The Marine Ecology of Juvenile Columbia River Basin Salmonids: A Synthesis of Research 1998-2011

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Report of the U.S. National Marine Fisheries Service,
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to

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Preface

Beginning in the late 1990s, the Bonneville Power Administration (BPA) funded three multi-year research, monitoring, and evaluation projects to determine the impacts of variable ocean conditions on Columbia River salmon. These projects are referred to collectively as the "ocean projects." They are comprised of the *Ocean Survival of Salmonids Study* by the National Marine Fisheries Service, National Oceanic and Atmospheric Association (NOAA), which began in 1998; the *Canada-USA Salmon Shelf Survival Study*, which has been conducted by the Fisheries and Oceans Canada (DFO) since 1999; and the *Coastal Ocean Acoustic Salmon Tracking* project (formerly Pacific Ocean Shelf Tracking Project), which was initiated by Kintama Research Services Ltd. (Kintama) in 2005.

In 2010, NOAA, DFO, and Kintama submitted independent but highly complementary proposals to address the 2009 *Ocean Strategies of the Columbia River Basin Fish and Wildlife Program* in response to a BPA request for proposals. During the review process, the Independent Scientific Review Panel (ISRP) stressed the importance of increasing the time series of data generated by the ocean projects.

Although each of the three ocean projects received highly favorable reviews from the ISRP and were considered to "meet the scientific review criteria," the ISRP provided a conditional qualification: that a synthesis report for the ocean projects be produced to "develop a strategic plan that prioritizes project hypotheses and management objectives" (ISRP 2010-44B). The ISRP also highlighted the need to "improve coordination and collaboration, standardization of methods (e.g., genetic stock identification), development of simulation and predictive models, and integration of results among Columbia River Basin estuary/ocean projects." In support of these ISRP suggestions, the Northwest Power and Conservation Council (NPCC) stated:

> We recommend that project sponsors jointly complete a comprehensive synthesis report per the ISRP comments. An important element to this synthesis report will be the inclusion of potential salmon management implications and recommendations based on the information collected and evaluated....The sponsors should address where appropriate, the qualifications raised by the ISRP in their final review (ISRP 2010-44B). Also we recommend that the proponents ensure data collected is standardized and accessible.

In response to this request, NOAA, DFO, and Kintama have coordinated efforts to produce this synthesis report.

Objectives of this report are to:

1) Provide the details of what has been investigated and learned to date, the conclusions that can be drawn from this knowledge now, and the expected time frame for the research to yield further conclusions
2) Identify potential salmon management implications, and where possible, provide recommendations for management based on the information collected
3) Describe how the complementary research projects will continue to be coordinated and managed from this point forward, including standardized data collection and improved data accessibility.

The document begins with an executive summary and an introduction followed by a discussion of our research results. We continue with a presentation of our forecasts of salmon returns, along with management implications, and conclude with a discussion of data gaps, uncertainties, and future research needs.

For each project, a detailed response to ISRP comments was submitted separately to the NPCC in late 2010. These responses are included in the appendices of this report as supplementary information (Appendix H, I, and J). To keep this report reasonably concise, most technical details on the methods used for data collection and analyses have been omitted. Complete information on these methods and results can be obtained from the annual reports submitted to Bonneville Power Administration by each project sponsor. All reports are readily available online via the BPA Pisces website.

Executive Summary

After decades of harvest, habitat, and hatchery impacts, and the completion of federally constructed hydropower dams in the Columbia River system, populations of Pacific salmon *Oncorhynchus* spp. declined drastically. There are now 13 Evolutionary Significant Units (ESUs) of Pacific salmon listed as either threatened or endangered under the U.S. Endangered Species Act (ESA). During the 1980s and 1990s, mitigation efforts for dwindling salmon and steelhead (*O. mykiss*) stocks focused on improving survival of juvenile migrants through each dam and on restoring freshwater habitats to improve adult spawning opportunities. Despite the relative effectiveness of these mitigations, the 13 ESUs continue to be listed under the ESA.

It is now recognized that during this same period, ocean survival of Columbia River salmon was anomalously low, and likely contributed to the observed declines in salmonid abundance. Poor ocean conditions were thought to be part of the problem. Several studies identified a number of physical oceanographic metrics that were strongly correlated with salmon survival. However, in spite of strong correlations between metrics such as sea surface temperature, upwelling strength, and the Pacific Decadal Oscillation (PDO), no mechanistic link was identified between large-scale physical ocean processes and the local physical and biological conditions that juvenile salmon experience. In the absence of clear and direct mechanistic links, these initial attempts to forecast juvenile salmon survival met with limited success.

To rectify this problem, the Bonneville Power Administration Fish and Wildlife Division (BPA) began an effort in the late 1990s to improve our understanding of how local ocean conditions affect juvenile salmon survival. Three projects have since been initiated to address the role of the ocean in overall survival of Columbia River basin salmonid stocks

Two of these, the *Ocean Survival of Juvenile Salmonids* study and the *Canada-USA Salmon Shelf Survival* study, are research partnerships established between BPA, National Marine Fisheries Service, National Oceanic and Atmospheric Association (NOAA) and Fisheries and Oceans Canada (DFO). These programs study juvenile salmon as they enter the ocean and during their first few months of marine residence, as well as monitor the ocean conditions experienced by these fish. The primary focus of both projects is to determine the physical, biological and ecological mechanisms that control survival of salmon during their early marine life. By collecting comparable and complementary biological and oceanographic data, these projects provide broad coverage of the plume and continental shelf waters exploited by Columbia River juvenile salmon.

A third ocean study (the *Coastal Ocean Acoustic Salmon Tracking* project) was initiated in 2005 by Kintama Research Services, Ltd. (Kintama), in order to better quantify where juvenile salmon mortality occurs. Acoustic tags were used to track juvenile salmon migration and mortality through the Columbia River hydropower system and into the coastal ocean. The information provided by this study is complimentary to that provided by the NOAA and DFO studies because it identified regions of early ocean mortality.

Research by these BPA-funded ocean projects has produced the following new insights as to when mortality occurs during the juvenile migration and which factors affect the survival of Columbia River juvenile salmon during early ocean residence:

- Different populations of Columbia River salmon migrate at different times and speeds. For example, acoustic tagging has shown that spring Chinook salmon (*O. tshawytscha*) migrate rapidly through the estuary; their survival is highest in the estuary, lowest in the Columbia River plume, and similar within the Columbia River hydrosystem corridor and the coastal ocean. Otolith analysis has shown that mean northward migration rates of interior Columbia River yearling Chinook during the first months at sea are higher during years of poor ocean conditions, suggesting juveniles may modify their migratory behavior based on ocean conditions.

- Different species and stocks occupy different habitats in the coastal ocean. Fall-run Chinook are most commonly found in the near-shore areas from the intertidal zone to within a few kilometers of shore. Spring-run Chinook are most often found from the near-shore zone to mid-shelf waters, whereas coho salmon (*O. kisutch*) range across the entire shelf. Some stocks appear to be residents of Pacific Northwest shelf waters (most fall Chinook and coho stocks) while others migrate farther north along the coastal corridor (spring Chinook, sockeye (*O. nerka*), and some coho salmon).

- There are large interannual fluctuations in abundance of juvenile salmon in the ocean that relate to adult returns; these fluctuations persist despite relatively stable production from Columbia River Basin hatcheries. Species and stocks differ as to when year class strength is determined. Our results suggest that juvenile salmon survival is set within the first year of marine residency and is partially related to food-web structure and growth conditions in the plume and coastal ocean.

- Food-web structure is set by large-scale atmospheric forcing associated with the PDO, which appears to control the types of water which feed the northern California Current. When currents flow from the north (coastal Gulf of Alaska), the base of the food web is dominated by lipid-rich northern copepod species; when water originates from the west or the south (subtropical water), the food web is dominated by lipid-poor copepod species. Differences in circulation patterns account for differences in prey abundance, composition, and quality (i.e. lipids) at the lower trophic levels. The distribution and abundance of predators (piscivorous fish and birds) and forage fish (smelts and anchovies) is also influenced by circulation patterns.

- Juvenile salmon need a lipid-rich food supply to realize their growth potential, and such a food supply is a characteristic of good ocean conditions. In contrast, poor ocean conditions result in a lipid-poor food web, which is detrimental for salmon. Juvenile salmon entering the ocean rapidly shift to a diet of primarily fish and krill and preferentially feed on taxa rich in essential fatty acids. Interannual variation in the quantity and type of prey available to juvenile salmon appears to influence the relative survival of Columbia River salmon populations.

- Predation on juvenile salmon varies interannually and spatially thus top down control appears to be mediated in part by oceanographic conditions. Predation by piscine predators (e.g. Pacific hake (*Merluccius productus*)) is higher during years of warm ocean conditions because these oceanic fishes move into warm continental shelf waters. In contrast, avian predation appears to modulate juvenile salmon survival at a local level (in and around the Columbia River plume and associated ocean-plume fronts). The prevalence of the salmon pathogen *Renibacterium salmoninarum* varies interannually by salmon species and stocks, in contrast to the freshwater parasite *Nanophyetus salmincola,* which appears to influence early marine survival of coho salmon irrespective of ocean conditions.

- Growth of juvenile coho, Chinook salmon and steelhead correlates positively with ocean survival and adult returns supporting the growth – survival hypothesis. Mortality of yearling Chinook appears to be regulated by bottom-up processes whereas the smaller subyearlings may be regulated by other factors. Mean body size and early marine growth in yearling Chinook is positively correlated with adult returns; conversely body condition of subyearling Chinook is negatively correlated with adult returns.

- In some years, a larger Columbia River plume (charactersitics of which can be predicted from a combination of river discharge and winds over the continental shelf) was associated with higher survival of some salmonid stocks. Acoustic telemetry demonstrates that river and ocean survival rates through the Columbia River hydropower corridor and coastal ocean are similar supporting the hypothesis that early ocean mortality can be substantial.

- Mortality during winter can also be substantial (80-90%), though the cause of this high mortality is unknown at southern latitudes. Size-selective overwinter mortality was apparent at northern latitudes, but not at southern latitudes. Hence, winter mortality is expected to affect different stocks of Columbia River salmon differently based on the migration behavior.

Our work is not finished. The recent variability in the PDO has provided a natural range of experimental conditions with which we can compare the response of juvenile salmon to a large variety of ocean conditions. Specifically, the years 2005 and 2008 provide pronounced contrasts in ocean conditions, with 2005 extremely warm due to a near-complete lack of upwelling and 2008 anomalously cold due to a strongly negative PDO. In addition, 2001 was a drought year; thus the volume of the Columbia River plume was reduced. We have also sampled during a major El Niño event in 1998 and during two smaller but significant events during 2003-2004 and 2009-2010. As a result, however, over the past 14 years, salmon have not experienced the same combinations of ocean conditions in any given year more than once. A longer time series is needed to track the responses of salmon to these recent high-frequency variations in the PDO and ENSO and associated variations in local ocean conditions. These data are necessary if we are to further explore biological responses to the increasingly variable conditions expected in the future.

This will require continued coordination and collaboration of the sampling programs initiated by NOAA and DFO as well as an integration of the direct area-specific mortality rates measured by Kintama. A coordination meeting will be organized each year and scheduled to coincide with the annual "Salmon Ocean Ecology" workshop, a meeting that NOAA and DFO have organized each spring since 1999.

The ocean projects have produced information that can inform management within the Columbia River Basin in three main areas. First, because of the role of ocean conditions in affecting adult returns, periods of high or low ocean productivity can mask underlying trends in freshwater habitat productivity and could lead to a misinterpretation of the proximate cause of the trend. Knowledge of the response of salmon to ocean conditions is key to providing the proper context for judging the effectiveness of habitat restoration, hatchery reform, harvest management, and hydropower system improvements being implemented to restore listed and wild salmon stocks.

Second, the combination of physical and biological information collected as part of the ocean projects has led to the development of simple models that now provide outlooks of future salmon returns. With a longer time series these metrics are expected to increase the accuracy of current forecasting.

Third, the ocean projects have improved our understanding of the responses of stocks with different life-history characteristics to variable ocean conditions. We anticipate that knowing the mechanisms that link ocean conditions with stock-specific salmon survival will be useful to managers as we jointly seek to identify specific 4-H actions that improve salmon returns in the Columbia River. Thus, we advocate a dialogue between scientists, managers, and policy makers initiated through several workshops to discuss the implications of the results obtained as part of the ocean projects for the management of Columbia River salmon with regards to the 4-H issues.

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I. Introduction

Problem Statement

Columbia and Snake River salmonid stocks comprise one of the most valuable commercial and recreational fisheries on the west coast of North America. Annual returns of salmon and steelhead to the Columbia River basin during the late 1800s were on the order of 10-16 million fish. However, after years of over-harvest, habitat destruction, increased hatchery production, and development of the hydropower system, returns declined precipitously to roughly one-half million during the 1980s and 1990s.

Various measures have been implemented to protect and recover the stocks of wild and ESA-listed fish (Pacific salmon listed as either threatened or endangered under the U.S. Endangered Species Act, ESA). These include harvest reduction, habitat restoration, hatchery enhancement and hydropower regulation—often referred to as the four Hs. However, it is now clear that variability in marine ecosystem productivity drives much of the variability in adult salmon returns. Ocean conditions can mask, enhance, or even override actions taken to improve salmon runs in freshwater habitats of the Columbia River basin. Hence, the ocean environment can no longer be treated as a black box and must be considered explicitly by resource managers.

In the mid-1990s, the Northwest Power and Conservation Council (the Council) recognized the need to include the ocean environment in the management of Columbia River Basin salmonids. The Gorton amendment to the Northwest Power Act states: "In making its recommendation to BPA, the Council shall: consider the impact of ocean conditions on fish and wildlife populations…" (Northwest Power Act 1996).

To fulfill this directive, the Council considered the role of the ocean in salmon recruitment and incorporated this role into their research program in three ways. First, they adopted an approach to directly obtain explicit, quantitative information on marine recruitment success. Second, they defined the North Pacific Ocean as "a geographic unit (of the Columbia River basin) that should be considered in research, monitoring, and evaluation actions" (NPPC 2000). Third, they amended the Columbia River Basin Fish and Wildlife Plan to include the need to "understand the relationship between the Columbia River estuary and nearshore ocean, and salmon marine survival."

In the 2009 Fish and Wildlife Program (NPCC 2009), the Council reiterated that the ocean environment is an integral component of the Columbia River ecosystem and that the marine ecosystem is utilized differently by various salmon species and populations.

Thus, there arose a clear need to better understand the interactions between salmon and the ocean in order to realistically plan goals and management options for the recovery of Columbia River salmon.

Starting in 1998, the Bonneville Power Administration (BPA) funded research by National Marine Fisheries Service, National Atmospheric and Oceanic Administration (NOAA) to quantify interannual variability in marine recruitment success. The objective of this research was to understand the oceanographic mechanisms that affect recruitment in the coastal environment off Oregon and Washington. Management would then use this information to predict and help enhance future adult salmon returns. In 1998, Fisheries and Oceans Canada (DFO) also funded a component of this ocean research. Since 1999, DFO has received funding from BPA to observe and study recruitment processes from Vancouver Island to Southeast Alaska, where large numbers of Columbia River juvenile salmon reside. Starting in 2005, BPA funded acoustic-tagging studies by Kintama Research Services (Kintama) to estimate survival in the hydropower system, estuary, and coastal ocean.

Historical Context

Pearcy and McKinnell (2007) reviewed the long history of research on Pacific salmon in marine environments. This research was conducted through both direct observation (i.e., catching salmon at sea) and tagging studies. Prior to the late 1970s, little research effort was focused on juvenile salmon in coastal U.S. waters during their first year at sea. Studies of juvenile salmon off Oregon and Washington were begun by Oregon State University and NOAA Fisheries in the late 1970s.

Pearcy and others reported on the feeding habits of juvenile coho and Chinook salmon (Peterson et al. 1982; Miller et al. 1983; Emmett et al. 1986), migration speeds and growth rates (Miller et al. 1983; Pearcy and Fisher 1988), and interannual variation in the distribution and abundance of Pacific salmonid species (Dawley et al. 1985; Pearcy and Fisher 1990). Pearcy and Fisher (1990) reported the especially important finding that juvenile salmonids are found primarily in coastal shelf waters, and that there are dramatic differences in abundance and growth among brood years.

William Pearcy had a major influence in beginning ocean research on salmon in the Pacific Northwest. Indeed, several members of the current BPA-funded science team (Brodeur, Emmett, Fisher, and Peterson) contributed to early efforts led by Pearcy. He was the first to coin the term “ocean conditions,” and also to show that multi-year time-series of ocean sampling were needed to unravel the impacts of variable “ocean conditions” on salmon growth and survival. Much of the research summarized in this report was formulated around issues brought forth in Pearcy's (1992) book, in which he quotes Mathews (1984):

> ...the causes of mortality are elusive, probably vary from year to year, and depend "on complex interactions involving many fluctuating populations of predators, competitors and forage species." Considering this, he [Mathews] says, "it is not surprising that variability in marine survival is so poorly understood. Therefore, the likelihood seems low of correlating marine survival of any particular stock to single or simple environmental factors well enough or for long enough time periods to be useful in terms of predicting salmon abundance or guiding management decisions."

Pearcy concluded that Mathew's remarks were "a strong argument for formulating testable hypotheses and focusing research on specific processes that affect marine survival of stocks." We followed these recommendations in conceptualizing, developing, and implementing the three BPA ocean projects.

Objectives and Scope of the Three BPA Ocean Projects.

Studies of the relationships between ocean conditions and the ecology of juvenile salmon were initiated in the late 1990s by NOAA and DFO. These two projects were designed to:

- Provide understanding of the role of ocean conditions on growth and survival of juvenile Columbia River salmon.
- Translate this understanding into useful information that would enhance the ability of federal action agencies to address issues related to recovery of salmon populations by accounting for prevailing and evolving ocean conditions.

Our first objective was to coordinate sampling effort so that both groups used similar protocols and sampling gear. This coordination ensured the production of comparable environmental and biological data sets among different geographic areas (Appendix A). For example, the Nordic 264-rope trawl[†] used by scientists from NOAA's Northwest Fisheries Science Center is the same trawl used by colleagues from NOAA's Alaska and Southwest Fisheries Science Centers and is very similar to the Cantrawl 240-rope trawl used by DFO.

[†] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

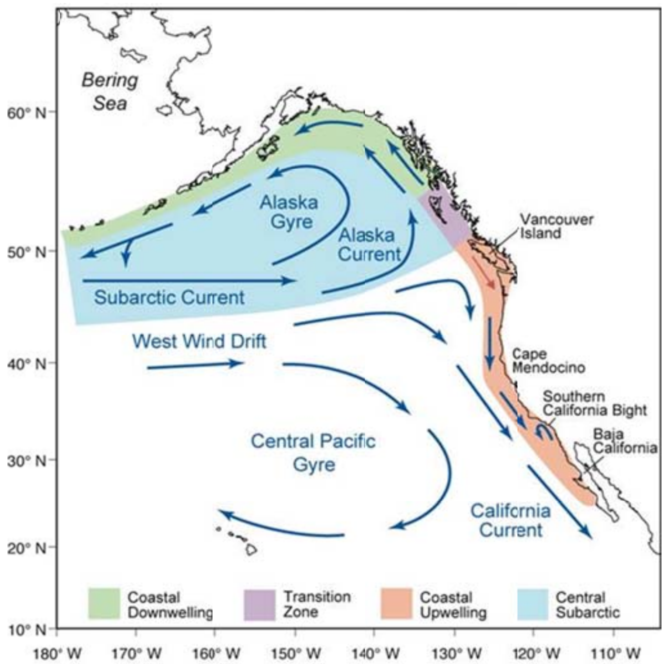

Figure 1. Map showing the general location of major ocean currents in the Northeast Pacific Ocean as well as oceanographic domains (habitats) occupied by Pacific Salmon: the coastal upwelling domain of the California Current; the coastal downwelling domain in the Gulf of Alaska, the transition zone between the two; and the Central Subarctic habitat. Redrawn from Ware and McFarlane (1989).

The NOAA and DFO studies encompass three distinct coastal oceanographic domains (Figure 1). Sampling in all three domains provides juvenile salmon from a natural range of contrasting environments that can be used to compare relationships among oceanographic conditions, climate, and the productivity of Columbia River salmon.

The Kintama research project was initiated in 2005 to address specific questions related to river, estuarine, and coastal ocean residency, as well as migration timing and survival.

Kintama's studies complements both the NOAA and DFO projects by providing habitat-specific estimates of juvenile salmon survival and migration timing. Collectively, these research efforts cover over 1,700 km of the continental shelf along the west coast of North America (central Oregon to Southeast Alaska). This area is used extensively by Columbia River salmon as a migratory corridor and rearing area during the first year at sea (Pearcy 1992; Teel et al. 2003; Van Doornik et al. 2007; Trudel et al. 2009; Tucker et al. 2009; Bi et al., 2011b; Fisher et al. In revision). Moreover, both the NOAA and DFO projects overlap geographically with acoustic lines of the Pacific Ocean Shelf Tracking (POST) project. Both the NOAA and DFO studies provide the oceanographic and biological data necessary to interpret region-specific mortality rates identified by the Kintama Coastal Ocean Acoustic Salmon Tracking (COAST) project.

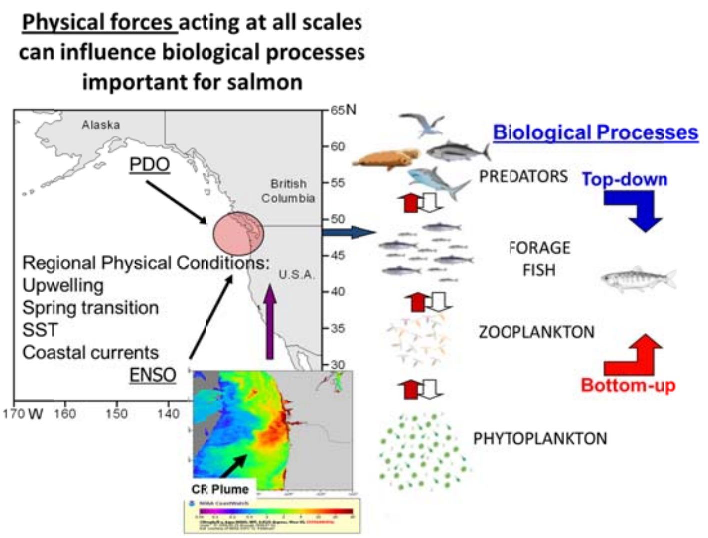

Figure 2. Conceptual model of physical processes operating at the basin-scale (PDO and ENSO) and local scale (upwelling, spring transition, coastal currents and the Columbia River plume) and biological processes (food-chain structure and predation) that affect juvenile Pacific salmon survival in continental shelf waters off Oregon, Washington, and British Columbia.

