fishery in the Columbia River below Bonneville Dam and found that implementation of this fishery was also infeasible.

angling fisheries remained at the low end of our target range of 10-20%. This suggested the need for additional effective harvest techniques. During 1991 and 1992, we developed and tested a modified (small-sized) Merwin trapnet. We found this floating trapnet to be very effective in catching Northern Pikeminnow at specific sites. Consequently, in 1993 we examined a system-wide fishery using floating trapnets, but found this fishery to be ineffective at harvesting large numbers of Northern Pikeminnow on a system-wide scale. In 1994, we investigated the use of trapnets and gillnets at specific locations where concentrations of Northern Pikeminnow were known or suspected to occur during the spring season (i.e., March through early June). In addition, we initiated a concerted effort to increase public participation in the sport-reward fishery through a series of promotional and incentive activities. In 1995, 1996, and 1997, promotional activities and incentives were further improved based on the favorable response in 1994. Results of these and other lessons learned over the 26 year period are subjects of this annual report. Evaluation of the success of fisheries in achieving our target goal of a 10-20% annual exploitation rate on Northern Pikeminnow is presented in Report C of this report. Overall program success in terms of altering the size and age composition of the Northern Pikeminnow population and in terms of potential reductions in loss of juvenile salmonids to Northern Pikeminnow predation is also discussed in Report C. Program cooperators include the Pacific States Marine Fisheries Commission (PSMFC), Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fish and Wildlife (WDFW). The PSMFC is responsible for coordination and administration of the program; PSMFC subcontracted various tasks and activities to ODFW and WDFW based on the expertise each brings to the tasks involved in implementing the program. Roles and responsibilities of each cooperator are as follows.

1. WDFW (Report A): Implement a system-wide (i.e. Columbia River below Priest Rapids Dam and Snake River below Hells Canyon Dam) sport-reward fishery and operate a system for collecting and disposing of harvested Northern Pikeminnow.
2. PSMFC (Report B): Provide technical, contractual, fiscal and administrative oversight for the program. In addition, PSMFC processes and provides accounting for the reward payments to participants in the sport-reward fishery.
3. ODFW (Report C): Evaluate exploitation rate and size composition of Northern Pikeminnow harvested in the various fisheries implemented under the program together with an assessment of incidental catch of other fishes. Estimate reductions in predation on juvenile salmonids resulting from Northern Pikeminnow harvest and update information on year-class strength of Northern Pikeminnow.
4. WDFW (Report D): Implement dam angling at The Dalles and John Day dams. Background and rationale for the Northern Pikeminnow Management Program can be found in Report A of our 1990 annual report (Vigg et al. 1990).

Woodson, L. E., B. K. Wells, P. K. Weber, R. B. MacFarlane, G. E. Whitman and R. C. Johnson (2013). "Size, growth, and origin-dependent mortality of juvenile Chinook salmon Oncorhynchus tshawytscha during early ocean residence." Marine Ecology Progress Series 487: 163-175.

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

Zamon, J. E., T. A. Cross, B. P. Sandford, A. Evans and B. Cramer (2013). Measuring estuary avian predation impacts on juvenile salmon by electronic recovery of passive integrated

transponder (PIT) tags from bird colonies on East Sand Island, 2012, Report of research by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington and Real Time Research, Inc., Bend, Oregon, for the U.S. Army Corps of Engineers, Portland District, Northwestern Division, Portland, Oregon.

Avian predation on juvenile salmon and steelhead is one factor limiting the recovery of threatened and endangered populations of Pacific salmon Oncorhynchus spp. in the Columbia River Basin. To measure, monitor, and manage the effects of avian predation, estimated predation rates are needed for individual Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) of Pacific salmon. One method to estimate predation rates compares codes from passive integrated transponder (PIT) tags deposited on avian nesting colonies after fish are consumed by birds to all codes detected on presumed live fish in the geographic area of interest.

This report presents results from our project to recover PIT-tag codes from seabird colonies on East Sand Island in the Columbia River Estuary. Tag-code recoveries were used in collaboration with Bird Research Northwest to derive estimates of estuary predation on juvenile salmon by Caspian terns Hydroprogne caspia, double-crested cormorants Phalacrocorax auritus, and Brandt's cormorants P. penicillatus.