Our joint efforts are built around physical and biological processes related to early ocean growth and survival of Columbia River juvenile salmon (Figure 2). We focus on how growth and survival are influenced by both bottom-up and top-down processes associated with productivity of coastal waters and the Columbia River plume habitat. Table 1 lists the hypotheses developed and tested to evaluate the influence of these processes.

Hypotheses Tested

Some of our testable hypotheses, which are listed in Table 1, were derived from the recommendations of Pearcy (1992). This group of hypotheses represents an integrated approach to the study of Columbia River salmon. To test these hypotheses, we examined the following:

1) Distribution, growth, and condition of juvenile Columbia River salmon in the plume and ocean environments
2) Physical and biological properties of the plume and nearshore ocean environment that define stock-specific juvenile salmon habitats
3) Relationship between juvenile salmon growth, health, and survival and oceanographic and plume conditions
4) Food habits of juvenile salmon and their relationship to the physical and biological oceanography
5) Role of predators, pathogens, and alternative prey (forage fish) in influencing salmon marine survival

A major goal is to distinguish how differences in ocean conditions affect different salmon populations and species and how these effects relate to marine growth and survival. This information can contribute to management and recovery efforts for Columbia River Basin salmon only if we can identify mechanistic links between the ocean-caught juvenile salmon and its previous freshwater history and source population or management unit.

Table 1. Summary of hypotheses addressed by the combined NOAA, DFO and Kintama ocean research projects.

H1 **Bottom-up processes:** Salmon growth and survival are controlled by the quantity and quality of prey resources.

- **$H1_1$** Local and basin-scale climate variability affects food availability and quality (i.e., presence and composition of lipid-rich prey).
- **$H1_2$** Juvenile salmon growth and survival are affected by food availability.
- **$H1_3$** Juvenile salmon growth and survival are affected by food quality.
- **$H1_4$** Overwinter energy depletion and mortality is higher in smaller salmon.

H2 **Top-down processes:** Predators and diseases have indirect and direct effects on salmon survival.

- **$H2_1$** Local and basin-scale climate variability affects the abundance and movement of predators.
- **$H2_2$** Predators: Salmon survival is lower when piscine and avian predators are abundant.
- **$H2_3$** Pathogens: The impact of disease on salmon marine survival is mediated (in part) by bottom-up and top-down processes, which vary depending on ocean conditions. When poor ocean conditions persist, infected fish experience higher mortality; however, under optimal ocean conditions, many infected fish survive.
- **$H2_4$** Forage fish: Forage fish mediate predation by providing alternate prey for salmon predators, when forage fish are abundant.

H3 **Plume structure:** River operations affect the plume structure and its interaction with tides, upwelling, etc., which affect bottom-up processes and thus juvenile salmon success.

- **$H3_1$** River operations affect plume structure and its interaction with tides and upwelling.
- **$H3_2$** Juvenile salmon success, i.e., growth and/or survival, is related to plume structure.

H4 **Hydropwer system**. Survival of Columbia River salmon is affected by the dams and transportation

- **H41** Downstream and marine survival is affected by the migration through the hydropower system (Delayed Mortality).
- **H42** Smolt transportation (i.e. barging) affect the marine survival of salmon (Differential Delayed Mortality).

H5 **Freshwater v Ocean.** Smolt survival rates (S) in the ocean (O) are greater than in the freshwater (fw) hydropower system, i.e., $S_o > S_{fw}$

Coordination and Collaboration among Ocean Projects

NOAA and DFO coordinate their sampling programs annually to provide a more comprehensive understanding of the processes regulating ocean survival of different Columbia River salmon Evolutionary Significant Units (ESUs). The two agencies exchange both data and fish tissue; for instance, NOAA has been participating in DFO surveys since 2007 to collect blood plasma for measurements of growth hormones. These analyses will allow NOAA and DFO to map habitat quality (with respect to growth) for juvenile Columbia River salmon over a broad geographic area. These data in turn will help to clarify limits to juvenile salmon production during early marine life.

Annual workshops have been organized for more than a decade by NOAA and DFO. These workshops review the results of the three BPA-funded ocean projects and plan future surveys. They also provide an opportunity to discuss the results of concomitant sampling programs, many of which are conducted outside the survey areas covered by the ocean projects. For example, the Bering Aleutian Salmon International Survey Program has been represented at these workshops. These strategies have led to increased collaboration between the ocean projects: to date, the NOAA and DFO projects have jointly published or submitted 12 manuscripts to peer-reviewed journals. Our collaborative effort on coastal ecosystems and the ocean ecology of juvenile Pacific salmon is reported in these manuscripts (Appendix B).

Ongoing collaboration between the NOAA and DFO field sampling programs provides added value in two important ways. First, if samples were collected only within a small geographic area (e.g., only off the coast of Washington), we could not obtain data on different Pacific salmon species and life-history types during the critical early marine stages. For instance, after ocean entry, the interior Columbia River spring Chinook, coho, and Redfish Lake sockeye salmon quickly undertake a northward migration. These fish are collected off the British Columbia (BC) coast by DFO during early summer, while NOAA is conducting surveys off Washington and Oregon. Fall Chinook salmon remain off Washington and Oregon for extended periods; they do not occur in significant numbers in the DFO survey area until fall.

Second, sampling over a broad geographic area provides a measure of the contrast in oceanographic conditions experienced by Columbia River salmon: these fish occupy different oceanographic domains during the first summer at sea (Figure 1). This broader sampling area increases our ability to detect ocean conditions and compare how they may affect Columbia River salmon. A sampling scheme limited to only the area covered either by NOAA or DFO would diminish our ability to understand these impacts. Third, sampling over a broad geographic area allows for independent confirmation of the observed mechanisms regulating ocean production of Columbia River salmon. By verifying that these processes are seen in different regions/systems, the reliability of results obtained in both projects is greatly increased.

At the same time, some data are collected by only one of the two groups and shared between groups. For example, growth hormones and parasites are measured only by NOAA; however, by working with DFO, NOAA has obtained samples from beyond the U.S. border. Likewise, winter mortality is determined only by DFO, but both agencies plan to extend the winter mortality survey to the coast of Washington and Oregon to target Columbia River salmon.

Research Synergies with Programs not Funded by BPA

Our interdisciplinary team of scientists has used their expertise of salmon and ecosystem-related problems to obtain additional research funding that complements the funding provided by BPA for the ocean projects.

Newport Hydrographic Line—One core activity funded by other sources has been the biweekly sampling of hydrography and plankton in continental shelf waters off Newport, Oregon. This sampling program along the Newport Hydrographic Line was initiated in 1996 and during this period has been funded by a number of agencies and programs. These include the U.S. Global Ocean Ecosystem Dynamics program (U.S. GLOBEC), which is joint program sponsored by NOAA and the National Science Foundation (NSF) and the NSF sponsored River Influences on Shelf Ecosystems program (RISE). Funding has also been provided by the NOAA Fisheries and The Environment (FATE) program and NOAA Stock Assessment Improvement Plan (SAIP). Biological Opinion (BiOp) funding provided by the NOAA Northwest Regional office has also supported this research.

The time series generated by this program has provided data used in our salmon forecasting efforts described later in this report. Work carried out in this program has had a direct bearing on the BPA study region (Peterson and Keister 2003; Peterson and Schwing 2003; Hooff and Peterson 2006) and has increased our understanding of ocean conditions prior to and during the period of juvenile salmon residency in shelf waters.

U.S. Global Ocean Ecosystem Dynamics (U.S. GLOBEC)—The U.S. GLOBEC program allowed us to expand hydrographic and zooplankton sampling to include offshore waters up to 100 km from shore and transects lines as far south as Eureka, California. One focus of that program was a 2-year study of the ecology of juvenile coho and Chinook salmon in coastal ecosystems from Newport, OR, to Crescent City, CA. This study took place during 2000 and 2002 in an area just south of our BPA sampling area and led to publications on the distribution (Brodeur et al. 2005; Fisher et al. 2007; Pool et al. 2012), stock structure (Brodeur et al. 2005), and ecology of juvenile salmon and co-occurring species (Reese and Brodeur 2006; Miller and Brodeur 2007; Orsi et al. 2007; Baldwin et al. 2008; Brodeur et al. 2008; Miller et al., 2010c).

U.S. GLOBEC and NOAA/CAMEO—The U.S. GLOBEC and NOAA/CAMEO (Comparative Analysis of Marine Ecosystems Organization) programs funded work that allowed us to define the physical and biological characteristics of continental shelf habitats occupied by juvenile coho and spring Chinook salmon, using data collected during our salmonid trawl surveys (Bi et al. 2007; Peterson et al. 2010; Bi et al. 2011a). We showed that the two species occupied different habitats, with coho found farther offshore than spring Chinook, and that the habitats could be defined from data on water depth, the distribution of chlorophyll-a (a proxy for phytoplankton biomass), and copepod biomass.

National Aeronautics and Space Administration (NASA)—Funding from NASA allowed us to explore the use of NASA's SeaWiFS satellite, whose sensors could detect the concentration of chlorophyll from space. These data allowed us to present a more detailed spatial representation of salmon habitats in coastal waters off Washington and Oregon (Bi et al. 2008). NASA also funded a study of transport in the northern California Current in which satellite altimeter data (AVISO) were used to calculate geostrophic flows. These data allowed for an estimate the relative amounts of water entering the current from the north and west (Bi et al. 2011b), details of which are discussed in following section on "Physical and Biological Processes Affecting Salmon."

Pacific Salmon Commission (PSC) and the Canadian Space Agency (CSA)—Funding from the PSC and CSA allowed us to measure growth hormone levels in juvenile Columbia River salmon and assess the origin of juvenile sockeye salmon collected off BC, respectively. These analyses have showed large regional variability in the growth of Columbia River salmon (B. Ferris, in preparation) and that Columbia River sockeye salmon, including Redfish Lake sockeye, are off the British Columbia coast by mid-June (Tucker et al. 2009; Trudel et al. 2010, 2011).

Natural Science and Engineering Council of Canada (NSERC)—Funding from NSERC contributed to measurements of stable isotopes in juvenile pink (*O. gorbuscha*) and chum salmon (*O. keta*) (Jenkins 2011), analyses of otolith microstructure of juvenile Chinook salmon (Middleton 2011), and measurements of fatty acids in juvenile salmon and zooplankton (R. El-Saabawi, in preparation). Although NSERC funding primarily targets salmon of Canadian origin, it allows the development of a framework that can be used for testing specific mechanisms that may regulate the production of Columbia River salmon.

U.S. Army Corps of Engineers (USACE)—Funding from the USACE for implementation of the Biological Opinion (BiOp), along with a previous and separate award from BPA, allowed for studies of juvenile salmon within the Columbia River estuary. These studies have provided information on juvenile salmon residence time within the estuary, habitat use, metrics of growth, condition, diet and stock identification that we compared with our ocean data. One of our initial and important results has been that the common subyearling Chinook salmon stocks in estuary samples are not the dominant subyearling stock groups caught in our near-shore samples. An effort to address this specifically is described later in this report.

River Influences on Shelf Ecosystems (RISE)—The RISE Program (funded by the NSF during 2004-2008) has contributed to our understanding of the impact of the Columbia River on coastal ecosystem dynamics and juvenile salmon habitat. The Columbia River is a significant source of iron (a micronutrient needed by phytoplankton) and plume waters pick up vast amounts of nutrients at the mouth of the estuary and in the nearshore ocean through intense tidal mixing with upwelled waters. Also, the plume is directed offshore and to the south when winds are from the north, but turns north and hugs the coast when winds blow from the south. Thus fertilization of coastal waters by the plume is most evident when the plume moves northward; when the plume is directed southward, fertilization occurs in more offshore waters (summarized in Hickey et al. 2010).

Science and Technology Center for Coastal Margin Observation & Prediction—The NOAA and DFO studies also overlap with the geographic domain of the SATURN Collaboratory (http://www.stccmop.org/saturn), maintained by the Science and Technology Center for Coastal Margin Observation & Prediction (CMOP). The SATURN Collaboratory includes a long-term inter-disciplinary observation network, a modeling system (the "Virtual Columbia River"), advanced cyber-infrastructure, and a broad range of scientific and non-scientific user communities that complement the NOAA and DFO studies.

Other Sources of Support—Support for early development of the prototype acoustic telemetry array used by POST was received from the Census of Marine Life (Alfred P. Sloan Foundation) and from the Gordon & Betty Moore Foundation. A number of BC agencies have also helped fund projects or infrastructure operations in the Strait of Georgia/Queen Charlotte Strait. Although funding for research in this region is not used directly in Columbia River salmon studies, it contributes an important component of the overall array because to date it demonstrates that tagged Columbia River smolts do not migrate into the Salish Sea (Strait of Georgia and Puget Sound).

II. Physical and Biological Oceanographic Processes that Affect Juvenile Salmon

California Current

The California Current is an eastern boundary current that flows along the coasts of Vancouver Island, Canada, Washington, Oregon, and California (Figure 1). The current has offshore and inshore arms: the offshore branch is characterized by a meandering flow that is generally southward year-round; the inshore flows alternate seasonally between north and south. In winter, southerly winds result in transport of water northward and shoreward as the Davidson Current, creating "downwelling." In summer, northerly winds transport water southward and offshore, creating "upwelling." It is this upwelling that makes the coastal branch of California Current cool, nutrient-rich, and highly productive.

Past research suggested that the upwelling process (and resulting productivity) was important to the growth and survival of juvenile salmonids in the upwelling zone off Washington and Oregon (Nickelson 1986; Fisher and Pearcy 1990; Pearcy 1992; Logerwell et al. 2003). Two aspects of upwelling seemed to be of greatest importance to juvenile salmonids during their first summer at sea: the strength of upwelling (Nickelson, 1986) and the starting date of the upwelling season, also called the date of spring transition (Logerwell et al. 2003). This framework drove early work on juvenile salmonid ecology off Oregon and Washington.

Similarly, in 1999, when the BPA-funded DFO ocean project was initiated in waters off southern BC, salmon production was believed to be regulated by ocean productivity. Ocean productivity in turn was thought to be regulated by the effects of sea surface temperature (SST) on mixed-layer depth (Gargett 1997; Hare et al. 1999; Mueter et al. 2002). Under this hypothesis, production by phytoplankton in the Northern California Current (NCC) System would be limited by nutrients, whereas plankton in the Alaska Coastal Current (ACC) would be limited by sunlight. As such, shoaling of the mixed-layer depth due to increased SST was expected to reduce the upwelling of nutrients to surface waters of the NCC, but to retain primary producers in the euphotic zone of the ACC. Thus, changes in SST were expected to have opposite effects on ocean and salmon productivity in the NCC and ACC.

Earlier suggestions that mixed-layer depth is important to salmon (Gargett 1997) have since been shown to have limited explanatory power. Our surveys have shown that plankton productivity decreases with increasing SST off the west coast of Vancouver Island, but an opposite trend was observed in the ACC (Figure 3).

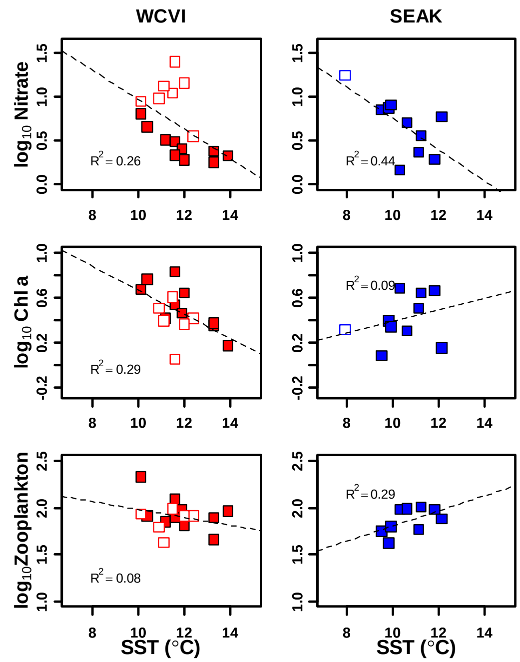

Figure 3. Relationship between phytoplankton and zooplankton biomass with sea surface temperature in the northern California Current and Alaska Coastal Current. Data from Trudel et al. (2011).

Moreover, the marine survival of Columbia River summer and fall Chinook and coho salmon are negatively correlated to SST off the west coast of Vancouver Island (Trudel, unpublished data). However, there was no significant correlation between Columbia River salmon survival and phytoplankton or zooplankton biomass, suggesting that the effect of SST on salmon survival was not mediated by changes in ocean productivity. Further, even though plankton biomass is higher in the NCC than in the ACC (Ware and Thomson 2005), salmon growth and survival is generally higher in the latter (Shaul et al. 2007; Trudel et al. 2011).

A proposed alternate mechanism may be related to the source waters that give rise to the NCC (Figure 1 and 4), and this alternate mechanism may also have cascading effects on food-web dynamics. Differences among years in both the source of waters that feed the California Current and the volume of water transported among years seem to be controlled by the phase of the Pacific Decadal Oscillation (PDO). The PDO is a spatial pattern in sea surface temperature seen across the entire North Pacific Ocean. When the PDO is in a “cold phase,” anomalously cold water is found around the Gulf of Alaska and in the California Current. Conversely, while the PDO is in a “warm phase,” the opposite pattern is seen, with equatorial waters dominating the NCC.

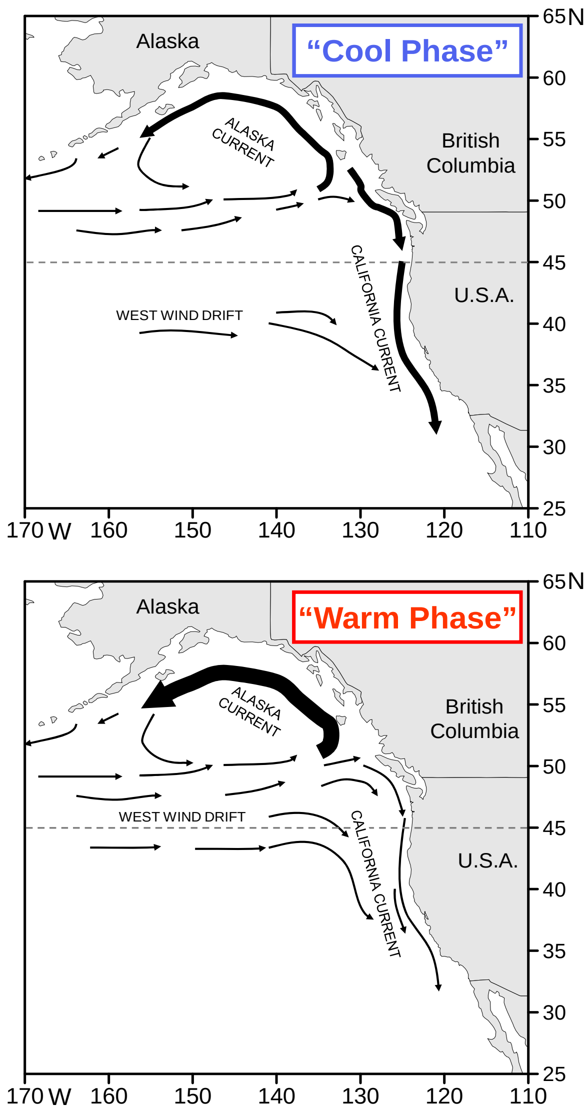

Figure 4. Cartoon showing how hypothesized changes in source waters feed the northern California Current during different phases of the PDO in summer. (Modified from Hallowed and Wooster, (1992) Figure 4.).

These patterns are driven by winds. During the cold phase, winds tend to be more northerly and westerly, leading to Ekman pumping of offshore waters, upwelling of coastal waters, and a general cooling of surface waters of the Gulf of Alaska and California Current. During the warm phase, winds are more southerly or southwesterly, resulting in the transport of warm subtropical water towards the coast of North America, and creating downwelling.

When the PDO was first described by Mantua et al. (1997) it was noted that the phase of the PDO shifted on decadal time scale (hence the term Pacific Decadal Oscillation). Shifts to a warm phase occurred in 1925 and 1977, while shifts to a cold phase occurred in 1947 and 1998. Since 1998, the phase of the PDO has oscillated with much higher frequency, with a 5-year cool phase during 1998-2002, a 5-year warm phase during 2003-2007. Recently the frequency of the oscillation appears to have increased again, with 2-year cool phase from 2008 to 2009 followed by one warm-phase year (mid-2009 to mid-2010) and one cool year (mid-2010 to 2011).

This recent variability in the PDO has provided us with natural range of experimental conditions with which we can compare the response of juvenile salmon to a large variety of ocean conditions. Specifically, the years 2005 and 2008 provide pronounced contrasts in ocean conditions, with 2005 extremely warm due to a near-complete lack of upwelling and 2008 anomalously cold due to a strongly negative PDO. In addition, 2001 was a drought year; thus the volume of the Columbia River plume was reduced.

Furthermore, we have conducted sampling during a major El Niño event in 1998 and during two smaller but significant events during 2003-2004 and 2009-2010. A longer time series is needed to track these recent high-frequency variations in the PDO and in the associated variations in ocean conditions and salmon survival. These data are necessary if we are to further explore biological responses to the extreme conditions expected in the future.

Widespread ecological changes are associated with shifts in the PDO (Mantua et al. 1997). Such changes include increased salmon landings in the Gulf of Alaska (GOA) and Bering Sea when the PDO is in positive phase, and vice versa. Francis and Hare (1994) noted that the ecosystem response was pronounced in the years when PDO change-points were observed, and that the response occurred in the year of the change. Therefore, they suggested that for salmon, the processes controlling production were acting during their first summer at sea, as also suggested by Pearcy (1992).

Given the strong linkages between the PDO and salmon, and the short time scale (no more than one year) over which ecosystem shifts have been observed, what might be the nature of the mechanism(s) that link PDO with zooplankton and salmon production? Our research suggests that the mechanistic link between PDO and salmon growth and survival is due to shifts at the base of the food chain between lipid-poor and lipid-rich plankton communities. These changes in the food chain lead to changes in feeding conditions for salmon and forage fishes (Peterson and Keister 2003; Peterson and Schwing 2003; Peterson and Hooff 2005; Hooff and Peterson 2006; Daly et al. 2010; Litz et al. 2010; Keister et al. 2011; Bi et al. 2011a).

When the PDO is in a negative (cold) phase, boreal, lipid-rich cold-water copepod species are transported southward out of the Gulf of Alaska (Figure 3) and dominate the lower trophic levels in the California Current. These species are also the dominant zooplankton of the coastal ecosystem of the Bering Sea and coastal Gulf of Alaska (Coyle and Pinchuk 2003, 2005; Coyle et al. 2008) and southern BC (Mackas et al. 2001, 2004).

When the PDO is in positive (warm) phase, warm water, and lipid-poor copepod species become important in the NCC and in some years dominate. These copepods are typical of the subtropical waters that lie offshore and south of Oregon. Also, during the warm phase of the PDO, upwelling tends to develop later in the year and subtropical copepod species that have been transported northwards in winter will linger longer, into the spring and summer months, leading to a "subtropical" copepod community on the shelf.

Shifts in the PDO also result in other changes in the coastal food web. Warm ocean conditions associated with the positive-phase PDO result in changes in the abundance of fish predators and fish prey in coastal waters of the NCC. Adult and juvenile hake (whiting) move up into shelf waters during warm ocean periods, resulting in increased predation on juvenile salmon (Emmett and Krutzikowsky 2008). Forage fishes (anchovy (*Engraulis mordax*) and smelts (Osmeridae)), which as juveniles, are prey of juvenile salmonids tend to be less abundant during warm ocean conditions (Emmett et al. 2006; Emmett and Sampson 2007). Thus, the PDO may affect the survival of Columbia River salmon through both its effects at the base of the food web as well as on salmon predators at higher trophic levels.

Columbia River Plume

The Columbia River is a major oceanographic feature of the Pacific Northwest. The river contributes 70% of the freshwater discharged to the eastern North Pacific between San Francisco and Juan de Fuca Strait. Its plume extends northward to BC or southward to California, depending on the coastal wind regime. The estuary functions as a key bioreactor, modifying biogenic inputs from land before they reach the continental shelf via the plume. Both the estuary and plume are controlled by a combination of large-scale ocean, atmospheric, and hydrologic forcing, all of which vary at scales ranging from tidal to seasonal and interannual.

Our understanding of seasonal and inter-annual variability in the physics of the estuary and plume has increased substantially over the last decade (Chawla et al. 2008; Hickey et al. 2009, 2010; Burla et al. 2010b). This variability is documented by a virtual Climatological Atlas (CMOP 2012), which describes a plume extending southward and offshore in during spring and summer dominated by upwelling. Likewise, a northward-extending and coastally attached plume is described in winters dominated by downwelling. However, the virtual atlas currently fails to capture some dramatic scales of variability in plume characteristics that are potentially relevant to salmon, such as hourly to daily changes in plume direction, which depend upon the speed and direction of coastal winds (Hickey et al. 2009; Burla et al. 2010b). Using plume simulations from the Virtual Columbia River numerical model, Burla et al. (2010b) showed that river discharge explains most of the plume variability (>40%), with coastal winds the next most important factor (>20%).

III. Ocean Migration and Distribution of Columbia River Basin Juvenile salmon

Delineation of the ocean distributions of Columbia River salmon is an important step in understanding mechanistic links between regional ocean conditions and their influence on the growth and survival of specific stocks and life-history types.

First, fish size at ocean capture is used to classify individuals as subyearling or yearling freshwater migrants (Fisher and Pearcy 1995). This terminology specifically applies to the age at which a fish left freshwater and entered the ocean and is a key life history characteristic. Additionally, DNA data are used to identify stock of origin (Seeb et al. 2007; Beacham et al. 2011b). Genetic stock assignments are typically made to an ESU level and therefore provide information on both the geographic region of origin and adult timing of the source population (e.g., Snake River fall run Chinook salmon and Snake River sockeye salmon). Individuals from each source population may adopt either a subyearling or yearling life history pattern.

Another goal of this study is to document life history diversity. Tags, (coded-wire, PIT, or acoustic are detected in a subset of individuals, yielding direct links to population sources (e.g., Trudel et al. 2009). Additionally, the elemental ratio (strontium:calcium) and structure of otoliths have been analyzed on a stock-specific basis. These analyses have generated more specific information on the variation in size and timing of juvenile migration within and among stocks. Finally, marks (e.g., adipose fin clips) are used to identify a larger proportions of hatchery fish (Daly et al. 2011). These data are used here (singly or in combination) to report results by juvenile life history type (subyearling or yearling), by stock or ESU, and by hatchery or natural origin when possible.

Coast-Wide Distribution Patterns

Different stocks and life-history types of Columbia River salmon have strikingly differing ocean distributions during their first weeks and months at sea, and these distributions persist across years. These patterns were evident from both genetic stock identification and coded-wire tag data collected for the NOAA and DFO ocean projects. These differing distributions expose juvenile salmon to different ocean conditions with implications for feeding opportunities, growth and survival.

This observation is in contrast to prior studies, including tagging experiments conducted in the 1960s. Earlier evidence suggested that juvenile spring Chinook, coho, and sockeye salmon undertake a northward migration upon entering the ocean, though the timing of these migrations was unknown (Hartt and Dell 1986; Healey 1991). In contrast, juvenile fall Chinook salmon were believed to remain in coastal waters for extended periods, though little was known of the distribution for particular stocks (Healey 1991).

Studies conducted in the 1980s revealed that many juvenile hatchery coho and subyearling fall Chinook salmon remained in coastal areas off Oregon and Washington throughout summer (Miller et al. 1983; Pearcy and Fisher 1988; Fisher and Pearcy 1995). The COAST study has demonstrated that Columbia River yearling Chinook smolts migrate primarily north upon ocean entry, and that only a very small proportion of these yearlings migrate south off the coast of Oregon before turning north.

Our ocean studies have identified three patterns of migration. First, some Columbia River basin salmon move rapidly northward soon after they enter the ocean in spring and early summer (Figure 5). By early summer, Snake River spring/summer and Mid and Upper Columbia River spring Chinook salmon are distributed along the entire coast, from the Columbia River to Southeast Alaska (Teel 2004; Trudel et al. 2004, 2009; Rechisky et al. 2009; Payne et al. 2010; Daly et al. 2011; Fisher et al. in revision). By fall, these juveniles are rarely found off Washington and British Columbia (BC), and by winter, they have moved further north and west, no longer present off BC or Southeast Alaska (Figure 5). Columbia and Snake River sockeye salmon show a similar pattern of rapid northward migration (Tucker et al. 2009; Trudel et al. 2010).

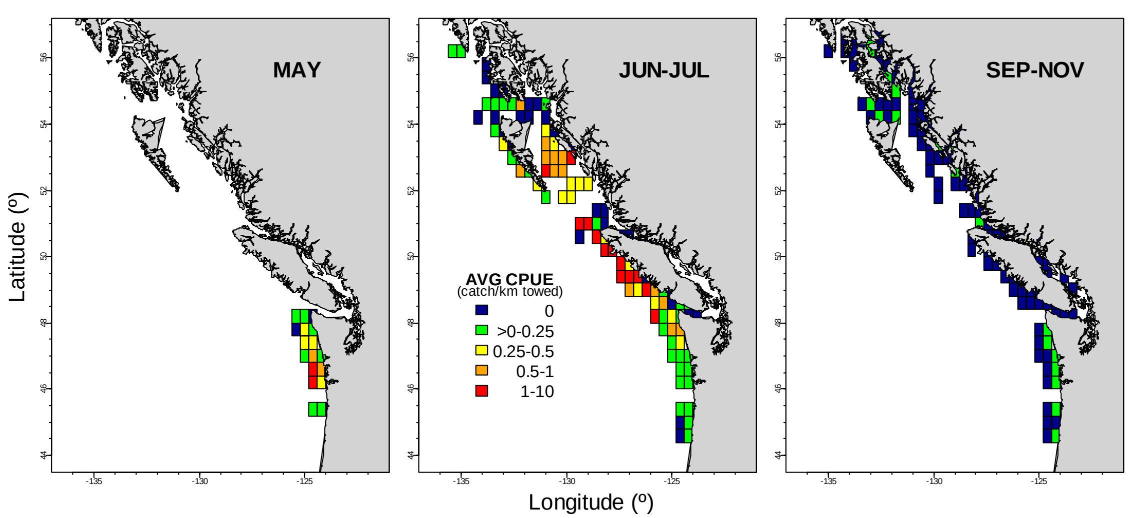

Figure 5. Catch per unit effort (CPUE) of Snake River yearling spring/summer Chinook salmon caught from the Oregon Coast to Southeast Alaska by NOAA Fisheries and DFO. Values are station averages for cruises conducted from 1998 through 2010, except for May which are from 2006 through 2010.

Second, other Columbia River Basin juvenile salmon migrate at much slower rates than those of interior-basin spring Chinook and sockeye salmon. For example, spring Chinook salmon from the lower Columbia River (e.g., from Cowlitz River Hatchery) remain in coastal waters from the Oregon coast to the west coast of Vancouver Island for an extended period (Trudel et al. 2009; Fisher et al. in revision). Similarly, populations of subyearling Snake River fall, Upper Columbia summer/fall, and Lower Columbia River fall Chinook salmon disperse slowly both south and north of the Columbia River following a protracted period of ocean entry that begins in spring and continues into autumn (Brodeur et al. 2004; Teel 2004; Trudel et al. 2004, 2009; Tucker et al. 2011; Fisher et al. in revision; Figure 6). These subyearlings reside in coastal areas off Oregon and Washington throughout summer and fall (Figure 6). A few are caught off Vancouver Island, but only in fall; in winter, they appear to initiate a northward migration (Tucker et al. 2011).

Third, several Columbia River Basin stocks cannot be easily characterized as having either rapid northward migrations or slower migrations with periods of residency. Rather, these stocks exhibit a diversity of dispersal patterns. For example, some Columbia River yearling coho salmon consistently reach Alaska during their first summer and fall at sea; however, many remain in coastal areas from Vancouver Island to central Oregon (Teel et al. 2003; Trudel et al. 2004; Morris et al. 2007; Van Doornik et al. 2007; Fisher et al. in revision). Spring Chinook from the Willamette River, as well as yearling Chinook from Snake River fall and Upper Columbia River summer hatchery programs, show similar complex migration patterns.

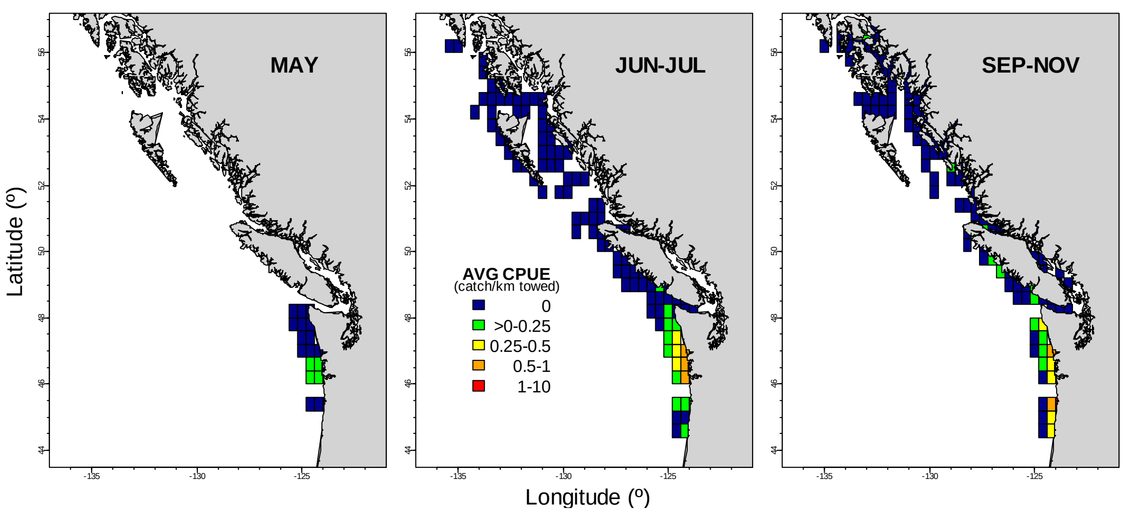

Figure 6. Catch per unit effort (CPUE) of Snake River subyearling fall Chinook salmon caught from the Oregon Coast to Southeast Alaska by NOAA Fisheries and DFO. Values are station averages for cruises conducted from 1998 through 2010, except for May which are from 2006 through 2010.

These results underline the importance of considering stock-specific spatial and temporal distributions in assessing the effects of ocean conditions on Columbia River salmon. The extent to which various stocks and life history types remain in regions that favor survival differently will determine their adult return rates. For subyearling fall Chinook, ocean conditions appear to be most relevant at the scale of the NCC (i.e., Oregon to the west coast of Vancouver Island), given their tendency to reside in these waters. Broad and more complex spatial and temporal scales must be considered for other Columbia River salmon as the distributions of these fish span both the NCC and ACC systems.

Fine-Scale (Spatial and Temporal) Habitat Usage Patterns and Factors Affecting Distribution

In addition to the coast-wide distribution patterns outlined above, our data also reveal substantial discontinuities in juvenile salmon distribution and abundance at local and regional scales. Juvenile Chinook and coho have been found almost entirely along inner- to mid-shelf areas (Fisher et al. 2007; Peterson et al. 2010), the region of greatest productivity and food biomass (Peterson et al. 2010). Within the continental shelf region, subyearling Chinook is found closest to shore, while coho and yearling Chinook extend much further offshore (Fisher et al. 2007). Similarly, subyearling Chinook is found in cooler waters, while yearling Chinook and coho occupy a broader range of temperatures (Peterson et al. 2010; in prep). Because these patterns are observed consistently from year to year, they suggest adaptive genetic differences. For example, use of different local habitats could have arisen from an evolutionary strategy to avoid competition for food.

Interannual shifts in distribution and abundance at local and regional scales are related to temporal fluctuations in the physical and biological characteristics of local habitats. In our June catches, for example, both coho and yearling Chinook salmon are found further offshore during years of strong upwelling (Peterson et al. 2010): 80% of coho and yearling Chinook were caught at respective depths of 150 and 100 m during years of strong upwelling and 100 and 60 m during year of weak upwelling. This finding implies that strong upwelling tends to disperse juveniles across a greater area of the continental shelf, whereas weak upwelling and its resultant warmer ocean tends to “compact” distributions into a narrower coastal band.

Analyses of yearling Chinook catch data off Oregon and Washington reveal consistent distributional effects of local environmental variables such as temperature and turbidity, even when spatial structure had been taken into account. This suggests that salmon are not passively dispersed by prevailing currents (e.g., upwelling), but actively search out preferred habitat during migration (Trudel et al. 2009).

At the same time, models suggest that for some stocks (e.g., interior basin spring run ESUs), large-scale, geospatial cues such as Earth's magnetic field may be more important than local environmental factors (B. Burke unpubl. data). These stocks may encounter suboptimal habitat during migration due to failure to respond to local conditions, a situation that could be exacerbated by climate change (Tucker et al. In press).

Rapidly migrating stocks of interior spring Chinook reach areas north of Washington by June-July (Figure 5; Trudel et al. 2009; Tucker et al. 2011; Fisher et al. in revision). However, there is some fine-scale interannual variation in this migration pattern. For example, Mid and Upper Columbia River spring Chinook consistently entered marine waters earlier than Snake River spring Chinook (Tomaro et al. in revision, J. Miller, unpubl. data).

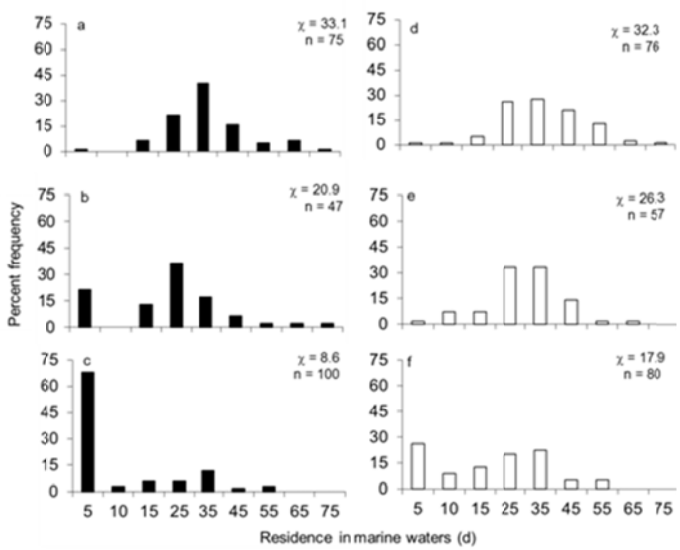

Figure 7. Estimated marine residence times for juvenile spring Chinook salmon across all years. Percent frequency shown in 10-d intervals for Snake (a–c) and mid-Upper Columbia River (d–f) juveniles. Fish were grouped by geographic region and include transects north of Grays Harbor, Washington (a, d); off Willapa Bay and Grays Harbor, Washington (b, e); and off the Columbia River (c, f). Mean residence time and sample size are included on each graph. "Marine" refers to brackish/ocean waters as determined by increased strontium:calcium ratios in the otolith, which indicate salinities above ~5.

This variable marine entry is reflected in the coastal residence of these two stocks: the Mid and Upper Columbia River Chinook salmon collected along the Columbia River had been in marine waters longer than the Snake River spring Chinook salmon (Figure 7).

There was also interannual variation in the marine migration rate of interior spring Chinook. Migration of Mid and Upper Columbia River Chinook was slower during years with a high biomass of lipid-rich, northern copepods; migration of Snake River Chinook was slower during years with extended upwelling seasons (J. Miller, unpubl. data). Although it is not clear whether these patterns are related to fish behavior or to other physical factors, the net effect is that juveniles move through coastal waters at slower rates when ocean conditions appear favorable for foraging and growth.

Data from Kintama's acoustic tracking show that for interior Columbia River Basin yearling Chinook, plume residence is related to timing of the downstream migration (with the plume defined as the area between Astoria and Willapa Bay acoustic lines.)

After release, tagged yearlings migrate downstream and turn north onto the continental shelf upon ocean entry. At John Day Dam, staggered releases of tagged yearlings covering most of the 2010 migration season indicate that the interval between release and arrival at the river mouth (Astoria) was nearly constant across release dates. However, residence in the plume region was substantially reduced for yearlings released late in May, as seen in the sudden narrowing of the interval between release and arrival at Willapa Bay (Figure 8).

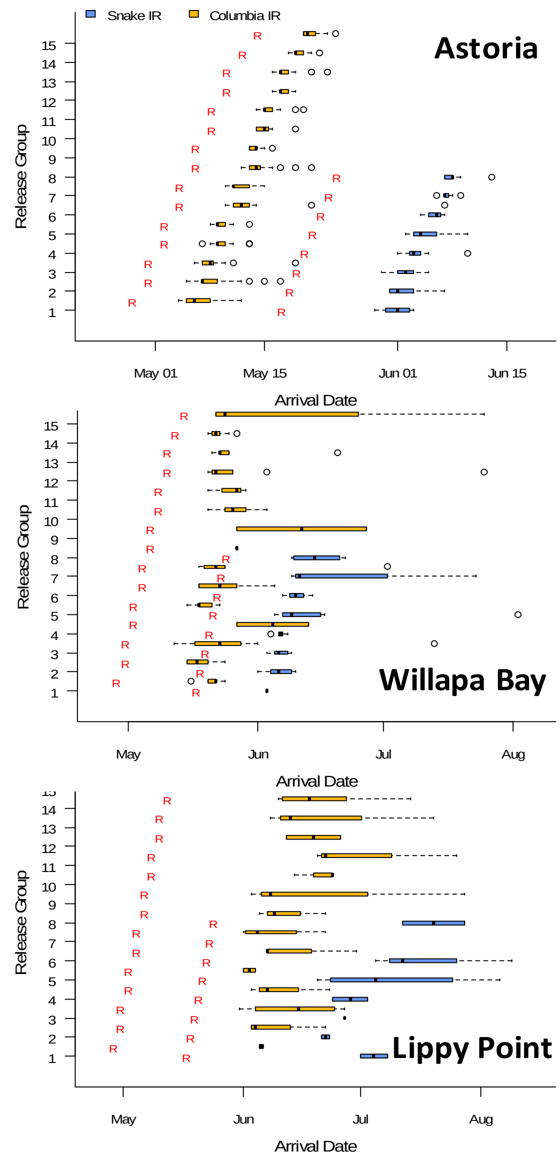

Figure 8. Distribution of 2010 arrival dates for Snake and Columbia yearling Chinook salmon detected at Astoria, Willapa Bay, and Lippy Point (northwest Vancouver Island). Snake River yearlings (blue) were tagged and released at Lower Granite Dam; Columbia River yearlings (yellow) were tagged at John Day Dam and were comprised of a mixture of upstream stocks. Release dates are indicated with the letter R and box and whisker plots show arrival times.

These findings are consistent with estimates of migration rate based on otolith chemical analyses (strontium:calcium) for Mid and Upper Columbia River yearling spring Chinook. These analyses indicate that movements are faster as the summer progresses (Tomaro et al. in revision).

Cross-Shelf Distribution of Tagged Smolts

To date, our acoustic tagging results indicate that the yearling Chinook smolt distribution off Willapa Bay extended farther offshore than our array extended in 2006 (29 km) and also in 2008-2010, when the array was extended to 34 km offshore. In 2011, the array was further extended to 46 km offshore: once again smolts were detected across the entire shelf, including the outer edge of the sub-array (Appendix C, Figure C-3).

Thus, our detection data are consistent with NOAA's yearling Chinook catch data at Willapa Bay. At Lippy Point (NWVI), both the NOAA and CDFO trawl surveys and the distribution of acoustic-tagged smolts indicated that north of Willapa Bay, where the shelf is wider, the distribution is clearly shelf-bound (Appendix C, Figure C-3). Additional analysis using NOAA catches of Chinook smolts off SE Alaska indicates that the Chinook distribution also remains strongly shelf-bound here as well (Porter et al. 2011). As a result, it seems likely that smolts may move farther offshore in the Columbia River plume before turning north after exiting the river.

IV. Marine Growth and Condition and Linkage to Adult Returns (H1)

Early marine mortality is believed to be a function of the growth and condition of individual fish. To understand the effects of ocean conditions on Columbia River salmon survival, we need to examine growth in the marine environment.

Pacific salmon sustain heavy and highly variable losses in the ocean, with natural mortality rates often exceeding 90-95% (Bradford 1995). Most of this mortality is thought to occur in coastal marine ecosystems during two critical periods: an early period of predation-based mortality that occurs within the first few weeks or months of ocean entry, and a later period of starvation-based mortality that occurs following the first winter at sea (Beamish and Mahnken 2001).

Both predation- and starvation-based mortality are size-dependent (Willette et al. 2001; Hurst 2007). Therefore, ocean conditions that lead to slower growth likely increase mortality during these critical periods of marine life, thereby reducing adult returns (Pearcy 1992; Beamish et al. 2004). Slower marine growth may also reduce the ability of adult salmon to complete their spawning migration (Crossin et al. 2004). Production in freshwater and riparian ecosystems may consequently be reduced through a reduction in marine-derived nutrients (Cederholm et al. 1999). Moreover, smaller adult fish tend to produce smaller eggs and fry, which are more vulnerable to predation than larger cohorts (Ruggerone and Rogers 1993; Quinn et al. 2004).