Here we present results from three primary study components:
1. PIT-tagging three groups of subyearling fall Chinook salmon O. tshawytscha from the Lower Columbia River ESU.
2. Recovery of PIT-tag codes from nesting colonies on East Sand Island 3. Estimation of estuary predation rates, including
i. Adjustments for tag-code detection efficiency and off-colony deposition rates where available
ii. Estuary predation rate estimates for ESU/DPS groups originating entirely above Bonneville Dam (Columbia River) or above Sullivan Dam (Willamette River)
iii. Estuary predation rate estimates for PIT-tagged Lower Columbia River Chinook salmon
iv. Estuary predation rate estimates for barge-transported vs. in-river migrant Snake River fall Chinook salmon originating above Lower Granite Dam

In May and June 2012, we PIT-tagged 8,885 Lower Columbia River fall Chinook salmon and released them directly into the estuary below Bonneville Dam. A subset of tags from these fish was subsequently detected on avian colonies. From these detections, we estimated that of the fish we released, 2.6% were consumed by Caspian terns, 14.9% by double-crested cormorants, and 0.8% by mixed species, including Brandt's cormorants.

On the East Sand Island Caspian tern colony, we recovered 15,298 unique tag codes from juvenile fish that migrated downstream in 2012. Tag codes recovered included those of fish from 13 Pacific salmon ESU/DPS groups listed as threatened or endangered under the U.S. Endangered Species Act. On the double-crested cormorant colony, we recovered 13,829 unique tag codes, also representing all 13 listed ESU/DPS groups.

Detection efficiencies varied through the season, and ranged from 42 to 90% on the Caspian tern colony and 56 to 81% on the double-crested cormorant colony. These efficiencies were comparable to those measured in prior years. Biologists from Bird Research Northwest used our tag-code recoveries for experiments designed to measure off-colony tag deposition of tags by double-crested cormorants. They estimated that 44% of tags consumed by double-crested cormorants were deposited on the colony, implying up to 56% of the tags consumed by these birds were deposited elsewhere. Data from this study were used to adjust estimated predation rates to account for off-colony deposition in groups originating above Bonneville Dam and Sullivan Dam.

We estimated estuary predation rates for groups of fish with geographical origins entirely above Bonneville Dam (Columbia River) or Sullivan Dam (Willamette River). These estimates showed Caspian terns having the greatest impact on steelhead (7.4-10.0%), with a lesser impact on other groups (0.7-2.2%). Double-crested cormorants had the greatest impact on steelhead from the upper Columbia River ESU (7.2%), with a range of impacts on other fish groups (0.6-5.4%). In general, Upper Willamette spring Chinook salmon experienced the least avian predation impact (<1%), and Brandt's cormorants appeared to have minimal impacts on all population groups we examined (<1%).

Fifty-two different sources contributed to PIT-tagged fish from the Lower Columbia River Chinook salmon ESU during migration year 2012; however, only three hatcheries above Bonneville Dam accounted for 66.3% of these fish. Estimated overall predation on tagged Lower Columbia River Chinook salmon was 0.91% for Caspian terns, 2.9% for double-crested cormorants, and 0.15% for mixed species including Brandt's cormorants. Fish included in the Lower Columbia River Chinook salmon ESU exhibit complex life history types, and there is no comprehensive, representative tagging program for the ESU as a whole. Therefore, inferences from these predation rates should not be made to the entire Lower Columbia River ESU, and generalizations to specific populations within the ESU should be made with caution.

All fall Chinook salmon that originate in the Snake River are included in the Snake River fall Chinook salmon ESU. For fish from this ESU, we compared predation impacts between barge-transported fish vs. in-river migrants in three ways. First, we calculated annual predation estimates using all available data from 2012. Second, we compared estimated weekly predation rates with weekly barge releases and detections at Bonneville Dam, where releases or detections exceeded 100 fish per week. Third, we compared estimates of daily predation for calendar days on which at least 100 fish from both barge-transported and naturally-migrating life histories occurred. Caspian terns and double-crested cormorants both had higher annual impacts on barge-transported fish (0.7 and 3.3%, respectively) than on in-river migrants (0.5 and 1.3%, respectively). Mixed species, including Brandt's cormorants, had similar impacts on in-river migrants (0.1%) and barged fish (<0.1%).

Paired comparisons of weekly estimated predation rates did not show any statistically significant differences between barged vs. in-river migrant fish for terns, cormorants, or mixed

species/Brandt's cormorants. However, paired comparisons of daily predation rates showed tern and double-crested cormorant predation were higher on transported fish (0.5 and 2.7%, respectively) than on in-river migrants (0.3 and 1.0%, respectively), although the difference was statistically significant only for cormorants. For mixed species including Brandt's cormorants, predation rates were identical for transported vs. in-river migrant fish (0.2%). The implication is that barging in 2012 did not necessarily decrease estuary avian predation on Snake River fall Chinook salmon. However, on East Sand Island, a significant number of PIT-tag codes from in-river migrants were recovered (n = 1,891) that had not been detected at Bonneville Dam. Thus, there may be more predation on in-river migrants than we could measure in this study.