We have estimated length, mass, body condition, and growth for fish caught in the May and June NOAA ocean surveys. These surveys occur within weeks of ocean entry for yearling Chinook and coho and within weeks-to-months for subyearling Chinook. For several populations of Columbia River Chinook salmon, growth has been estimated by measuring otolith growth after seawater entry (Tomaro et al. in revision). Coho and Chinook salmon growth has also been indexed by measures of the hormone, insulin-like growth factor 1 (IGF1; Beckman 2011). Otolith growth is measured to estimate marine growth rate over a period of weeks to months (entire seawater history before the fish was captured), whereas measures of IGF1 relate to growth for approximately one week. Fish size, mass, and body condition (defined as the residuals of the mass-length relationship) can each provide a different perspective on overall fish health. In addition, somatic growth (May-October) has been estimated by DFO using smolt size and ocean entry date for juvenile salmon caught during the first fall at sea (Trudel et al. 2007b, 2011b).

Interannual Variation in Salmon Food and Growth

Field estimates of salmon prey abundance and growth rate have varied interannually, with high estimates of both in 1999-2002 and 2008. Lower rates of salmon food abundance and growth rate were especially evident in 2005 (Figure 9), a year of known low ocean ecosystem productivity (AGU 2006).

Overall, estimates of salmon food availability are positively and significantly related to June growth rates for both juvenile coho (Figure 9) and Mid and Upper Columbia River and Snake spring Chinook salmon. Somatic growth in juvenile coho and Chinook salmon is positively correlated with both food consumption rates and the carbon/nitrogen (C/N) ratio of ocean zooplankton off Vancouver Island and Southeast Alaska (Trudel et al. 2011). The C/N ratio is an indicator of lipid concentration in aquatic animals such as zooplankton (Post et al. 2007). Thus, this latter relationship indicates that juvenile salmon growth is affected by both prey abundance and quality (Trudel et al. 2011).

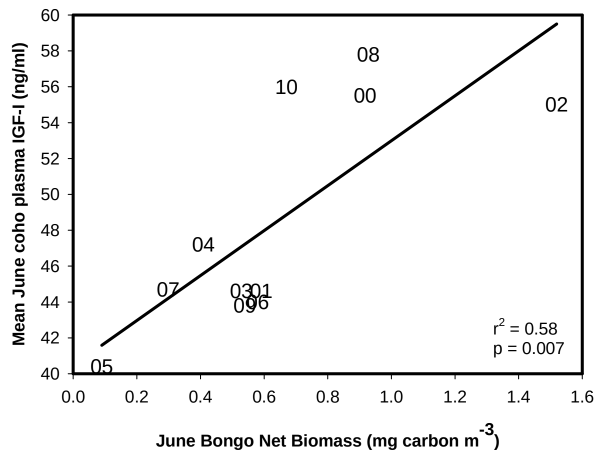

Figure 9. Relationship between plasma IGF1 in juvenile coho salmon and Bongo net prey field biomass in our June surveys. "Year" indicates the data point for that year.

Marine Growth and Adult Abundance

Perhaps the best test of whether bottom-up processes regulate marine survival and abundance is whether juvenile growth is related to adult abundance for Columbia River salmon. We have evaluated this question for both coho and Chinook salmon, including several independent populations of Chinook salmon. In every case we have found a positive and significant relationship between growth and adult abundance (Table 2).

Table 2. Relationships between post-ocean entry growth and adult abundance for yearling salmon for several populations of salmonids from the Columbia River basin.

Species	Population	Ocean entry years	n (year)	Growth estimate	Abundance estimate**	*P*	R^2
Chinook	Snake River spring	1999-2000, 2002-2004, 2006-2008	8*	otolith	Adults at Lower Granite Dam (stock specific)	< 0.01	0.49
Chinook	Mid-upper Columbia River spring	1999-2000, 2002-2004, 2006-2008	8*	otolith	Adults at Priest Rapids Dam (stock specific)	< 0.01	0.58
Coho	Columbia River (composite)	2000-2010	11	June IGF1	Oregon Production Index (hatchery) coho survival	< 0.01	0.82
Chinook	Mid and Upper Columbia River Snake spring (composite)	2000-2009	10	June IGF1	Spring Chinook adults at Bonneville Dam	< 0.01	0.79
Chinook	Willamette River spring	2006-2009	4*	May IGF1	Spring Chinook adults at Willamette Falls	0.08	0.85
Steelhead	Columbia River (composite)	2006-2009	4*	May IGF1	Steelhead adults at Bonneville Dam	< 0.01	0.82

* Not enough Chinook otoliths were collected in 2001 and 2005; analysis of Willamette River Chinook and Steelhead were first initiated in 2006.

** Adult return is considered to be an indicator of marine survival for Columbia River salmon (Appendix D and E).

Together, these data present strong evidence that variation in marine productivity directly controls marine abundance of Columbia River salmon. Moreover, these data suggest that estimates of juvenile salmon growth soon after ocean entry may be used to estimate adult salmon returns.

Juvenile Chinook Growth and Condition vs. Life History Type

In the previous section, we reported the differing ocean migration and distribution patterns observed for different stocks of spring- and fall-run Chinook salmon. Different populations and life-history types of Chinook salmon also display different responses to early marine residence.

For interior spring-run Chinook, which migrate predominantly as yearlings, early marine growth leads to interannual differences in body length. Length at capture and subsequent survival (i.e., counts of adults at Columbia River dams) are greater during years when coastal waters are cool and productive, as predicted if bottom-up processes dominate during early marine residence.

A reverse pattern is observed for fall-run subyearlings. During years when the ocean is relatively cool and productive, body condition after the first summer in the ocean is lower for fall-run subyearling Chinook. Two mechanisms may explain the lower mean body condition (based on residuals of mass:length regressions) observed during high survival years (Figure 10a). The first is that more fish survive in years with favorable ocean conditions, including those in poor condition that would not have survived in other years. The second is increased competition for prey in high survival years (a density-dependent effect).

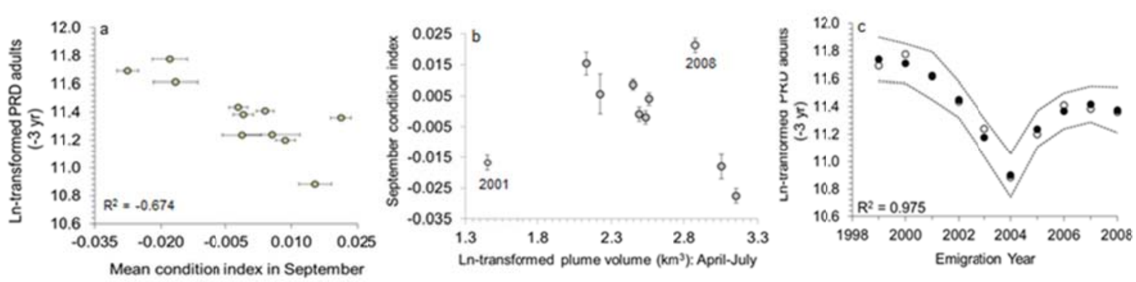

Figure 10. *Left panel* (a) shows relationships between adult returns of fall Chinook salmon to Priest Rapids Dam (3-year lag) vs. mean condition index (with SE) for subyearlings collected in September (1998-2008).

Center panel (b) shows mean condition index (with SE) for subyearlings collected in September vs. plume volume from April to July 1998-2008.

Right panel (c) shows observed and expected adult returns of fall Chinook to Priest Rapids Dam (indicated by open and closed circles, respectively) vs. year of juvenile migration during 1999-2008, where expected returns are based on subyearling condition index, plume volume, and the interaction between plume volume and condition index.

We also found that interannual variation in plume volume (1999-2008) accounts for a high level of the variation in subyearling body condition (Figure 10b) with the notable exceptions of 2001 (drought year) and 2008. In fact, a regression model that included subyearling body condition in September and plume volume during the juvenile migration (and the interaction between them) accounted for more than 97% of the variation in returns of adult fall Chinook to Priest Rapids Dam (Figure 10c). These data indicated that measurement of subyearling body condition in late summer may be useful for hindcasting, and potentially forecasting adult returns, as well as for identifying specific mechanistic links between ocean conditions and early marine survival.

Regional Variation in Growth Rates and Survival

Research conducted by the ocean projects suggests that changes in prey quality affect the growth and survival of salmon in the marine environment. Therefore, the relative survival of different stocks of salmon in the ocean will depend on where they migrate in the ocean and how long they remain within regions of varying ocean productivity. Questions about specific patterns of ocean habitat use are being addressed by the ocean project enhanced telemetry studies. For example, while plankton productivity and temperatures tend to be higher in the Northern California Current (NCC), salmon in the Alaska Coastal Current (ACC) are generally larger and fatter, and have higher growth rates (Figure 11). Similarly, growth hormones measured in juvenile salmon collected in both the NOAA and DFO trawl surveys indicate that growth is generally higher north of Vancouver Island (Figure 12), although there is interannual variation in growth hormones. The poorer growth and condition of salmon in the NCC appears to be related to a calorie-deficient diet rather than to a direct effect of temperature on salmon growth (Trudel et al. 2002).

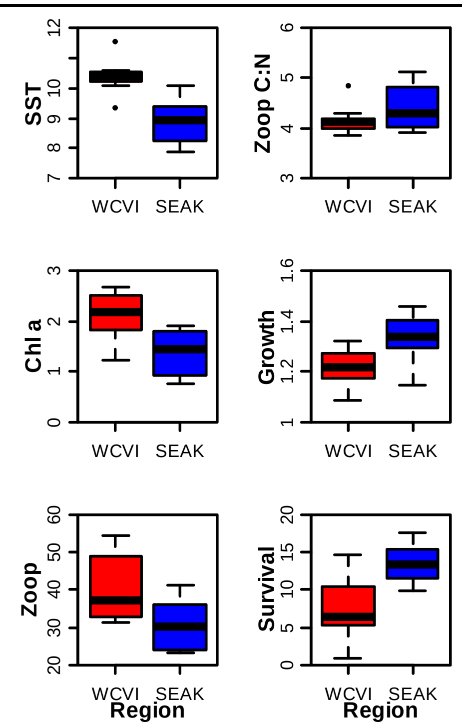

Figure 11. Mean annual sea surface temperature (SST), phytoplankton (Chl a) and zooplankton abundance (Zoop) and C:N ratio (Zoop C:N) vs. growth and survival of coho in the NCC (WCVI) and ACC (SEAK). Data from Trudel et al. 2011a.

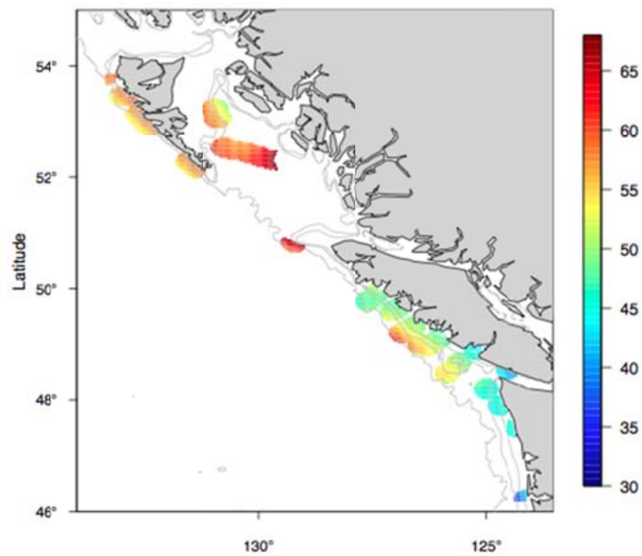

Figure 12. Blood plasma concentration of insulin growth factor I (IGFI) in juvenile yearling Snake River/Upper Columbia River Chinook salmon collected during NOAA and DFO trawl surveys June-July 2009. Cool and warm colors respectively indicate low and high growth. (Personal communication, B. Ferris, L. Rohrbach and B. Beckman, NOAA Fisheries, Seattle).

Support for this hypothesis was first documented by Peterson and Schwing (2003), who showed that the marine survival of coho salmon in the Oregon Production Index (OPI) was positively correlated with abundance of lipid-rich northern copepods. For Columbia River summer and fall Chinook and Redfish Lake sockeye salmon a similar pattern was observed between summer growth and abundance of northern copepods off Vancouver Island and between summer growth and the C/N ratio in zooplankton (Trudel et al. 2011).

Winter Growth and Mortality

Overwinter survival of juvenile Pacific salmon during the first year at sea has been recognized as an important factor limiting recruitment and has been linked to lipid and energy dynamics (Beamish et al. 2004). Research on size-selective overwinter mortality in juvenile salmon has focused on northern stocks, such as Prince William Sound pink (Moss et al. 2005; Cross et al. 2009) and Bering Sea sockeye (Farley et al. 2011). However, Beamish et al. (2004) also studied a southern stock of coho salmon from the Strait of Georgia.

These studies have generally supported the hypothesis that winter mortality is higher in smaller juvenile salmon. However, none of these studies quantified the extent of mortality that occurs during winter, and none have focused on the southern regions of the NCC used by Columbia River salmon.

DFO has conducted trawl surveys during fall and winter since 2000 to assess the extent of size-selective mortality in juvenile Chinook and coho salmon. For Marble River juvenile Chinook salmon from northern Vancouver Island, we observed high mortality (80-90%) between the first fall and winter at sea (Figure 13). However, the cause of this mortality was unknown, as there was little evidence that size-selective mortality occurred in this area during winter.

In a collaborative study with scientists working on the Gulf of Alaska, DFO also observed size-selective overwinter mortality in juvenile Chinook salmon rearing in Gulf of Alaska (Trudel et al. 2011). This mortality may have been due to the reduced availability of food during winter or to the longer winter at northern latitudes or both.

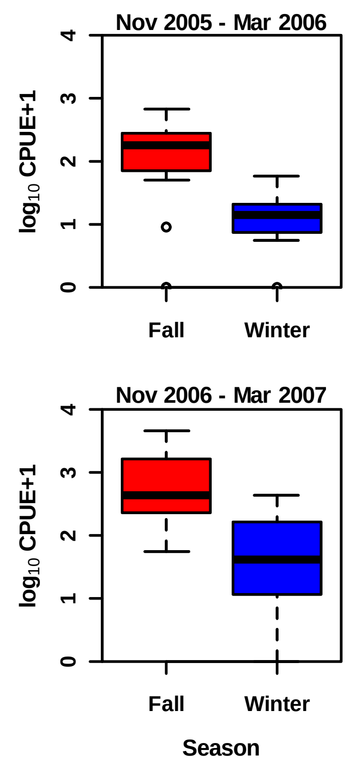

Figure 13. Catch-per-unit-effort (CPUE) of Marble River Chinook salmon during fall and winter off the west coast of Vancouver Island. Middleton (2011).

The implications of these results for Columbia and Snake River salmon are as follows:

1) Stocks that reside in southern regions of the coast, such as fall Chinook, are unlikely to experience size-selective mortality the first winter at sea; however, they may still sustain high levels of mortality during that period.

2) Stocks that rear in the Gulf of Alaska during their first winter, such as sockeye and spring Chinook, are likely to experience significant size-selective mortality during the first winter unless they grow rapidly soon after entering the coastal marine environment (Trudel et al. 2007c).

V. Mechanisms Influencing Salmon Growth and Survival

Pearcy (1992) suggested two types of ecosystem processes that regulate salmon population abundance: bottom-up processes, which affect food supply (*H1*), and top-down processes, which influence mortality (*H2*). In simple terms, bottom-up processes are based upon production at the lower trophic levels, whereas top-down processes are based upon predation or disease. Direct mortality results from starvation; predation by fish, birds, or marine mammals; or weakening of overall fitness due to pathogens. Indirect mortality can result from slowed growth due to inadequate food resources upon ocean entry. Although starvation has not been documented for salmon, food limitation would likely slow growth and swimming speed, thus increasing susceptibility to predation.

Bottom-Up Processes (*H1*)

To understand interannual variation in salmon survival, the ocean projects have focused research on understanding the processes affecting interannual variation in prey quantity and quality (i.e., lipid content). Our hypothesis is that prey quantity and quality are controlled through transport within the California Current, i.e., by the strength and direction of currents. If source waters of the coastal currents originate from the north, then the plankton communities, which anchor the food chain are dominated by "northern" species. Northern copepods have a high fat content, and high levels of omega-3 fatty acids.

Conversely, if source waters of the California Current originate from offshore, the plankton community is dominated by small "subtropical" species with low lipid content. Given that subtropical species are deficient in omega-3 fatty acids and rich in saturated fat (Lee et al. 2006), it is logical to assume that salmon growth and survival is higher during years when lipid-rich northern copepods dominate, since they result in lipid-rich forage fish and krill upon which salmon feed.

Stomach Content Analysis—Comparisons of stomach content have shown that prey consumed by juvenile salmon during early ocean residence is significantly different between year of warm (positive PDO) and cold (negative PDO) ocean conditions ($P = 0.005$). These changes in the diet composition of spring Chinook and coho salmon were significantly related to adult survival. These differences in diet composition were observed in the stomach of fish caught in May but not June, suggesting that the early summer prey community is the most critical to survival.

In particular, we have found that as salmon grow older (and larger) during their first summer at sea, the incidence of fishes in the stomachs tends to dominate over krill and other invertebrates. This shift to a more piscivorous diet appears to be an important determinant of marine growth and survival for juvenile coho and Chinook salmon (Daly et al. 2009; Trudel et al. 2011). During years of low marine survival, coho salmon consumed fewer and smaller fish, while subyearling Chinook consumed less total food, and more individuals had empty stomachs.

Diets of both juvenile Chinook and coho varied significantly between oceanographic regions (west coast of Vancouver Island vs. Southeast Alaska; $P = 0.022$) and seasons ($P < 0.001$) possibly due to temporal and spatial changes in prey availability (Brodeur et al. 2007; Trudel et al. 2010). However, this finding is compounded by the fact that different salmon stocks have different mean sizes and arrive within a given area of the coastal shelf at different times. Juvenile Chinook and coho salmon are more piscivorous off the west coast of Vancouver Island than Southeast Alaska during summer, but this pattern reverses during the fall. The degree of piscivory declines in both species during winter, with increased proportions of euphausiids eaten at this time. No significant differences in stomach contents were noted between years with differing oceanographic regimes (PDO) in either the region off Vancouver Island or Southeast Alaska.

Stable Isotope Analysis—Stable isotopes of carbon and nitrogen are frequently used to infer feeding relationships in marine and freshwater ecosystems because these isotopes provide a longer-term image of the predator diet (Post et al. 2007). Stable isotope profiles were developed from the diets of juvenile coho and Chinook salmon sampled off Vancouver Island and Southeast Alaska. These profiles differed significantly with salmon species, region, water source (coastal vs. inner shelf), season, year, oceanographic regime (warm vs. cold PDO signal), and body size.

Trophic level, or degree of piscivory, was marginally higher in Chinook than in coho salmon (Miller et al. 2010c). Trophic level also increased with size, and degree of piscivory was generally higher in warmer than colder years for both species. An ongoing coastwide study (central California to Bering Sea) has found large gradients in $\delta^{13}C$ signatures along a continental spatial scale that corresponds to regional changes in diet and productivity (Mazumder et al. 2011). Taken together, these results suggest that diet is likely affected by processes on a regional basis, and that juvenile Chinook and coho salmon experience similar responses to changes in prey availability.

The Role of Prey Quality—Differences in survival between regimes or geographic regions may be directly related to the quality of prey consumed by salmon (as reflected by lipid and fatty acid composition). The lipid and fatty-acid composition of prey available to juvenile Chinook and coho salmon was examined from samples collected in May and June 2009. Results showed that commonly eaten fish prey had significantly higher levels of specific important essential fatty acids than prey that were also present in the marine environment, yet rarely eaten (Daly et al. 2010).

Lipid contents in zooplankton also differed among regions, with higher lipid concentration off Southeast Alaska than off the west coast of Vancouver Island (Trudel et al. 2011). Thus juvenile Columbia River salmon that migrate north encounter more nutritious prey as they get further north. This suggests that ocean conditions prevailing in the NCC may limit the growth of Columbia River salmon during summer.

Inferences Based on Trophically Transmitted Parasites—Trophically transmitted parasites can provide valuable information on the trophic interactions of juvenile salmon beyond the 24-30 h window allowed by stomach content analysis (Baldwin et al. 2008; Bertrand et al. 2008; Valtonen et al. 2010). These parasites use trophic interactions at multiple levels in a food web to complete their complex life cycles. This life history strategy makes it possible to use parasites as indicators of the diet and habitat used by individuals and populations of salmon.

We found that several metrics of salmon growth and health (IGF1, ocean growth, and Fulton's condition factor) were highest among salmon with high parasite-species richness. This indicates that a diverse diet in both the freshwater and marine environments is important to growth of Chinook and coho salmon (Losee et al. in prep).

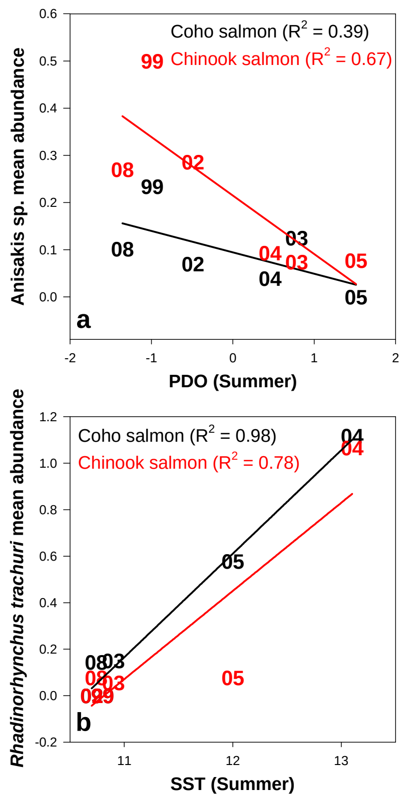

Figure 14. Relationship between a) *Anisakis sp.* to sea surface temperature and b) *Rhadinorhynchus trachuri* and mean values of the PDO (May & June) for yearling Chinook and coho salmon in 1999, 2002, 2003, 2004, 2005 & 2008.

In addition, we found that marine parasite communities of juvenile Chinook and coho salmon differ in "cold" vs. "warm" PDO ocean years. This finding reinforced the hypothesis that marine trophic interactions of yearling Chinook and coho salmon vary with ocean conditions. Some parasites recovered from yearling Chinook and coho salmon were present in all years; however, the appearance of several others was directly correlated with local (SST) and basin-scale indices (PDO) of ocean climate (Figure 14). Zooplankton are used as intermediate hosts by these parasites; thus, this pattern was probably due to changes in the abundance and species composition of the marine zooplankton community (Marcogliese 1995) as well as the proportion of fish in the diet (Pascual et al. 1996; Petric et al. 2011).

Top-Down Processes (*H2*)

Predation in Shelf Environments—Ocean predation appears to be a major driver of salmon mortality during early marine residence (Pearcy 1992; Bax 1998; Emmett 2006). Potential ocean predators of salmon include fishes, birds, mammals, and possibly Humboldt squid. Ocean project research has demonstrated that Pacific hake abundance is usually much higher in the coastal NCC during warm years. Thus we hypothesize that during warm ocean years early marine mortality rates of Columbia River juvenile salmon are influenced by hake and other piscine predators (chub mackerel (*Scomber japonicus*) and jack mackerel (*Trachurus symmetricus*), Humboldt squid (*Dosidicus gigas*); Emmett et al. 2006; Emmett and Sampson 2007; Litz et al. 2011).

Our biweekly survey of fish predators off the mouth of the Columbia River and Willapa Bay have shown that Pacific hake abundance in these areas is related to adult returns, and that measures of hake abundance provide a useful index of predation for coho and fall Chinook salmon (Figure 15).

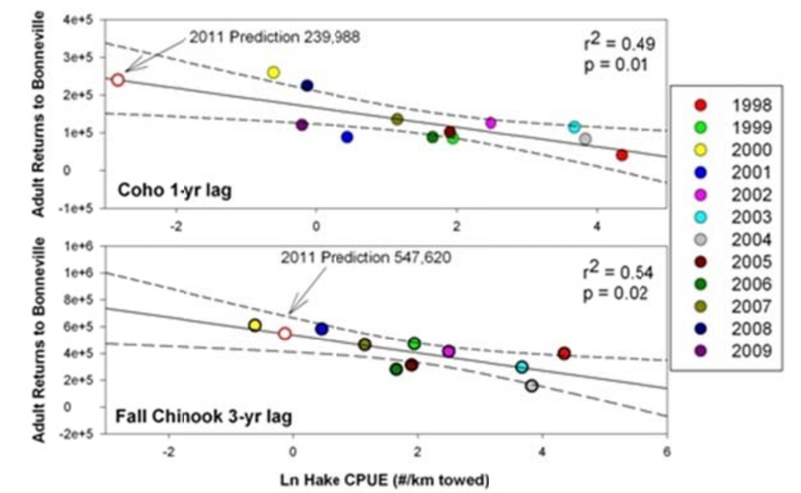

Figure 15. Regression of adult returns to Bonneville Dam for coho and fall Chinook salmon vs. Pacific hake catch-per-unit-effort (CPUE; number/km towed) during the juvenile migration period. Predictions for 2011 adult returns are also shown.

However, the effect of piscivorous predators on juvenile salmon may be modulated by a number of factors, such as environmental conditions or the availability of alternative prey. For example, abundance of forage fish such as northern anchovy, Pacific sardine, Pacific herring, and whitebait smelt varies seasonally (and interannually) off the Columbia River. Juvenile salmon may enter the nearshore ocean during a period before these forage fishes are abundant. If predator abundance is also high during this period, these salmon may sustain higher mortality rates than those of later-migrating conspecifics.

Predation near the Columbia River Mouth and Plume—Results from the ocean project studies suggests that seabird predation is a direct cause of mortality for Columbia River juvenile salmon. Seabird predation may also be a significant top-down cause of post-hydrosystem mortality.

Our initial hypothesis was that the turbid waters of the plume provide juvenile salmon with a refuge from visual predators, but results of the ocean projects research suggest otherwise. We have found that bird predators are significantly more abundant in the plume, and that the plume does not necessarily provide a refuge from bird predation. Telemetry studies have also found that survival in the plume is lower than elsewhere, possibly due to predation by birds and fish.

We have measured densities of the two numerically dominant seabird species: the common murre (*Uria aalge*) and the sooty shearwater (*Puffinus griseus*) in the plume region. Densities of these birds have been found higher in the plume region than elsewhere on the Oregon or Washington continental shelf (30.1 vs. 3.3 murres per km^2

and 30.1 vs. 8.5 shearwaters per km^2; Zamon et al. in prep). Land-based biweekly surveys 5.5 km from the river mouth showed that bird predators are significantly more abundant during spring tides than neap tides. This means that predation pressure near the river mouth varies significantly with the tides.

We found salmon in 11% of the stomachs of common murres sampled (n = 30). We identified remains of Chinook and coho salmon, as well as steelhead, using genetic markers. Salmon have yet to be found in any of the available samples of shearwater diet (n = 37), but a Columbia River steelhead PIT tag was recovered from a shearwater stomach in 2007.

There is a significant linear relationship between the density of birds in May of a given year and adult returns at Bonneville Dam of coho salmon from that migrated as juveniles during that year ($R^2 = 0.56$; $P = 0.05$). No such relationship has been detected for Chinook salmon, or for bird densities in June. Similar relationships have not yet been explored for individual Chinook stocks or for other salmon species because diet sample sizes are too small.

Pathogens—Similar to predators, pathogens can have a significant effect on the survival of juvenile salmon during migration and early marine residence (Jacobson et al. 2008). The outcome of an infection is mediated by interactions among a pathogen, its host, and the environment. A number of pathogens have been reported to affect juvenile salmon during the freshwater migration (Fryer and Sanders 1981; Bartholomew et al. 1992; Stocking et al. 2006; Ferguson et al. 2011), yet little is known about the effects of pathogens on juvenile salmon during early marine residence. Our analyses have focused on several freshwater pathogens that contribute to mortalities of juvenile salmon in estuarine and marine environments.

The freshwater trematode, *Nanophyetus salmincola*, encysts in all tissues and organs of Pacific salmon. We recorded a decline of highly infected coho salmon between early and late summer in our ocean samples, which suggested that approximately 20% of coho salmon mortality during the first months at sea was associated with this parasite (Jacobson et al. 2008). Abundances of this parasite are much lower in yearling and subyearling Chinook salmon, probably due to differences in freshwater residence and exposure to the infective stages of the parasite.

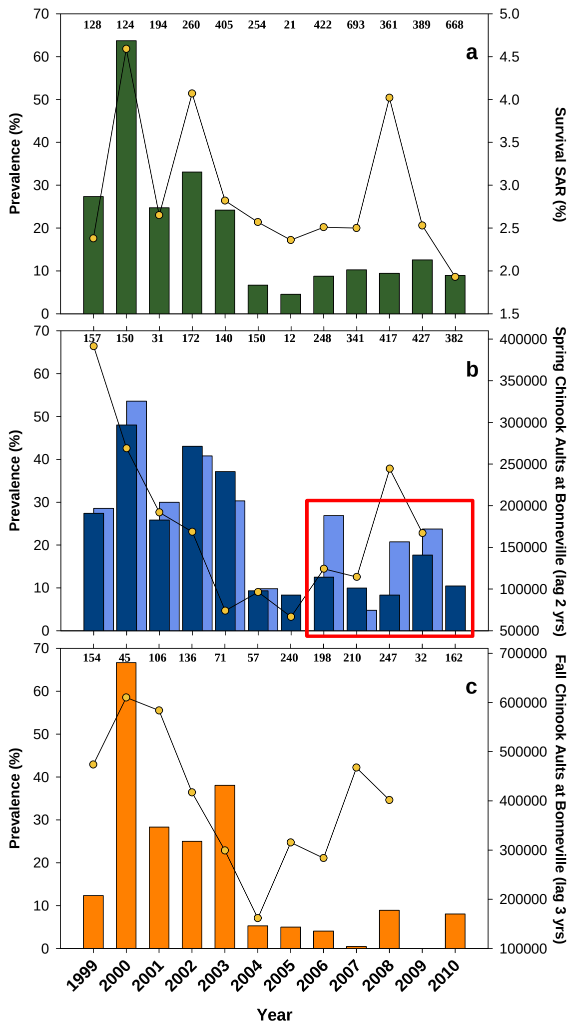

Figure 16. *Renibacterium salmoninarum* prevalence and survival in a) yearling coho salmon in May and June vs. coho SAR, b) yearling Chinook salmon in May and June vs. spring Chinook adult returns to Bonneville Dam lagged by 2 years (all stocks dark blue, UCRSu/Fall light blue) and c) subyearling Chinook in June and September vs. fall Chinook adult returns to Bonneville Dam lagged 3 years. Sample sizes are above bars.

Renibacterium salmoninarum (Rs), the causative agent of bacterial kidney disease (BKD), is the most common freshwater pathogen of Pacific salmon populations (Fryer and Sanders 1981; Elliott et al. 1989). Infections in marine-caught coho and Chinook salmon vary interannually (Figure 16). For coho salmon during 1999-2010, the prevalence of Rs has been positively related to good adult survival ($R^2 = 0.48$; excluding 2008 as an outlier $R^2 = 0.75$). This relationship suggests that during years of good ocean conditions, more infected juvenile coho salmon can survive.

Prior to 2004, overall prevalence of Rs was similar in Chinook and coho salmon and was relatively high. Since 2004, prevalence has been relatively low and we have noted differences among three major stocks of yearling Chinook salmon. The Upper Columbia River summer/fall stock group has had the highest prevalence in most years, and unlike the other stocks, has not continually had low prevalence since 2004 (red box, Figure 16b). Prevalence in this stock is correlated with adult returns ($R^2 = 0.43$).

The prevalence of Rs has also been significantly different among stocks of yearling coho salmon, with Columbia River stocks having the highest prevalence (18.6%).We compared prevalence of Rs in coho salmon caught off Oregon and Washington to the prevalence in the same stocks caught off Vancouver Island (17.6 and 4.9%, respectively, $P < 0.05$). For the Oregon and Washington stocks examined, the much higher prevalence of Rs in fish caught further south indicated that mortalities from BKD may occur during early ocean migration.

To help identify where mortalities occur and the role of freshwater, estuarine, and marine conditions on survival of infected salmon, we began to measure Rs prevalence in juvenile salmon collected at Bonneville Dam and the lower estuary in 2008 and 2009. In 2008, Rs prevalence was low in all habitats. However, in 2009, prevalence of Rs was significantly higher in yearling Chinook salmon originating above Bonneville Dam (44.6%) than in those originating in the lower estuary (10.4%) or ocean (17.6%). This suggests this pathogen had a significant impact on salmon during downstream outmigration in 2009.

We also record the occurrence the parasitic copepod *Lepeophtheirus salmonis*. As part of a collaboration among NOAA, DFO, and the University of Victoria, BC, we examined fish from areas off Oregon through Alaska coastal waters. We reported that numbers of this lice were relatively low on all salmon species collected (Trudel et al. 2007a). Although this parasite can be a major factor on populations of farmed salmon, at this time it does not appear to be a factor for Columbia River Chinook and coho salmon populations.

Inferences from Ecosystem Modeling

Ecosystem models provide a mechanistic framework to understand the pressures acting upon salmon by integrating observed variability of ecosystem productivity, community structure, and species interactions. We have developed a suite of trophic models using data from pelagic trawl and zooplankton surveys. The goals of the ecosystem modeling are to 1) investigate how interannual changes in pelagic community structure (bottom-up processes) affect the efficiency at which energy is transferred from primary producers to higher trophic levels, 2) estimate predation pressure upon juvenile salmon (top-down processes), and 3) test specific ecosystem state scenarios.

Bottom-up processes—Upwelling supported zooplankton production correlates well with juvenile salmon survival (Ruzicka et al. 2011). However, structural rearrangements among trophic pathways greatly affect the efficiency with which energy is transferred up the food web. For example, in some years jellyfish become major consumers of zooplankton, diverting energy from fish production (Ruzicka et al. 2007; Brodeur et al.

2011). Thus jellyfish may affect juvenile salmon survival, despite a low dietary overlap between these species (Brodeur et al. 2008).

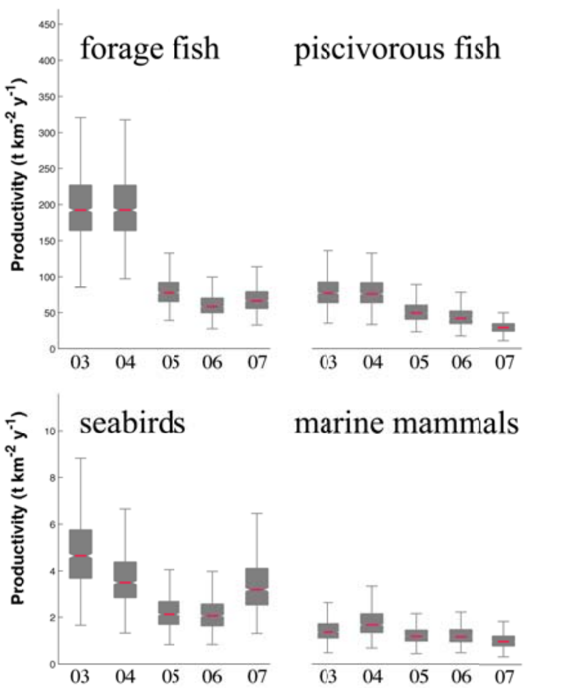

Figure 17. Interannual indices of food-web efficiency showing differences in the relative amount of energy supporting production of higher trophic-level groups under a common level of primary production.

Large interannual differences in food-web transfer efficiency were apparent when different trophic levels were modeled under identical primary production rates (Figure 17). This suite of models can be used to trace the flow of primary production to juvenile salmon through prey of differing food quality.

These models complement existing indices of biological ocean conditions by providing estimates of the efficiency with which lower trophic production is transferred upward in the food chain.

Top-down processes—We are developing an interannual index of marine predation on juvenile salmon based on observed composition of the pelagic community. This index accounts for observational variability and the propagation of parameter uncertainty. Among years modeled so far, 2003-2007, marine predation accounted 75-90% of juvenile salmon production. In other words, 75 to 90% of the prey eaten by juvenile salmon and converted to salmon tissue is in turn consumed by other predators.

Through sensitivity analyses, we are investigating the potential impact of outbreak predators such as Humboldt squid and the role of forage fishes in mediating predation pressure. Our analyses incorporating current information about Humboldt squid diets indicate that as competitors, these squid can be at least as detrimental to juvenile salmon survival as they may be as predators. On the other hand, we find that direct and indirect competition with forage fishes remains very small across the range of interannual abundance observed. As a buffer against predation, forage fishes can potentially benefit juvenile salmon to an extent that overshadows their negative effect as competitors.

VI. Freshwater and Ocean Survival Estimates

Coastal Ocean Acoustic Salmon Tracking (COAST) Objectives

Objectives of the acoustic telemetry project were to:

i) Demonstrate the technical feasibility of using acoustic tags to determine the mortality and migration of Columbia River Chinook salmon);

ii) Measure survival in saltwater where other technologies were economically unfeasible;

iii) Determine freshwater anthropogenic impacts on a key ESA-listed group, Snake River spring Chinook, by conducting a formal experimental test of two important theories (Delayed Mortality: that greater cumulative dam passage reduces estuary/coastal ocean mortality; Differential-Delayed Mortality: that transport via barge reduces estuary/coastal ocean mortality relative to non-transported smolts);

iv) Establish the first “non-invasive[1]” measurements of ocean migration behavior and baseline measurements of coastal ocean survival for comparison with the extensive current understanding of freshwater survival.

Kintama’s acoustic sub-arrays monitored survival of yearling spring Chinook during their seaward migration from the Columbia River basin to as far as Alaska in 2006-2011 (Figure 18). The array allows contrasting mortality in four important habitats: (a) the 8-dam Hydrosystem (release to Bonneville Dam), the unimpounded lower river and estuary (Bonneville Dam to Astoria; 220 km); the “plume” (Astoria to Willapa Bay; 56 km); and the coastal ocean (Willapa Bay to Lippy Point, NW Vancouver Island, 483 km).

Because the array is at fixed geographic locations, there is some inclusion of different habitats within these migration segments. The highly mobile plume region is bracketed between the Astoria and Willapa Bay sub-arrays but the region we label as “Plume” also contains a small amount of the estuary and some of the coastal shelf north of the plume proper. The Pacific Ocean Shelf Tracking (POST) project contributed additional sub-arrays within the Strait of Juan de Fuca/Strait of Georgia/Queen Charlotte Strait regions that are critical to our study because they demonstrate that tagged Columbia River yearling Chinook do not migrate east around Vancouver Island. Within the geographic confines of the array, hydrosystem operations and intrinsic smolt behavior jointly determine the period of time smolts spend in the four environments (“residence time”).

1 In the sense that individual animals can be followed over multiple arrays without affecting them; conventional trawling results in the death of captured smolts.

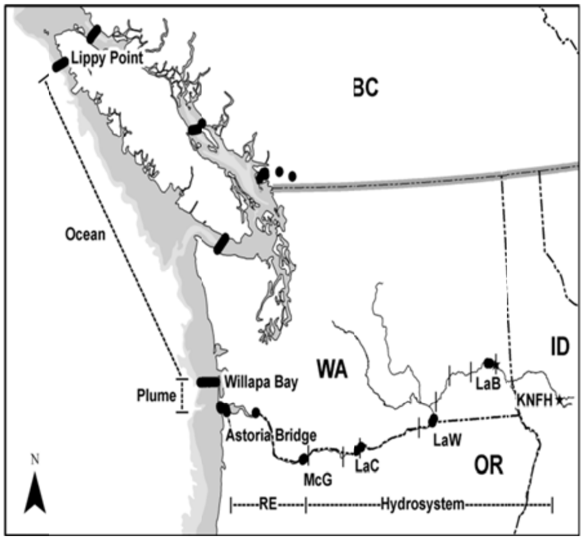

Figure 18. Geographic layout of the acoustic telemetry array; the Alaska sub-array is not shown. Vertical lines show the location of the 8 dams forming the hydrosystem for Snake River smolts. Dots show sub-array locations: McG, McGowans Channel; LaC, Lake Celilo; LaW, Lake Wallula; LaB, Lake Bryan); KNFH, Kooskia National Fish Hatchery; RE, Lower River/Estuary.

The material reported here summarizes these findings and adds some more recent context on where in the life history most mortality occurs for Columbia Basin salmon stocks. Because few tagged smolts reach Alaska, we limit our survival measurements to Lippy Point, but note that marine migration speeds to Alaska are similar and persist beyond Vancouver Island. This summary of the Kintama study is presented without technical detail of the methods used and most of the underlying assumptions, which are reported in our annual reports to BPA (Porter et al. 2010a, b, 2011) and in Appendix C of this document; the Porter at al. (2010a) report provides a concise multi-year synthesis of the results and implications for policy makers. A comparison with other telemetry systems is Appendix F.

Survival Estimates in the Columbia River, Estuary, Plume, and Coastal Ocean.
In-River and Ocean Survival—In the Columbia River, smolt-to-adult survival rates (SAR) now average about 1% for many salmon stocks, although several decades ago they were much higher. For Snake River spring Chinook, SARs were 3-4% in the 1960s (Williams et al. 2005) and now average 0.5-1.0% for many groups (Tuomikoski et al. 2009), a 6-8 fold decline. For Dworshak spring Chinook, the Snake River stock used for these acoustic tagging studies (2006-2009), SARS are the lowest observed amongst hatchery populations, at approximately 0.5%. Similar declines are also evident for many species in British Columbia: sockeye salmon (Peterman and Dorner, 2011), steelhead (Welch et al. 2000), coho salmon (Beamish et al. 2000), and, possibly, Chinook salmon (English et al. 2008).

Although Snake River spring Chinook experience some of this mortality in the hydrosystem (up to 50%), most of the mortality occurs within and beyond the first 1-2 months in the coastal ocean. Immediately below the hydrosystem, survival in the lower river and estuary for spring Chinook released from hatcheries (2006-2009) and for yearling Chinook tagged at dams (2010 and 2011) was high (81-99%) regardless of migration timing. In the plume, survival was generally low despite the short migration distance (14-71%). Subsequent survival in the coastal ocean from Willapa Bay to Lippy Point ranged between 2-25% (Porter et al. 2011).

Survival estimates are the metric commonly reported in salmon studies, but can be misleading because survival to adult return is the product of survival in successive life history periods. For example, if mortality through the 8-dam hydropower system is 50% (or half the fish), then it still takes 7.6 successive bouts of 50% mortality to reduce survival to a SAR of 0.5%. From this perspective, mortality in the hydrosystem is 1/7.6, or only 13% of the total mortality, while the remaining mortality from Bonneville Dam to adult return is 87%.

We used our freshwater and early marine survival data to estimate the magnitude of the mortality experienced during the rest of the life history (beyond the area where fish are tracked) using Dworshak and Yakima spring Chinook (and we also include multiple BC salmon stocks to extend the comparison; Table 3). Within the hydrosystem, acoustic estimates of survival closely matched PIT tag estimates of survival in most years (see Appendix C). To evaluate the relative contribution of the later life history period to overall smolt-to-adult survival, we compared the number of animals needed in the early life history period to the number needed later in the life history to produce one survivor. This provides a simple way to evaluate the relative importance of mortality in different parts of the life history.

Assessing mortality ratios for Dworshak spring Chinook for example, mortality still to be experienced beyond the river mouth (Astoria) is 20 times greater than the combined mortality experienced in the hydrosystem and the unimpounded lower river and estuary to Astoria (Table 3); if mortality through the plume to Willapa Bay is included, mortality still to be incurred is 9 times total mortality to this point (reached about one month after release upriver). By the time the smolts reach Lippy Point, the northern end of the California Current region and the start of the region of good growth conditions, the majority of the mortality seems to have been experienced.

For the hydrosystem only, the proportion of total mortality is 1/(24+1)=4%, and for the estuary the proportion of total mortality is 1/(154+1)=0.6%. For the Columbia River plume (which we operationally define as extending from Astoria to Willapa Bay, 40 km north of the Columbia River mouth), the proportion of total mortality is 1/(33+1)=3%. Even if we include all sources of mortality to Willapa Bay, from Table 3 this includes only 1/(9+1)=10% of the total mortality, or SAR, demonstrating that the majority of the mortality is occurring north of Willapa Bay[2]. Results are similar for Yakima River smolts, a mid-Columbia stock. Freshwater effects (hydrosystem, estuary and plume combined) are small unless the hydrosystem exerts large latent effects on subsequent ocean survival.

Table 3. Comparison of smolt survival in different life history periods. Early survival is calculated as the average across all available years of acoustic tag data.

	Acoustic-tagged smolt early survival (%)	Current SAR (%)[a]	Mortality ratio[b]
Columbia River Chinook			
Snake River (Dworshak spring Chinook)			
Release to Astoria (2008, 2009)	31.5	~0.5	20
Release to Willapa Bay (2006, 2008, 2009)	21	~0.5	9
Release to Lippy Point (2006, 2008, 2009)	2.0	~0.5	0.08
Hydrosystem only (Release to Bonneville, 2006, 2008, 2009)	34.5	~0.5	24
Estuary only (Bonneville Dam-Astoria; 2008, 2009)	87.8	~0.5	154
Plume only (Astoria-Willapa Bay; 2008, 2009)	40.5	~0.5	33
Yakima River (Cle Elum spring Chinook)			
Release to Astoria (2008, 09)	44.0	~2.3	8.4
Release to Willapa Bay (2006, 2008, 2009)	23.2	~2.3	2.3
Release to Lippy Point (2006, 2008, 2009)	1.9	~2.3	0.02
Estuary only (Bonneville Dam-Astoria; 2008, 2009)	93.0	~2.3	38
Plume Only (Astoria-Willapa Bay; 2008-2009)	36.8	~2.3	5.9
British Columbia[c]			
Steelhead	17	~1	3
Sockeye	19	~1	3.6
Coho (FW only)	62	~1	38
Chinook (FW only)	27	~1	7

a From Comparative Survival Study and Yakima Nation annual reports to BPA.

b We compare the ratio of mortalities (m) necessary to yield one survivor in the early and late life history periods. As $SAR=S_{Early} \cdot S_{Late}$, then the mortality ratio, m_{Late}/m_{Early} is $S^{-1}_{Late} / S^{-1}_{Early} = S_{Early} / S_{Late} = S^{2}_{Early}/SAR$.

c Survival data are averages from all prior British Columbia acoustic studies, with sockeye & steelhead survival measured for multiple rivers to exit from Salish Sea (Queen Charlotte Strait/Juan de Fuca Strait); for coho & Chinook (only) freshwater survival are measured to Fraser or Squamish River mouth; see (Welch et al. 2011) for details.