To improve understanding of estuary avian predation on Columbia River salmon, we recommend that future work include support to determine the mechanisms driving variation in seasonal and annual predation rates. We also recommend that
1) A comprehensive tagging program be developed for Lower Columbia River Chinook salmon to more accurately characterize overall estuary predation for this ESU
2) An effort be made to improve detection numbers at Bonneville Dam for estuary entry timing of in-river migrant Snake River fall Chinook salmon.

Zamon, J. E., J. M. Mannas, B. P. Sandford, A. Evans and B. Cramer (2014). Measuring estuary avian predation on juvenile salmon by electronic recovery of passive integrated transponder tags from nesting colonies, 2013, Report of research by the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington, and Bird Research Northwest via Real Time Research, Inc., Bend, Oregon for the U.S. Army Corps of Engineers, Portland District, Northwestern Division, Portland, Oregon.

Avian predation is one factor limiting the recovery of threatened and endangered populations of Pacific salmon Oncorhynchus spp. in the Columbia River Basin. To measure, monitor, and manage the effects of avian predation, estimated predation rates are needed for individual Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) of Pacific salmon. One method to estimate predation rates is to retrieve codes from passive integrated transponder (PIT) tags deposited on avian nesting colonies after birds have consumed a tagged juvenile fish. Proportions of fish consumed (number consumed/number available) can then be estimated for all PIT-tagged salmonids in that group. If the tagged group is representative of a specific ESU or DPS, avian predation impacts can then be extrapolated to non-tagged fish in that ESU or DPS.

This report presents results from recovery of salmonid PIT tag codes after the breeding season on three seabird colonies on East Sand Island in the Columbia River Estuary. Tag-code recoveries were used in collaboration with Bird Research Northwest to derive estimates of estuary predation on juvenile salmonids by Caspian terns Hydroprogne caspia, double-crested cormorants Phalacrocorax auritus, and Brandt's cormorants P. penicillatus.

We present results from the following two primary study components:
1. Recovery of PIT-tag codes from nesting colonies on East Sand Island
2. Estimation of ESU/DPS-specific estuary predation rates, including
i. Adjustments for tag-code detection efficiency and on-colony deposition rates where available
ii. Estimates of estuary predation rate for 10 ESU/DPS groups originating above Bonneville Dam (Columbia River) or above Sullivan Dam (Willamette River)
iii. Reporting of tag releases and recoveries of PIT tag codes from Lower Columbia River Chinook salmon found on East Sand Island
iv. Minimum estimates of estuary predation rate for barge-transported and in-river migrant Snake River salmon and steelhead originating at or above Lower Granite Dam

On the East Sand Island Caspian tern colony, we recovered 11,860 unique PIT tag codes from juvenile fish that migrated downstream in 2013. Tag codes recovered included fish from 10 of the 13 Pacific salmon groups tagged in 2013 that were listed as threatened or endangered under the U.S. Endangered Species Act. On the double-crested cormorant colony, we recovered 11,020 unique tag codes, also representing all 10 listed groups.

Daily detection efficiencies of PIT-tag codes on East Sand Island varied through the nesting season, ranging from 41 to 72% on the Caspian tern colony and 45 to 72% on the double-crested cormorant colony. These efficiency ranges were comparable to those measured in prior years. However, we did detect a downward trend in detection efficiencies on the tern colony beginning in 2009. This suggests PIT tags are accumulating in surface layers and causing tag-code collisions, which reduce efficiency when scanning for tags.

Bird Research Northwest used our tag-code recovery data to estimate on-colony tag deposition rates by double-crested cormorants. They estimated that 60% (95% CI = 47-73%) of tags consumed by double-crested cormorants were deposited on the colony, implying that up to 40% of the tags consumed by double-crested cormorants were deposited off-colony. Detection efficiency and on-colony deposition adjustments were used to estimate 2013 predation rates for PIT-tagged groups of salmonids originating above Bonneville Dam and Sullivan Dam.