[2] Note that because of the lack of the Astoria sub-array in 2006, survival proportions are based on a varying number of years in Table 3, and thus are not exactly comparable.

Similar results are also evident for British Columbia salmon stocks: the magnitude of the differences in mortality is particularly pronounced when marine mortality is contrasted with freshwater mortality to the river mouth (7-38 times larger). For both British Columbian and Columbia River salmon, most mortality thus occurs whilst the salmon are in the ocean, providing the basic conditions necessary for large differential effects in the ocean to affect different salmon stocks differently—and also great potential for ocean effects to be mistakenly attributed to operation of the hydrosystem. The results also indicate that the majority of mortality forming the SAR occurs by the time the smolts reach the northern terminus of the NCC.

Survival Rate in Different Habitats—A major focus of current management practice involves transferring smolts from the hydrosystem to the ocean as rapidly as possible because of the belief that hydrosystem mortality is high. This approach implicitly assumes that survival beyond the hydrosystem is better. We tested this assumption by comparing survival rates of tagged Snake River yearling Chinook salmon smolts across four different habitats: hydrosystem, lower river and estuary ("estuary"), plume, and coastal ocean as they migrate from fresh water to the ocean. We did this by fitting a survival model with different rate constants for each of the four habitats through which the smolts migrate.

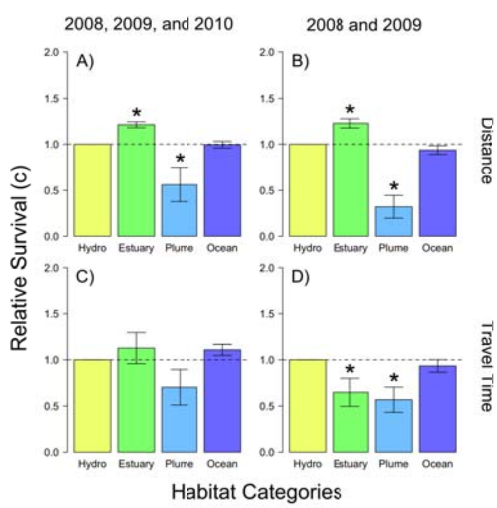

Figure 19. Habitat-specific rate constants for (top row) smolt survival per 100 km and (bottom) per week of travel for Snake River spring Chinook. The left column includes the 3 years 2008-2010; the right column excludes 2010. Error bars are ±1 SE and * indicates rates significantly different from the hydrosystem (P <0.05). Survival rates are scaled relative to hydrosystem survival.

We ran the analysis including 2008-2010, and then again excluding 2010, a year when acoustic tag-based survival estimates for freshwater were lower than independent PIT-tag based survival estimates (Figure 19; note that 2006 is excluded because the Astoria sub-array was not deployed, preventing separate estimates of survival in the estuary and the plume).

Regardless of whether or not 2010 was included, we found survival rates in the hydrosystem and coastal ocean to be nearly equivalent. This also held whether we compared the survival rate per 100-km traveled (Figure 19, top row) or per week of travel time (Figure 19 bottom row; see Porter et al. 2011 for detailed explanation).

When 2010 was excluded, relative ocean survival rates were reduced slightly and became marginally lower than survival in the hydropower system. However, in no case was the ocean survival rate statistically distinguishable from the hydrosystem survival rate. If relative survival in the ocean is not higher than in the hydrosystem, then this raises important questions about the current management philosophy of accelerating smolt movements from the hydrosystem into the ocean.

In terms of the remaining habitats (estuary and plume), we found evidence that plume survival rates were lower than hydrosystem survival rates on average, but also variable between years. This was observed whether we modeled survival rate as a function of distance or time and irrespective of whether we included results from 2010. We also found mixed evidence for the estuary survival rate differing from that for the hydrosystem (Figure 19). Survival-by-distance models showed higher survival rates in the estuary (regardless of whether or not 2010 was included), but survival-by-time estimates were more variable and produced survival rates that were higher than hydrosystem if 2010 data was included and lower if 2010 data was excluded. Overall, the results from the acoustic tagging experiments result in strong evidence for lower plume survival rates, but unclear evidence for differences in estuary survival. Plume survival was variable from year to year and, as plume residence by yearling Chinook was relatively short, the overall effect on SARs may be small.

Our acoustic tagging results, made in a period of what appears to be better ocean conditions than occurred in the 1990s (when SARs were substantially lower), indicates that ocean survival rates per day are at best currently only very slightly higher than hydrosystem survival rates (Table 4).

Table 4. Average habitat survival rates (%) per day, averaged across 2008-2010 (2006 was excluded because estuary and plume survival could not be separated).

Habitat	**2008, 2009, 2010**			**2008, 2009 only**		
	$\hat{S}$	se ($\hat{S}$)	95% CI	$\hat{S}$	se ($\hat{S}$)	95% CI
Hydrosystem	94.4	0.37	(93.7, 95.1)	95.7	0.31	(95.1, 96.3)
Estuary	96.0	2.05	(92.0, 100)	89.9	2.97	(84.1, 95.7)
Plume	89.8	3.51	(82.9, 96.7)	88.2	3.03	(82.3, 94.2)
Ocean	95.8	0.78	(94.3, 97.3)	94.7	1.00	(92.8, 96.7)

Plume Survival and Residence Time—Plume survival estimated from acoustic telemetry varies substantially within years and between spring Chinook release groups with a mean survival of 56% (SD: 19%).[3] When survival is scaled by residence time, a clear overall relationship emerges, with plume residence explaining much of the observed variability (Brosnan unpub.; Figure 20).

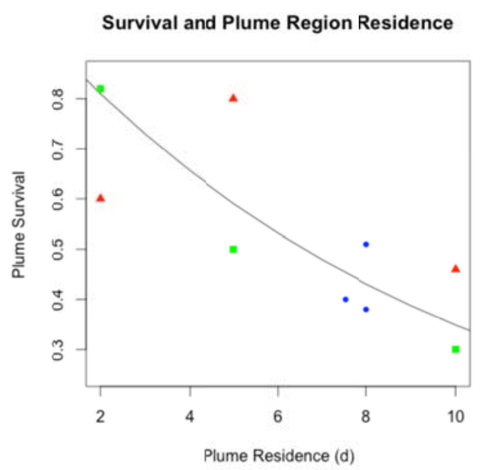

Figure 20. Plume survival as a function of residence time; dots show estimated survival of groups of acoustic tagged spring Chinook smolts from Astoria to Willapa Bay, with replicate release groups averaged; the line shows $S_{Plume}=0.9^d$, where d is the observed median residence time. (An influential 2009 outlier, is excluded and not shown). 2008: ●; 2009: ■; 2010: ▲.

Our results demonstrate that overall survival within the plume varies strongly with residency and that once residence time is taken into account, plume survival rates appear to be relatively constant.

As with smolt movement out of the hydrosystem, the importance of the plume environment for salmon recruitment thus depends upon the *relative* survival rate experienced by the migrating smolts in and beyond the plume, since smolts leaving the plume quickly have more exposure to the coastal environment. It follows that attempts to improve plume survival by reducing plume residency should: (1) identify the factors influencing plume residency time and (2) establish *relative* survival in and beyond the plume (because time not spent in the plume is spent in the coastal ocean).

3 This section is part of a Ph.D. thesis by Ian Brosnan at Cornell University, who is examining the potential for remote sensing data on oceanographic conditions to explain measured variation in marine survival of acoustic tagged smolts.

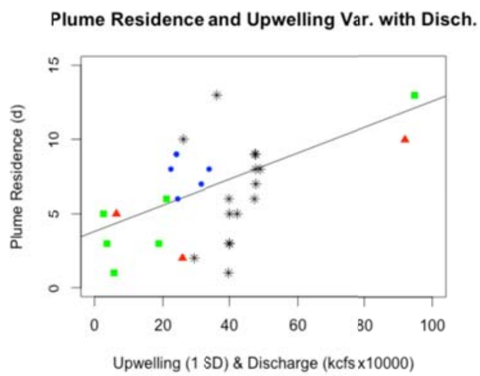

Figure 21. Scatterplot of plume residence time relative to upwelling variability (colored symbols as in Figure 20) and river discharge (black stars)..

We illustrate here two examples of how physical variables may affect plume residency and thus survival. Plume residence of tagged smolts was essentially invariant with Columbia River discharge (10^7 ft^3/s), but shows some covariation with variability in coastal upwelling (but not intensity), particularly for two release groups that had especially long median residence times (Figure 21).

Thus, smolt ocean entry could conceivably be manipulated using spill to better align entry with periods of predicted low upwelling, thereby minimizing plume residence; the graph shows that discharge itself had no discernable influence on residence time. For simplicity, this scenario ignores the much more important survival conditions experienced in the coastal ocean (where the majority of time and thus mortality occurs), but establishes the principle that manipulating smolts to shift them from low to high survival rate environments should bring a net conservation benefit. Other variables examined that might conceivably influence plume residency (river turbidity, SST, daily mean upwelling, the occurrence of downwelling during migration, and the duration of downwelling) had no detectable influence on the duration of plume residence.

Testing Delayed and Differential-Delayed Mortality Theories—Theories concerning the existence of delayed or differential-delayed mortality play large roles in shaping hydrosystem management because of the poorer than expected survival of Snake River salmon, and there has been general acceptance that some form of “latent” mortality occurs (ISAB 2007). In essence, these ideas posit an anthropogenic effect from 1) dams or 2) transportation that is expressed as additional latent mortality after the Snake River smolts pass downstream of Bonneville Dam.

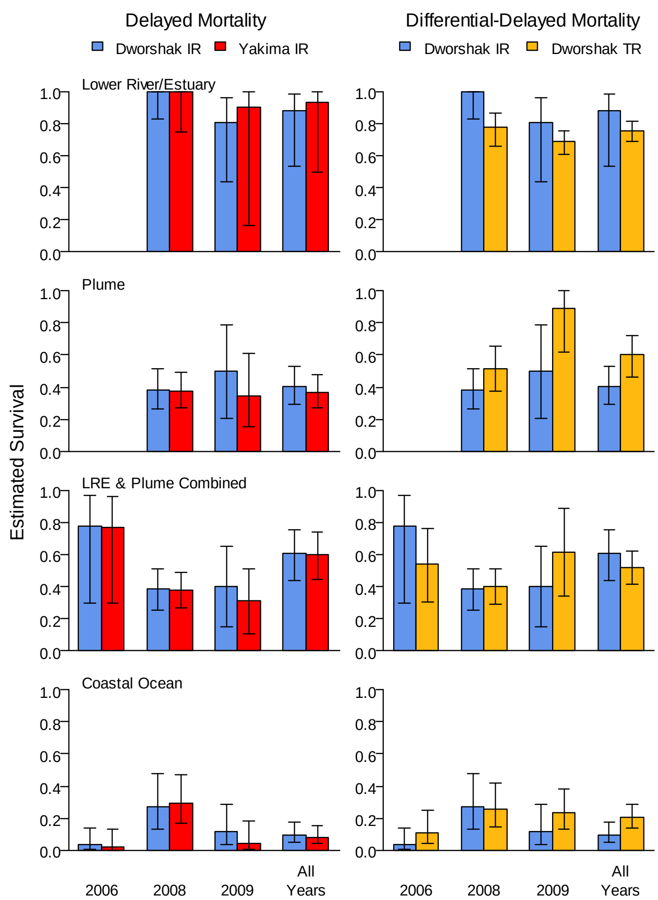

Figure 22. Test of the delayed mortality (left) and the differential delayed mortality theories (right). Error bars are ±95% confidence intervals. The Astoria sub-array was not deployed in 2006.

The *delayed mortality* theory was tested by releasing acoustic-tagged Snake River yearling Chinook smolts that migrate in-river, and comparing their survival with size-matched groups of Yakima River smolts which acted as the control group (i.e., they were not exposed to Snake River dam passage). Similarly, the *differential delayed mortality* theory was tested by comparing the survival of transported to in-river migrating acoustic-tagged Snake River spring Chinook salmon smolts over the array.

Our tests of these two hypotheses are graphically summarized in Figure 22. In no individual year or for any of the three habitats studied (lower river/estuary, plume, or coastal ocean) did we find a consistent reduction in survival of Snake River smolts exposed to additional hypothesized sources of stress (Snake River dams or transport in barges), relative to control groups. Our results therefore provide no support for theories that smolts exposed to greater anthropogenic influence (dams, barges) have substantially reduced subsequent survival (Porter et al. 2010b, 2011; Rechisky et al. Submitted).

These results are specific to Dworshak hatchery-reared spring Chinook (2006, 2008, 2009); however, our more recent work tagging a mixture of smolts at Lower Granite Dam and John Day or Bonneville dams indicates that these results hold more broadly. Results are of direct relevance for Columbia River salmon management because they suggest that hydrosystem operations may not reduce smolt survival in the ocean and, if accepted, should allow managers to focus on direct effects of the dams with reasonable certainty that large latent effects are unlikely.

VII. Forecasting and Management Tools

Earlier in this document we showed several examples of correlations between aspects of fish condition and salmon returns. Here we summarize our efforts to summarize ocean conditions in a given year and illustrate how we produce forecasts of salmon returns. Our forecasts are based on a suite of physical, biological and ecological indicators that describe "ocean conditions" important to juvenile salmon. The indicators are displayed in a stoplight chart (Table 5), with ocean factors in a given year that are known to be good for salmon (i.e., are correlated with salmon returns) are given a "green-light", intermediate a "yellow-light" and poor "red-light." These indicators provide outlooks (qualitative forecasts) of survival for Chinook (both fall and spring) and coho salmon and on the number of fish counted at Bonneville Dam.

Table 5. Stoplight chart illustrating variations among years in the indices of ocean conditions used in our salmon forecasting efforts. Red indicates poor ocean conditions; yellow, average; green, good. Note that ocean conditions in 2008 were mostly "good" whereas the years 1998 and 2005 were mostly poor.

Environmental Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
PDO (December-March)	13	5	2	9	6	14	8	12	10	7	4	1	11	3
PDO (May-September)	8	3	5	4	9	13	12	14	10	11	1	7	6	2
ONI Jan-June	14	1	1	5	10	11	9	12	6	8	3	7	13	4
SST at 46050 (May-Sept)	12	8	3	4	1	7	14	11	5	13	2	9	6	10
SST at NH 05 (May-Sept)	8	4	1	6	2	5	14	11	7	13	3	12	10	9
SST winter before (Nov-Mar)	14	11	3	5	7	10	12	9	8	2	1	4	13	5
Physical Spring Trans (UI Based)	3	6	13	12	4	9	11	14	9	1	5	2	7	8
Upwelling Anomaly (Apr-May)	7	1	12	3	6	10	9	14	7	2	4	5	11	12
Length of upwelling season (UI Based)	6	2	13	9	1	10	8	14	5	3	7	3	11	12
Deep Temperature at NH 05	14	4	6	3	1	9	10	11	12	5	2	8	7	13
Deep Salinity at NH05	14	3	6	2	5	12	13	8	7	1	4	10	11	9
Copepod Richness Anomaly	14	2	1	6	4	10	9	13	11	7	5	8	12	3
N.Copepod Anomaly	13	9	5	6	3	12	11	14	10	8	2	7	4	1
Biological Transition	13	9	6	5	7	12	8	14	11	2	1	4	10	3
Copepod Community structure	14	4	3	6	1	10	11	13	12	8	2	5	9	7
Winter Ichthyoplankton	14	6	2	4	5	13	12	8	11	10	1	7	3	9
Catches of salmon in surveys														
June-Chinook Catches	13	2	3	11	7	9	12	14	8	6	1	4	5	10
Sept-Coho Catches	10	2	1	4	3	6	11	13	8	9	7	14	12	5
Mean of Ranks of Environmental Data	11.3	4.6	4.8	5.8	4.6	10.1	10.8	12.2	8.7	6.4	3.1	6.5	8.9	6.9
RANK of the mean rank	13	2	4	5	2	11	12	14	9	6	1	7	10	8

Results of these efforts are posted on the NOAA Northwest Fishery Science Center's web-site (http://nwfsc.noaa.gov under "Ocean conditions and Salmon Forecasting") and include a diagnosis of past and present ocean conditions, a prognosis of future ocean conditions and qualitative outlooks of salmon returns one to two years in advance.

The ocean indicators include 1) basin-scale physical factors, 2) local physical factors, and 3) local biological factors. Basin-scale factors such as the PDO and the El Niño-Southern Oscillation (indexed by the Oceanic Niño Index) are taken from University of Washington and NOAA websites; local physical factors such as SST, the date when coastal upwelling is initiated each year, the amount of upwelling in spring are from NOAA websites whereas the temperature and salinity of deep waters on the continental shelf are from our biweekly cruises off Newport. Local biological factors including food chain indicators such as zooplankton abundance, species composition and community structure, and ichthyoplankton species composition are all from the Newport biweekly surveys; catches of juvenile salmon are from the BPA-funded trawl surveys.

Figure 23 displays the correlations between salmon returns and a single variable which is very highly-correlated with returns – the Copepod Community structure index. This index is the result of a non-metric multi-dimensional scaling ordination of a 16 year time series of zooplankton samples collected biweekly off Newport, Oregon). Negative values of the index indicate a "cold-water lipid-rich" copepod community; positive values indicate a "warm-water, sub-tropical, lipid-poor" copepod community. This index alone accounts for ~ 70% of the variance in counts of adult spring and fall Chinook passing Bonneville Dam.

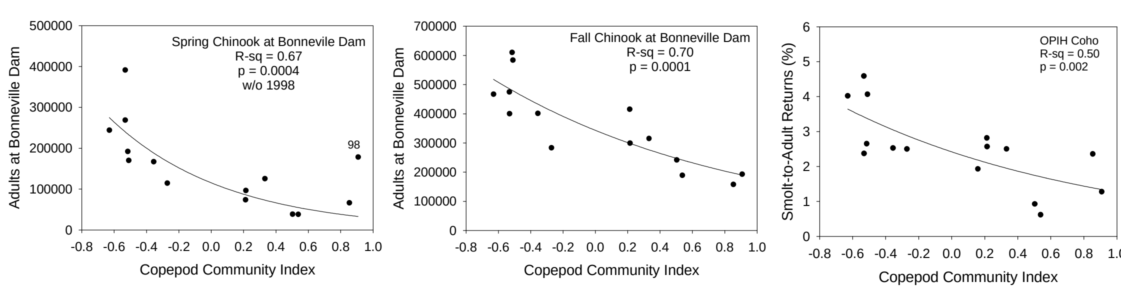

Figure 23. Regression of the Copepod Community Structure Index (from the table above) on counts of adult spring and fall Chinook at Bonneville Dam, and on Oregon Production Index (Hatchery) coho salmon. In each case, the regressions are highly significant, with coefficients of determination (R^2) of 0.67, 0.70 and 0.50 respectively. Based on the CCI value of -0.37 in 2011, forecasts for returns in 2013 for spring and fall Chinook are 193K and 433K respectively, and the forecast for OPIH coho in fall 2012 is 3.1%.

Figure 24 shows correlations between Chinook salmon counts at Bonneville and OPI coho, and a simple composite integrative indicator -- the mean rank of all indicators (the second line from the bottom) in Table 5. This index explains less of the variance in adult counts than the copepod-based index, but still produces highly significant results. However a weakness of this simple non-parametric approach is that each indicator is given equal weight, an assumption that may not be true, therefore we have recently explored a more quantitative analysis of the indicators in Table 5 using principal components analysis (PCA).

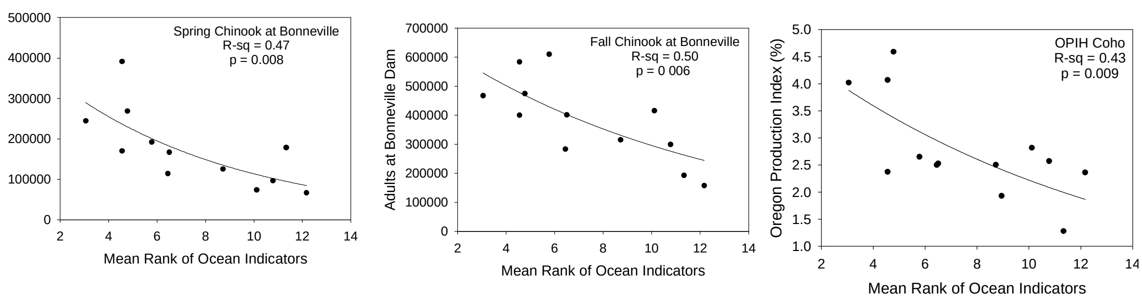

Figure 24. Scattergrams showing correlations between salmon returns and the mean rank of the ocean indictors shown in Table 6. Based on a Mean Rank in 2011 of 6.9, forecasts of returns in 2013 for spring and fall Chinook are 171K and 389K respectively, and in fall 2012 OPI coho, 2.8%.

PCA was run on the indicator data, a procedure which reduces the number of variables in a dataset as much as possible, while retaining the bulk of information contained in the data (a sort of weighted averaging of the indicators). Another important feature of PCA is that the principal components (PCs) are orthogonal which eliminates one of the original problems with the indicator data set (i.e., multi co-linearity). We used the PCs obtained from the PCA as new predictor variables in a linear regression analysis of adult salmon returns (this process is termed principal component regression, or PCR, Figure 25).

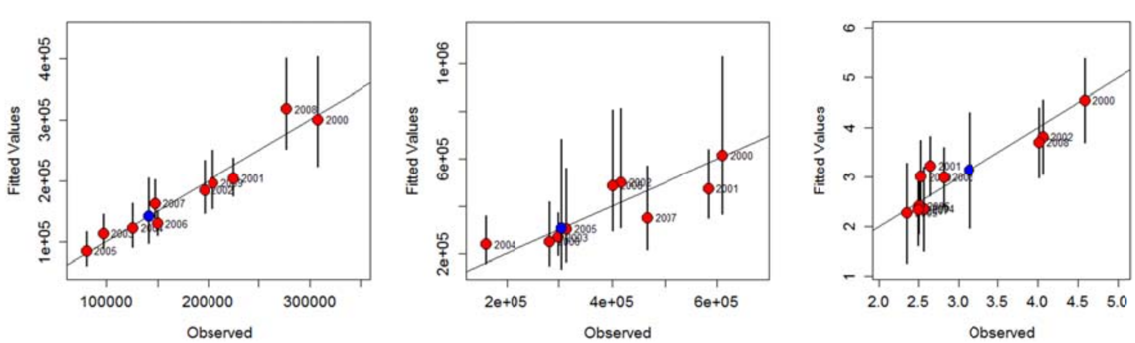

Figure 25. PCR model fits with 95% confidence interval (red) and 2012 predictions (blue) with 95% prediction interval for spring Chinook, fall Chinook, and coho OPI. Predictions for spring and fall Chinook for 2013 are 142K and 306 K respectively and for OPI coho, 3.1% in fall 2012.

We have recently begun to develop salmon *performance indicators*, which index salmon growth and survival directly based on metrics of the salmon themselves. Some of these indicators have already been discussed in the main body of this Synthesis Report and include metrics such as growth measured by IGF1 and otoliths, condition as length-weight residuals and pathogens such as *Renibacterium salmoninarum*, attributes related to feeding habits, abundance of alternate fish prey such as anchovies, and predators (hake). Preliminary work suggests that analysis of this more complete set of indicators (using PCA) may result in better forecasts because both environmental variability and fish performance will be included in the analysis. Other indicators such as trophically transmitted parasite loads in salmonids, diets of seabirds, and lipid content of salmon prey have only been measured for a short period of time thus more years of work will be required before they can be considered in this new analysis.

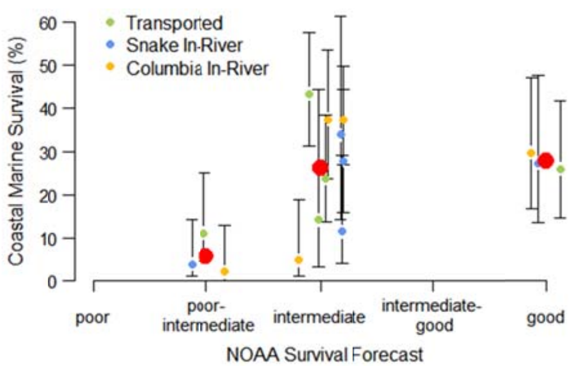

Figure 26. Comparison of NOAA survival forecast and Kintama measured survival in 2006-2011 (2007 excluded, Willapa Bay to Lippy Point; errors are 95% CI). Red dots represent Kintama average survival for each forecast category. Smaller dots are annual average across all releases of a treatment group and obscure within-year differences with time. For example, NOAA observed poor-intermediate ocean conditions until late May and very good conditions in June. Kintama estimates tracked this pattern, with poor survival in May and intermediate survival in early June. Ocean forecasts from NOAA website.

It is also possible to compare NOAA's qualitative measurements of ocean conditions with Kintama's telemetry-based early marine survival estimates (Figure 26). In general, these corroborate the NOAA "report card" (Table 5), showing that in years of poor-intermediate conditions coastal survival was only one-fifth that of years with good environmental conditions.

Similar efforts based on conditions measured off the west coast of Vancouver Island as part of the DFO Study are currently underway for Columbia River spring, summer and fall Chinook salmon, coho salmon, and Redfish Lake sockeye salmon as well as British Columbia salmon (see Trudel et al. 2011). To date, DFO's analysis has been restricted to simple linear models with a single factor at a time however future effort will include more complex multidimensional models. All of this work will be done in collaboration with the NOAA efforts (Appendix G).

Our forecasting efforts are grounded upon our mechanistic understandings of linkages between physical forcing (associated with the PDO) and biological responses (a lipid rich food chain that leads to higher salmon growth and survival). Our research, which has been focused on specific processes that affect marine survival, is now reaping benefits because it provides a clear understanding of how ocean conditions set salmon survival. However, we caution the reader that as in the past (notably Nickelson 1986, Ward 2000 and Logerwell et al. 2003) our correlations may breakdown over time.

Some would argue that the correlations between physical factors (e.g., coastal upwelling and salmon survival) work well only within a given climate regime, only to break down with a shift to a different regime. Advocates of chaos theory would argue that when the ecosystem flips to a different state, the relative importance of processes affecting salmon survival may differ between states resulting in new and unexplored correlations. For these reasons, we need to continue our work because additional years of data not only increase our degrees of freedom but provide us with the ability to better weight the indicators (i.e., which indicators seem to be most important) under different variable ocean conditions.

Our information on ocean conditions and salmon forecasting is used in a variety of ways. We have met with the TAC on two occasions and they are beginning to use our indicators in their evaluations of the number of salmon expected to return to the mouth of the Columbia River in a given year. We also regularly share data and analyses with coho salmon managers with the States of Oregon and Washington as well as a number of tribes that are interested in coho. Furthermore, NOAA scientists give ~ 10 invited presentations a year using the indicator table to "interested parties" including the Council (three briefings have been made to date), the annual meetings of the Pacific States Marine Fisheries Commission, the Pacific Fisheries Management Council, and watershed councils in Oregon. We have found that our "ocean conditions" indicators are of great interest to managers and the general public because they provide plausible and detailed explanations of how ocean conditions affect salmon survival and why returns of salmon in a given year are better or worse than "normal". In contrast, there are problems associated with the use of jack salmon to forecast adult returns – in many years jack returns provide a sufficient amount of information for a successful forecast, but in other years, the jack index fails, and no explanation can be offered other than ocean conditions must not have been favorable.

VIII. Management Implications

Background

Our ability to control or manage variability in marine recruitment of Pacific salmon is limited. However, our understanding of the mechanisms affecting this variability, as summarized here, suggests that there are opportunities to exert some control. Most importantly, our current understanding allows salmon management actions and decisions to be undertaken in the context of the full life history. Given the complex, highly evolved life cycle of Pacific salmon, and especially their reliance on anadromy, effective management actions to produce, sustain, recover, and harvest them must consider all aspects of their life cycle.

Management of Columbia River basin salmonids is driven by a number of legal mandates (U.S. Endangered Species Act, Pacific Northwest Electric Power Planning and Conservation Act, Magnuson-Stevens Fishery Conservation and Management Act, etc.). These mandates are implemented through an interacting suite of programs and plans developed by federal, tribal, and state agencies. Most of these programs and plans recognize the importance of marine-phase influences in understanding and implementing freshwater management strategies.

For example, the Fish and Wildlife Program 2009 Amendments (NPCC 2009) concluded that a better understanding of the conditions experienced by salmon and the factors critical to their survival in the Columbia River plume and ocean environment was needed. In addition, the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion and 2010 Adaptive Management Implementation Plan mandate a variety of marine-phase monitoring actions.

Mitigation efforts in the basin are presently centered around the “4-H” approach of simultaneously addressing habitat, hydrosystem, hatchery, and harvest issues (Marmorek and Peters, 2001). Until recently, harvest management was the only focus on the marine life-history phase. Now, there is increasing recognition of the role of ocean variation. This role is important in determining salmon population dynamics (e.g., Beamish et al. 2000; Logerwell et al. 2003; Scheuerell and Williams 2005) and for interpreting the response of populations to management actions (Bradford and Irvine 2000; Kareiva et al. 2000). Thus, the 4-H approach needs to include an ocean perspective, which we call the H_4O approach. The ocean research and monitoring described in this report contributes substantially to this expanded management perspective.

Our contributions to management can be divided into three main areas:

- Information on ocean variability as a context for understanding the response of populations to 4-H actions.
- Information that can improve projections of adult returns; this is valuable for both ocean and in-river harvest planning.
- Incipient information on the responses of stocks with different life-history characteristics to variable ocean conditions.

To date, analysis of management implications has not been an emphasis in the scope of work of the ocean projects. Rather, the ocean studies have focused on improving our understanding of juvenile salmon ecology during early marine residency (e.g., migration, distribution, and the mechanisms linking ocean conditions to juvenile salmon survival) in order to inform rather than direct management efforts. However, our efforts over the years have led to a time series of basic information from which we have built a suite of ocean productivity indicators. The ocean projects have not yet tried to explicitly link these data to discrete management actions, and their contributions presently represent unrealized potential. We anticipate that future ocean work will include effective interactions with the 4-H management and policy communities. To facilitate these interactions, we propose a series of workshops at which research results and needs of managers will be shared and discussed. The result should allow us to modify our research for maximum benefit to the management and policy communities.

Ocean Variability as a Context for 4-H Management

Salmon mitigation and recovery efforts in the Columbia River are substantial and expensive. Efforts are underway to develop the monitoring infrastructure needed to measure the effectiveness of various recovery actions: for example, FCRPS performance measures, the Integrated Status and Effectiveness Monitoring Program (ISEMP), and the Columbia Habitat Monitoring Program. These programs are designed to identify how salmon respond to mitigation and recovery efforts at various levels of organization (population, main population group, or ESU), and how spawning, rearing, and migratory corridor habitat is improving at various spatial scales (site, reach, watershed, and river basin).

Because of the importance of the ocean phase in salmon life history, it is difficult to evaluate freshwater management actions without understanding changes in the ocean. Because ocean conditions affect adult returns periods of high or low ocean productivity can mask underlying trends in freshwater habitat productivity and could lead to a misinterpretation of the proximate cause of the trend. Information on ocean productivity helps to disentangle marine and freshwater influences, assists in the interpretation of population trend data, and reduces the risk of falsely interpreting the trend data and misconstruing the true cause of an underlying trend in population abundance.

Within the basin, many important management activities consist of a single intervention (such as a mainstem dam modification, change in transportation of juvenile salmon, or change in harvest policy). Many of these activities affect the entire basin, or a substantial part of it, and thus provide no opportunity for statistical replication. In these cases, evaluation depends primarily on before-after (BA) comparisons, which confound the effect of these actions with other contemporary changes in the system. Therefore, to evaluate the effectiveness of a given management action within the basin, measures of these other changes are needed, and ocean conditions are major pieces of that puzzle.

As a more optimistic example, monitoring and evaluation of freshwater or estuarine habitat restoration projects can rely on more informative before-after/control-impact (BACI) studies. It would seem that having side-by-side controls would eliminate any need for ocean information. However, even with controls, statistical analyses can be improved with the use of environmental covariates (Smith et al. 1993) that account for common trends in the data, such as marine survival or climate indicators.

Typically, smolt-to-adult return ratios (SARs) have been used as covariates in such analyses, but SARs do not provide detailed information about a population's response to ocean conditions. For those populations for which these data are available, age-specific SARs can provide some information about marine survival for retrospective evaluation. However, SARs are available only for a very few salmonid populations, and even when available, they do not tell when or where mortality occurred.

SARs provide survival estimates between two points in a complex life-cycle, which includes residence time in river, estuary, early ocean, and long-term ocean habitats, and adults back through the estuary and river. They do not reflect important aspects of population dynamics, such as diversity of responses to changing conditions or sublethal effects on fish health or vitality. Nor do SARs by themselves provide the information needed to conduct prospective evaluations of future management actions or policies—simulating future conditions ideally involves an understanding of the environmental processes that affect the condition, growth, and survival of fish with diverse life-histories.

Our programs of coordinated efforts, which form an ecosystem approach to the study of juvenile salmon migration and early marine residence, include observations on their migration patterns, survival, biology, and the status of their surrounding ecosystem. This approach will over the long-term substantially contribute to our understanding of how

4-H activities in the basin affect salmonid sustainability. In the short-term, these observations can contribute valuable information for monitoring the effectiveness of management actions.

Improving Recruitment/Return Forecasts

Regular monitoring of salmon and their environment during the early marine phase provides a wealth of information that can contribute to stock forecasts. Past studies using ocean climate indicators to forecast salmon stocks have relied on long-term physical indices such as the Pacific Decadal and El Niño Southern Oscillations (Logerwell et al. 2003; Scheuerell and Williams 2005; Rupp et al. 2011). While such models appear to have improved forecasts in the short-term, we do not understand the mechanisms connecting these physical indicators to salmon life histories. Therefore, we cannot rely on these past predictive relationships to continue into the future (Walters 1987; Welch et al. 2000). For example, the model developed by Logerwell et al. (2003) to forecast marine survival of OPI coho salmon provided reasonable accuracy during the first 2 years, but failed afterward.

Our ocean projects provide a number of more proximate measures of conditions directly relevant to salmon. These measures are reported here and include direct survival estimates from acoustic tagging (section VI); abundance indices from trawl surveys (section III); measures of salmon condition (growth, condition index, pathogens) from associated laboratory analyses (sections IV and V); ecosystem conditions; food web structure (section V), and physical oceanography (section II). We have begun using this information to develop new forecasts for salmon returns (section VII); we focus on two examples here.

Forecasts based on a suite of ocean indicators were presented to the US v. Oregon Technical Advisory Committee (TAC) in 2010. The TAC has considered incorporating various river and ocean indicators into models that predict adult escapement levels and are used to establish in-river harvest allocations. Historically, the TAC has relied on traditional cohort relationships when estimating escapement levels of salmon stocks returning to the Columbia River.

As with any predictive model, there has been variation between the forecasts and actual returns, but overall, the models tended to be unbiased, with predictions having an equal likelihood of over or underestimating actual returns. However, in recent years, the actual return has been less than the forecast. In 2011, TAC considered alternative methodologies and criteria for forecasting the upriver spring Chinook return. They reviewed numerous alternative models, including the ocean indicators developed by NOAA, and chose a range of models that appeared to reflect actual returns reasonably well. Incorporating our suite of ocean ecosystem indicators into the model scenarios was hindered primarily by the indicator time series being shorter than what TAC needed for hindcasting back to the 1980s. Over time, the ocean ecosystem indicator time series will become more informative of recruitment processes, and will be considered by TAC when developing their ensemble of models to improve forecasts of adult returns.

As reported here, NOAA and DFO have both been investigating the relationship between ocean indicators and the return of Columbia River salmon (section VII). For example, NOAA has used ocean indicators to predict returns of upriver spring/summer Chinook salmon above Bonneville Dam. We predicted that between 288,000 and 304,000 spring and summer Chinook salmon would pass Bonneville Dam through 15 June 2010, while the TAC predicted this number to be 470,000. The actual return was 277,389 (CRDART 1995). For the same run in 2011, we predicted between 188,000 and 194,000, while the TAC predicted 198,400; the actual return was 205,431. Similarly, the DFO forecast for fall Chinook salmon at Bonneville Dam was within 2% of the returns in 2010 and 2011 (Trudel et al. 2011, M. Trudel, unpublished). Both projects continue to explore additional multivariate analysis of the indicator data and its utility in predicting adult escapement and for increasing the accuracy of the forecasts. This predictive work cannot continue without continuing long-term observations.

Other Management Issues

Beyond our forecasting efforts and the direct evaluation of 4-H management activities in the context of ocean conditions, there are a number of other ways that our ocean research can contribute to management needs. Specific examples include:

Example 1. Ecosystem-based management—The Pacific Fisheries Management Council (PFMC) is mandated by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act to base fishery management on sound scientific principles and a healthy ecosystem. Information developed by ocean project sponsors is being considered by the PFMC as it develops an ecosystem fishery management plan (EFMP) for the California Current.

In particular, information from our ocean surveys and food-web analyses (section V) was instrumental in informing the Pacific Fishery Management Council’s (PFMC) deliberations on whether to adopt a complete ban on commercial fishing for all species of krill in West Coast federal waters. Although there is no fishery for krill in PFMC waters, krill are fished in Antarctica, Japan, and off the west coast of Canada. Because of the importance of krill to the marine food chain, the PFMC took action in March 2006 to ban krill harvest immediately. This ban will help sustain productivity of the California Current ecosystem for all species, including salmon.

Example 2. Life history diversity and salmon population resilience—The importance of life history diversity to the resilience of salmon populations has become more widely recognized in recent years (Hilborn et al. 2003; Greene et al. 2010; Schindler et al. 2010). Yet studies of the ocean life history of juvenile salmon have lagged far behind freshwater investigations, impeding the development of management strategies to strengthen and conserve diversity in Columbia River populations. Our research programs have developed new tools for investigating marine rearing habitats and migration pathways of individual fish. Tools that can elucidate patterns of life-history diversity include:

1) An improved genetic baseline for Columbia River Chinook salmon, to which DFO and NOAA ocean sampling contributed (Beacham et al. 2006);
2) Collaborative work among Oregon State University, NOAA, and DFO has applied otolith micro-chemical techniques for reconstructing freshwater and estuarine/ocean life histories (Middleton 2011);
3) Kintama has developed improved tagging and detection methods for tracking the migrations of individually tagged fish at sea (section VI).

Together these methods have provided and will continue to provide new insight into the identification of distinct temporal and spatial patterns of juvenile migration, habitat use, and performance among salmonid species and genetic stock groups within a species.

Understanding species- and stock-specific differences in ocean life history is critical to the management and recovery of at-risk Columbia River populations. For example, retrospective studies of the collapse of Sacramento Chinook salmon (Lindley et al. 2009) and Oregon coastal coho salmon (Lichatowich, 1999) suggest that erosion of genetic and life-history diversity weakened population resilience to changing ocean conditions.

River management actions may involve important tradeoffs among species and stocks with different life histories. For example, flow manipulation that modifies plume characteristics could benefit stocks with one migration pattern, while adversely affecting others. Moreover, river management actions directly influence salmon life histories in the ocean. For example, hatchery programs that select for particular freshwater phenotypes also limit ocean life history expression by selecting the timing, sizes, and ages of fish entering the ocean. Monitoring the ocean life histories of salmon provides important clues to marine survival mechanisms and their implications for salmon recovery actions.

Ocean information thus has important implications for the conservation and recovery of Columbia River salmon:

1) Genetic and life history indices are long-term indicators of population resilience and should be integrated into salmon monitoring programs along with more traditional short-term performance measures (*i.e.*, abundance, productivity, and survival);
2) It is important to maintain and strengthen population resilience during favorable ocean conditions, when opportunities for life history expression are greatest; and
3) The risks and uncertainties of future climate change also emphasize the need to continue monitoring stock-specific ocean life histories and minimize the effects of various stressors (*e.g.*, hatchery impacts, habitat loss, flow modifications, etc.) that may limit life-history expression, and could further undermine population viability in a changing environment.

Example 3. River Flow and the Columbia River Plume—An initial focus of our ocean research was the hypothesis that hydrosystem operations affect plume structure and its interaction with tides and local upwelling, and this in turn affects ecosystem productivity processes and juvenile salmon recruitment success. Our ocean study results provide evidence that river flow affects plume structure and salmon recruitment processes. First, we have found that river discharge explains most of the variability of the Columbia River plume, with coastal upwelling an important but distant second. Importantly, we now have the simulation and forecast tools that allow us–within some uncertainty bounds–to correlate past, present and future hydrographs at Bonneville Dam with prevailing plume characteristics during smolt outmigration.

Second, there is an apparent relationship between plume characteristics at time of ocean entry and SARs for steelhead. Steelhead SARs also increase with the size and offshore distance of the plume under favorable large-scale ocean conditions, but did not change when ocean conditions were poor (Burla et al. 2010a).

To the extent that hydrosystem operations influence the seasonal timing of river outflow, these findings, when combined with an understanding of ocean productivity each year, could inform the development of hydrosystem, hatchery, and fish transportation operations that optimize potential survival. These findings could also influence long-term operation policy analysis, such as those needed for the renegotiation of the U.S.-Canada Columbia River Treaty of 1964.

From a management perspective, almost all interventions proposed for the hydropower system involve accelerating the transfer of smolts from the river to the ocean—reducing freshwater exposure at the expense of increasing ocean exposure. For most purposes, then, survival rate comparisons per unit time are of greatest relevance, because hydropower operations potentially trade off smolt exposure times in different environments: fewer days spent in the river means more time spent in the ocean. Our tagging results indicate that for the plume environment as well, it is important to consider both residence time and survival rate of some yearling Chinook salmon stocks, as it is the product (time × survival rate) that determines overall plume survival. Mortality rate is correlated with residence time, and greater mortality is associated with longer plume residence. More importantly, daily survival rates in the plume appear to generally be lower than in the coastal ocean. Therefore, management actions that can reduce plume residence time (which may conceivably be modified by changing hydrosystem operations) may improve yearling Chinook salmon smolt survival of some stocks by increasing time spent in the coastal ocean and decreasing time spent in the plume. Whether or not hydrosystem operations can actually be effective in achieving this fine level of control over smolt residence time is unclear and would need to be formally tested. Not all salmon species and populations respond to the plume environment in the same way. Fine-scale management that benefits one species may be detrimental to other species or life history types.

Example 4. Addressing *Latent* and *Differential* Mortality—There is a debate about the degree to which poor survival in the ocean results from direct effects of the ocean or delayed effects of hydrosystem passage—so called *latent* mortality (ISAB 2007; Anderson et al. 2011). The Independent Scientific Advisory Board (ISAB) concluded that the hydropower system causes some fish to experience latent mortality, but strongly advised against continuing to try to measure absolute latent mortality. They explained that "latent mortality relative to a damless reference is not measurable" (ISAB, 2007).

Rather, the ISAB recommended a focus on estimating the total mortality of in-river and transported fish and the processes that can be measured directly, such as in-river vs. transport mortality. This has been accomplished by acoustic tagging efforts (section VI). In addition, the ISAB (2007) recognizes "there will be considerable uncertainty in estimates of post-Bonneville survival," and recommends that "this uncertainty be accounted for as efforts to reduce it continue. Estimates of uncertainty should be bounded and incorporated in simulation models and annual management planning processes."

Smolts have been collected at hydropower facilities and trucked or barged downstream below the last Columbia River dam in an effort to reduce the negative effects of the FCRPS on salmon run sizes (Ebel et al. 1973; Ebel 1980; Williams et al. 2005). Studies to evaluate the efficacy of transportation have generally shown a benefit, but adult returns of transported smolts have fallen short of expectations, particularly for wild spring/summer Chinook salmon (Ward et al. 1997; Williams et al. 2005). In-river survival of spring/summer Chinook salmon from the uppermost dam on the Snake River to below Bonneville Dam has ranged from 45 to 61% in non-drought years and has averaged 49% since 1999 (Williams et al. 2005; Ferguson, 2011), while the survival of smolts transported in barges to below Bonneville Dam is nearly 100% (Budy et al. 2002). If estuary/ocean mortality were equal, then the transport group of fish arriving below Bonneville Dam would have roughly twice the adult return as from those that migrated in-river, but this has not been observed, indicating that transported smolts suffer a higher level of estuarine/ocean mortality than in-river migrants.

This differential survival between transported fish and in-river migrants suggests that mortality events below Bonneville Dam (in the estuary or ocean) differentially affects transported smolts after their release. The ocean projects have addressed the question of *differential* or *delayed* mortality due to transportation. Kintama conducted tagging experiments and observed no evidence that barging of Snake River smolts elevated their mortality after release below Bonneville (section VI).