We estimated estuary predation rates for in-river-migrant PIT-tagged fish from 10 ESUs/DPSs with geographical origins above Bonneville Dam (Columbia River) or Sullivan Dam (Willamette River). Deposition-adjusted estimates showed Caspian terns had the greatest impact on steelhead DPSs (8.6-12.5%, depending on DPS), with a lesser impact on salmon ESUs (0.6-1.4%, depending on ESU). By ESU/DPS, double-crested cormorants had the greatest impact on Snake River spring/summer Chinook salmon (2.9%), with impacts ranging 0.7-2.6% on other groups. Double-crested cormorant predation on salmonids declined compared to 2012, even though the number of breeding pairs increased and reproductive success was higher on East Sand Island in 2013. In general, Upper Willamette River spring Chinook salmon experienced the least avian predation impact (< 1.0% for both Caspian terns and double-crested cormorants), and Brandt's cormorants appeared to have minimal impacts (<0.3%) on all groups evaluated in 2013.

Fish included in the Lower Columbia River Chinook salmon ESU exhibit complex life history types, and while some components of this ESU are PIT-tagged, there is no comprehensive, representative PIT-tagging program for the ESU as a whole. Thirteen different sources contributed a total of 97,255 PIT-tagged juveniles from the Lower Columbia River Chinook salmon ESU during migration year 2013. However, just three hatcheries above Bonneville Dam accounted for 72% of these fish. Due to this extremely skewed representation of the ESU in the PIT-tagged groups, we elected not to estimate predation rates on this ESU. Many groups from this ESU, including wild fish above and below Bonneville Dam, were clearly not represented by tagging in 2013.

However, we did evaluate tag recoveries from avian colonies on East Sand Island for Lower Columbia River Chinook salmon, and those recoveries indicated the following patterns: (1) the majority of tag codes (83.6%) were detected on the double-crested cormorant colony, (2) the majority of tagged fish detected on a colony were released from a hatchery on or before 1 May (75.3%), and (3) 78.7% of all tag codes recovered on East Sand Island originated from releases that occurred on or before 2 May 2013. These results suggest that existing tagged hatchery releases from this ESU are particularly susceptible to double-crested cormorant predation.

During 2013, 123,595 PIT-tagged sockeye, steelhead, and Chinook salmon from the Snake River were transported through the hydropower system by barge and released directly below Bonneville Dam; of these, 4,035 were recovered on East Sand Island bird colonies. At Bonneville Dam, 26,469 in-river migrants from the Snake River were detected; of these, 719 were subsequently recovered on East Sand Island bird colonies. We compared avian predation impacts between barge-transported fish vs. in-river migrants in two ways. First, we estimated minimum annual predation using all available data from 2013. Second, we compared estimated minimum weekly predation between barge release groups and in-river migrants detected at Bonneville Dam for weeks during which at least 100 tagged fish were present in both groups.

When examining patterns in estimates of minimum annual predation rates for transported vs. in-river migrant Snake River fish, qualitative comparisons suggest barged fish experience lower tern predation but higher cormorant predation. Caspian terns had the largest impacts on steelhead (4.7-9.0%), as did double-crested cormorants (1.0-2.3%). All groups experienced low predation from Brandt's cormorants (</= 0.2%). When comparing estimated mean minimum weekly predation rates of barged fish and in-river migrants, unpaired t-tests did not show statistically significant differences in 12 possible comparisons. Results imply that barging in 2013 was not linked to large changes in susceptibility of Snake River salmon or steelhead to estuary avian predation. However, sample sizes for statistical comparison were small (n </= 8), and therefore the power of the tests to detect anything but large differences between mean minimum predation rates was relatively weak. In addition, test results would be confounded if there is any as-yetunidentified
within-season temporal variation in the vulnerability of barged fish or in-river migrants.

To improve understanding of estuary avian predation on Columbia River salmon, including the potential effects of barge transport on Snake River groups, we recommend that future work

include support to determine the mechanisms driving variation in seasonal and annual predation rates. Specifically, we recommend
1. Measurement of temporal and spatial abundance of dominant non-salmonid prey species in the estuary, to test whether or not annual and weekly/seasonal changes in predation rates are correlated with changes in the availability of non-salmonid prey species, and
2. A synthesis of multiple years of data for barged fish vs. in-river migrant comparisons, to improve the statistical power necessary to resolve what, if any, biologically meaningful differences exist in estimated minimum predation rates

With specific regard to basin-wide PIT tag programs, improvement in our ability to measure and resolve avian predation estimates would benefit from
1. A comprehensive tagging and interrogation program for Lower Columbia River salmonids, to more accurately characterize overall estuary predation for this ESU as a whole
2. Improvements to PIT-tag detection capability at Bonneville Dam, or as close to estuary entry as possible, so as to provide sufficient detection