Summary

Since 1998, the BPA ocean projects have been implemented to aid salmon recovery efforts and address aspects of the Council's Fish and Wildlife Program mandated by the U.S. Congress. The ocean projects have produced information that can inform management within the Columbia River Basin in three main areas. First, because of the role of ocean conditions in affecting adult returns, periods of high or low ocean productivity can mask underlying trends in freshwater habitat productivity and could lead to a misinterpretation of the proximate cause of the trend. Knowledge of the response of salmon to ocean conditions is key to providing the proper context for judging the effectiveness of habitat restoration, hatchery reform, harvest management, and hydropower system improvements in process to restore listed and wild salmon stocks.

Second, the combination of physical and biological information collected as part of the ocean projects has led to the development of simple models that now provide outlooks of future salmon returns. With a longer time series these metrics are expected to increase the accuracy of current forecasting.

Third, the ocean projects have improved our understanding of the responses of stocks with different life-history characteristics to variable ocean conditions. We anticipate that knowing the mechanisms that link ocean conditions with stock-specific salmon survival will be useful to managers as we jointly seek to identify specific 4-H actions that improve salmon returns. Thus, we advocate a dialogue between scientists, managers, and policy makers initiated through several workshops to discuss the implications of our results for the management of Columbia River salmon with regards to the 4-H issues.

IX. Data Gaps, Uncertainties, and Research Needs

The ocean projects have revealed that juvenile salmon marine survival is both complex and dynamic across a range of spatial and temporal scales, and that no single factor consistently influences survival. Only by collecting a time series of ocean/salmon data over a broad geographic area has it been possible to determine and identify these ocean factors. The variability of ocean conditions observed during the 14 years of our work has provided "natural experiments" but the shortness of the time series has only provided limited opportunities for repeat occurrences (like the extremes of 2005 and 2008).

Thus, because of the short time series, uncertainties still exist around the delineation of mechanisms responsible for determining early marine survival of salmon. Additional years of data will not only increase our degrees of freedom but provide us with the ability to better weight the indicators (i.e., which indicators seem to be most important) under different variable ocean conditions. A longer time series is also needed to discern how ocean conditions influence interactions between hatchery and wild salmon, stock specific responses, and potential density-dependence, both intra- and inter-specific.

It is also fortuitous that these projects were started after the 1998 regime shift (Overland et al. 2008). Given that regime shifts are frequently associated with a major internal reorganization of marine ecosystems and functions and that they typically last 10-20 years (Overland et al. 2008), the relative importance of the mechanisms identified in this synthesis report may shift suddenly over time. Thus, it is important to recognize that the simple models developed as part of the ocean projects may fail over time as a result of regime shifts. Furthermore, greenhouse gas forcing may also drive ocean climate back towards a more extreme version of the warmer climate holding through the 1980s and 1990s (IPCC, 2007), and may induce Columbia River salmon to migrate farther north (Welch et al. 1998, Abdul-Aziz et al. 2011).

Previous sections highlighted our various efforts investigating juvenile salmon marine survival. While extensive, there are still many areas of research for which we do not presently have sufficient data to draw definite conclusions, or the resources to directly investigate them. We have been asked by the ISRP to consider several topics that have always been outside of our hypothesis-driven research. Thus below we discuss ISRPs request (for information on density dependence, hatchery/wild interactions, and steelhead ecology. This is followed by a discussion of gaps and uncertainties that we have identified.

Information Requested by the ISRP

Density Dependence—The impact on wild salmon of billions of salmon released to the North Pacific Ocean each year from hatcheries in Korea, Japan, and Russia is poorly understood (Ruggerone et al. 2010). Density-dependent interactions have been documented for pink, chum, and sockeye salmon in the North Pacific (Ruggerone and Nielsen 2004) and Strait of Georgia (Beamish et al. 2010). However, in these regions in the Pacific, salmon are a dominant fish.

A good deal of work has been done to document ocean density-dependence in both growth and survival for pink, chum, and sockeye salmon in the northern North Pacific (Ruggerone et al. 2010, and references therein). However, much less evidence exists for such effects on coho and Chinook salmon in the NCC, probably because salmon are not an abundant species in the NCC relative to other fish species (Orsi et al. 2007).

There are some data suggesting that during years of low productivity Columbia River smolts may experience density-dependent mortality in the ocean (Scheuerell and Williams, 2005). Stable isotope analyses performed by DFO revealed that niche overlap between juvenile pink salmon and chum salmon increased with juvenile salmon density, but decreased with zooplankton abundance (Jenkins 2011). Furthermore, their size generally decreased with juvenile salmon density, suggesting that they may be competing for food in coastal waters. As smaller fish tend to have lower survival rates, increasing juvenile pink salmon and chum salmon abundance through hatchery releases may reduce the productivity of threatened Columbia River chum salmon.

Finally, density-dependence can occur at a number of scales. For example, it could be local such as in the plume or it could occur at the scale of the NCC. Further, the scale at which density dependent mechanisms may operate may vary be species/life history types.

Hatchery/Wild Interactions—Ecological interactions between natural and hatchery juvenile salmon during their early marine residence have received little attention (Rand et al. In press). These interactions may negatively influence survival and hamper the ability of natural populations to recover (Levin et al. 2001). There is high spatial overlap in distribution and diet of both marked (hatchery) and unmarked (i.e., mostly natural) juvenile spring run Chinook salmon (Daly et al. 2011). Similarly, 75-90% of the juvenile Columbia River Chinook salmon caught off British Columbia during summer are marked, indicating that very few wild Chinook salmon are produced in the Columbia River (Trudel et al. 2011). However, hatchery clipping rates that are less than 100% complicate any comparisons between naturally produced and hatchery fish. The incomplete marking (adipose fin clipping) of hatchery juveniles in the Columbia River Basin largely precludes identifying and therefore studying natural origin salmon in freshwater, estuarine, and ocean habitats. Once hatchery marking is 100%, this data gap can be closed for research on future brood years of juveniles.

In addition, feasibility tests of parentage based tagging (PBT; Garza and Anderson, 2007) are being conducted in Snake River hatcheries and have demonstrated that individual Chinook salmon and steelhead can be genetically identified using single nucleotide polymorphism (SNP) loci (Steele et al. 2011). Juveniles originating from participating hatchery programs can be linked back to a specific hatchery and even to the individual parents of the fish. Basin-wide implementation of PBT therefore offers great potential for the identification of hatchery fish in estuarine and ocean habitats.

Steelhead Ecology—Steelhead marine survival appears to be linked (in some years) to the size of the plume (Burla et al. 2010a). How and why a larger plume size might benefit steelhead is uncertain but may be related to moving them quicker through an area of high predation (i.e, estuary and nearshore coastal shelf) or it allows them to move off the shelf into the deeper North Pacific Ocean, their preferred marine habitat (Myers et al. 1996). Unfortunately, being neustonic, our surface trawl equipment does not sample them as effectively as a purse seine and our sampling program does not sample very far beyond the continental shelf. Prior to 2006 we did not catch enough steelhead to provide any information, but since 2006, for unkown reasons our catches of steelhead have increased substantially. Thus we have initiated studies of the health, growth, and food habits of juvenile steelhead andexpect to have greater insights into the marine ecology of this salmonid in the near future.

Collaborating genetics laboratories have recently developed a standardized microsatellite DNA dataset that can be used for stock identification of Columbia River Basin steelhead (Blankenship et al. 2011). NOAA geneticists have now begun to use this baseline to study the timing of the basin's steelhead stocks arrival in the Columbia River estuary. However, baseline data for coastal sources have not yet been collected. Those data, particularly for Oregon and Washington populations, are necessary to estimate the origins of steelhead sampled in our ocean trawls. Attempts to obtain funding to make the necessary expansions to the steelhead baseline have not yet been successful.

Research Needs

Estuary/plume (*H3*)—We are in the process of creating short-term "watches" and "forecasts" that enable management strategies to be developed for timing of release of smolts, complemented or not, by strategic changes in hydropower operation to improve estuary/plume characteristics at the time of ocean entry. Over the next several years, we anticipate that we will produce 7-day-ahead forecasts of plume conditions designed to guide choices of timing of release of smolts. We also need better information on how long the salmon reside in the estuary, how much they grow, their overall health before migration, and specific migration patterns through the estuary, and how all of this influences overall marine survival.

In addition to short-term watches and forecasts, we are also in the process of defining and simulating scenarios of long-term change of estuary and plume characteristics, associated with change in climate in the coming years. To the extent that we can mechanistically show how plume characteristics are relevant for salmon survival, scenarios of long-term change of those characteristics will offer exceedingly valuable information for long-term planning for the region.

Also, we seek approaches to determine more specifically why high plume volume is correlated with high survival for some taxa. This effort would greatly benefit from some coordination with managers and inland scientists as we should be able to design tractable studies that could address some of these key questions about the potential to influence survival by altering aspects of flow and/or hatchery releases. We hope to address these issues at the workshops proposed for 2012 and out-years.

Estuary/Ocean Linkages (*H1 and H2*)—Life history diversity spreads mortality risks broadly in time and space and minimizes the likelihood of brood failure in variable environments (Healy 1991, 2011). This diversity is especially important for salmon during their critical transition between estuarine and ocean habitats. In particular, the specific suite of ocean conditions experienced by juvenile salmon varies with time of ocean entry, prey availability and vulnerability to predators. We hypothesize that variability in timing and size at ocean entry leads to variation in marine survival. A recent study (Claiborne et al. 2011) found that tagged fish that were smaller than 150 mm at release in the Columbia River estuary were under-represented in returning adults, suggesting smaller fish had low survival. Furthermore, increased diversity in these parameters (both between and within stocks) is expected to increase the resilience of populations to increasingly variable ocean conditions (Bottom et al. 2009).

Comparisons of the salmon species and stocks caught in the estuary with those in the ocean indicate that although many stocks are well represented in both habitats types, some are effectively missing from our ocean sampling. In particular, small wild-origin subyearling Chinook salmon (Spring Creek group fall Chinook and West Cascade fall Chinook) that are abundant in shallow waters of the estuary are relatively rare in our trawl surveys. However, we do know from the work of a Ph.D. student at Oregon State University (Marin Jarrin et al. 2009, In Review) that these fish inhabit shallow (<25 m) marine habitats and can even be found in the surf zone. Additional efforts to sample in this shallow marine habitat are planned for summer 2012.

We are undertaking comparisons of juvenile salmon collected in the estuary (through NOAA and FCRPS BiOp funds) with those in the ocean with respect to a suite of factors (e.g., size, conditions, rearing and geographic origins, parasites and pathogens, food habits, etc.). This effort was only recently initiated because estuarine sampling in open waters of the estuary did not commence until 2007, therefore the number of years of data is still relatively small for statistical rigor. These efforts would have to continue to make these comparisons and provide baseline data for the ocean studies.

Additional Acoustic Tagging (*H5*)—Kintama hopes to extend acoustic tagging to additional stocks of yearling spring Chinook and to fall Chinook (which remain resident for much longer time periods near the Columbia River). This is important for validating the finding that ocean survival rates currently match freshwater survival rates, and should be continued before major changes to management are implemented. Increasing the power of statistical tests to identify which ocean variables truly affect survival in the early life history by relating ocean variables to the mortality occurring at that time will also increase the speed with which answers can be obtained, as can tagging over the entire run, which should capture any sudden changes in ocean conditions that occur during migration.

Relationship between Ocean Survival and Riverine and Estuary Growth—Muir et al. (2006) showed that barging smolts early can sometimes get them to the ocean “too early” for good survival. Claiborne et al. (2011) also showed that marine survival of yearling Chinook salmon benefited by some estuarine growth before entering the ocean. Although we have been conducting some research (NOAA and USACE sponsored) in the estuary, we need to identify the life histories and feeding habits of juvenile Chinook salmon in the estuary and compare with past (1980’s) data and see if there has been a change in their diets which might have influenced their growth. We also need to analyze adult salmon scales to identify how important estuary/river growth might be on marine survival for many different stocks of salmon (i.e., similiar to Claiborne et al. 2011). Moreover, there is a need to expand upon research on residence timing, migration timing and growth using otolith microchemistry to examine lower Columbia spring and fall Chinook stock groups to determine if their response to ocean conditions and subsequent survival is consistent with Interior Columbia River populations.

Bottom-Up Processes (*H1*)—*Forage Fishes:* While forage fish can act as a buffer for salmon predation, they can also act as competitors during years with poor ocean conditions (Holsman et al. In prep). We have been identifying the abundance of forage fish in the plume – especially in spring. In the past we have conducted stomach analysis of some forage fish species. In the future we hope to conduct stomach analysis of some larger forage fish such as older Pacific sardine.

Additional Diet Studies. We need to more fully address whether juvenile salmon are food limited in their early marine period during times of poor conditions to assess competition from other salmon or non-salmonid planktivores. This can be addressed through direct sampling of salmon prey fields and spatially explicit bioenergetic modeling in and out of the plume.

Top-Down Processes (*H2*)—*Avian predators*: Some marine birds are known to prey heavily on juvenile salmon in the Columbia River estuary (Caspian terns). The amount of salmon eaten is influenced by many factors, including alternative prey abundance and oceanographic conditions. To complete the investigation of ocean bird (shearwaters and murres) predation on salmon marine survival, it will be necessary to (1) quantitatively describe the diet of sooty shearwaters and common murres collected in the plume so the frequency of occurrence of salmon species/stocks in ocean bird stomachs can be calculated; (2) determine the abundance of murres on their colonies so that diet frequency data can be "scaled up" to a rough estimate of total mortality of salmonids; and (3) quantify the daytime distribution, abundance, and size composition of forage fishes with newly-available fisheries hydroacoustic, so the relationship of alternative prey availability to bird abundance and the frequency of salmon in bird diet can be estimated.

Marine Mammal Predators: While pinnipeds are known predators on adult and juvenile salmon in rivers and estuaries, we presently do not know if pinnipeds (and harbor porpoises) are significant predators of juvenile salmon in the ocean. Similar to marine birds, this is difficult to assess because we cannot directly sample their stomachs. However, we have been recording their abundance on our cruises.

Cannibalism: Adult salmon are frequently abundant off the Columbia River and other coastal areas where juvenile salmon also reside, and are thought to feed on juvenile salmon. We are interested in pursuing this avenue of research. Although we do not have the permits necessary to collect adult salmon or their stomachs, it is possible to obtain stomachs from fishers.

Pathogens: Future efforts need to examine salmon collected in freshwater as well as the estuary and ocean to provide a baseline and better identify the mechanisms influencing *R.*

salmoninarum infections and its effects on species of salmonids and stock groups, and differences between natural and hatchery-produced salmon. In addition, there is a need to add stock specific data to preliminary observations of other pathogens, such as *Ceratomyxa shasta*, which among the few years studied we noted in fairly high prevalence in the Columbia River estuary, but was virtually absent from ocean samples.

Management Tools—As noted above, our work has not focused on products that target specific management needs. We have outlined several areas where we believe results from our monitoring and research activities can assist with policy and management decisions in the Columbia River Basin, and advocate future work to incorporate this information into management tools. Potential new efforts include modeling of river flow effects on plume structure in relation to hydrosystem operations, continued improvements of stock forecasts using ocean climate indicators, further investigation of the effects of river discharge timing on plume characteristics and salmonid recruitment, and incorporating ocean information and full-system survival estimates (combining data from CWTs, PIT tag, COAST, and Juvenile Salmon Acoustic Telemetry System (JSATS)) efforts into life-cycle models. Planning this work will require close collaboration between the ocean research and the management communities, which can be initiated in the workshops described below and elsewhere.

Other Issues—

Delayed Mortality (H4). The ISAB recognizes that resolving the issue of delayed mortality will require further research on how the plume and the hydropower system affect smolt survival upon entering the ocean. Other than our studies, no other work is being conducted to collect empirical information and measure coastal ocean survival directly (although there are JSAT measurements for the lower river and estuary). As a result, no further progress can be made toward resolving the role of delayed hydropower system mortality for the 2008 BiOp or future Biological Opinions without additional data collection and analysis similar to that reported here.

*Winter Mortality (H1)***.** Substantial mortality seems to occur during winter, however to resolve better this issue, it will be necessary to sample in winter off Washington and Oregon (and continue the ongoing sampling off BC) to determine how variable this mortality is among years, and the mechanisms that are involved with winter mortality.

Long-Term Automated Observations. To make the research programs stronger in the future we need to continue to analyze our existing data and incorporate new information and technologies. The addition of oceanographic sensors associated with the incipient Integrated Ocean Observing System (IOOS, http://www.ioos.gov/) will provide specific temporal and spatial observation's on a scale which we have been unable to conduct (i.e., primarily due to limitations of ship time). Furthermore, as part of IOOS, high-resolution physical oceanographic models will become available for our use and these should be useful as we construct new cutting-edge habitat models for juvenile salmon. We will also more closely integrate information on salmon during their riverine, estuarine, and oceanic life histories to begin to understand how salmon must integrate these various habitats into their life history to return as adults to the Columbia River.

Workshops—Our research is now sufficiently mature to allow us to provide information and advice on a variety of management actions. However, specific actions are not discussed here because of the complexity of the 4-H issues. We advocate a dialogue between scientists and managers that is best addressed through several workshops to be initiated in 2012. Moreover, to increase the relevance of the ocean projects to BPA, BiOp, and the Fish and Wildlife Program, it will be necessary to effectively communicate the prognosis regarding the likely impacts of ocean conditions on Columbia River salmon to BPA and to various organizations involved with the restoration of the freshwater and estuarine environment. An additional workshop on full-system survival estimates (combining info from the various tagging efforts) will help connect and integrate estimates and mechanisms across habitats. The workshops would serve as a forum for all involved and could be jointly organized by NOAA and the Council. It is time to move towards a predictive science and initiate discussions with BPA, NWPCC and hatchery managers as to how they might modify the operations of the hydropower system, barge transportation, and timing-of-release of smolts to improve the survival of salmon in the marine environment (i.e. operational oceanography).

Future coordination and collaboration among the ocean projects.

The importance of coordinating the ocean projects to provide a comprehensive understanding of the processes regulating the survival of different Columbia River salmon ESUs in the ocean has long been recognized by NOAA and DFO. The coordination and collaboration between NOAA and DFO that started with the inception of these projects is expected to continue in the future, as the integration of efforts from both projects has already yielded fruitful results and joint publications (Appendix B). Coordination of the projects will be performed annually, at a minimum, coinciding with attendance at the annual "Salmon Ocean Ecology Meeting" that NOAA and DFO have organized each year since the late 1990s. In addition, communication and data exchange among scientists of both programs occurs throughout the year with phone, emails, and web conferencing. Future collaboration will include participation of DFO scientists on NOAA surveys and vice versa, as well as joint winter surveys that extend from the west coast of Vancouver Island to Oregon.

Collaboration between the NOAA and DFO projects with the Kintama project has been somewhat limited to date, due to the shorter Kintama time series. However, because the NOAA and DFO surveys overlap in space with the Kintama acoustic arrays, it is expected in a few years that the area-specific mortality rates estimated by Kintama using acoustic telemetry will be overlaid with the ocean conditions measured by NOAA and DFO along the coast and Columbia River plume. This should also allow a more statistically powerful analysis of cause and effects than using adult returns alone.

In combination, the ocean projects provide a promising avenue of future collaboration and increases our ability to understand the response of Columbia River salmon to changing ocean conditions. By distinguishing between hydrosystem-induced mortality and ocean effects, the cause of poor adult returns can be properly identified and direct measurements of early marine survival can help quickly test theories about how regional ocean conditions influence juvenile survival without waiting three years for adult salmon to return.

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References

Abdul-Aziz, O.I., Mantua, N.J. and Myers, K.W. (2011) Potential climate change impacts on thermal habitats of Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean and adjacent seas. *Can. J. Fish. Aquat. Sci.*, **68,** 1660-1680.

AGU (American Geophysical Union) (2006) Warm ocean conditions in the California Current in spring/summer 2005: causes and consequences. *Geophys. Res. Lett.,* **33(22),** L22S01-L22S11.

Anderson, J., Ham, K. and Gosselin, J. (2011) Snake River Basin differential delayed mortality synthesis, 95% progress report dated September 2011. Walla Walla District, Walla Walla, WA, Prepared for the U.S. Army Corps of Engineers.

Baldwin, R.E., Miller, T.W., Brodeur, R.D. and Jacobson, K.C. (2008) Expanding the foraging history of juvenile Pacific salmon: combining stomach-content and macroparasite-community analyses for studying marine diets. *J. Fish Biol.,* **72,** 1268-1294.

Bartholomew, J.L., Fryer, J.L. and Rohovec, J.S. (1992) Impact of the myxosporean parasite, *Ceratomyxa shasta*, on survival of migrating Columbia River basin salmonids. *In* Proceedings of the 19th US. and Japan meeting on Aquaculture ISE, Mie Prefecture, Japan. October 29-30, 1990. US Dept. of Commerce NOAA Technical Report NMFS 111.

Bax, N.J. (1998) The significance and prediction of predation in marine fisheries. *ICES J. Mar. Sci.,* **55,** 997-1030.

Beacham, T.D., Candy, J.R., Jonsen, K.L., Supernault, J., Wetklo, M., Deng, L.T., Miller, K.M., Withler, R.E. and Varnavskaya, N. (2006) Estimation of stock composition and individual identification of Chinook salmon across the Pacific Rim by use of microsatellite variation. *Trans. Am. Fish. Soc.,* **135,** 861-888.

Beacham, T.D., Wetklo, M., Deng, L. and MacConnachie, C. (2011) Coho Salmon Population Structure in North America Determined from Microsatellites. *Trans. Am. Fish. Soc.,* **140,** 253-270.

Beamish, R.J., McFarlane, G.A. and King, J.R. (2000) Fisheries climatology: understanding decadal scale processes that naturally regulate British Columbia fish populations. In: *Fisheries Oceanography: an integrative approach to fisheries ecology and management.* P.J. Harrison and T.R. Parsons (eds). pp. 94-139.

Beamish, R.J. and Mahnken, C. (2001) A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Prog. Oceanogr.,* **49,** 423-437.

Beamish, R.J., Mahnken, C. and Neville, C.M. (2004) Evidence that reduced early marine growth is associated with lower marine survival of Coho salmon. *Trans. Am. Fish. Soc.,* **133,** 26-33.

Beamish, R.J., Sweeting, R.M., Neville, C.M. and Lange, K.L. (2010) Competitive interactions between pink salmon and other juvenile Pacific salmon in the Strait of Georgia. NPAFC Doc. 1284. 26pp.

Bertrand, M., Marcogliese, D.J. and Magnan, P. (2008) Trophic polymorphism in brook charr revealed by diet, parasites and morphometrics. *J. Fish Biol.,* **72,** 555-572.

Bi, H., Ruppel, R.E. and Peterson, W.T. (2007) Modeling the pelagic habitat of salmon off the Pacific Northwest (USA) coast using logistic regression. *Mar. Ecol. Prog. Ser.,* **336,** 249-265.

Bi, H., Ruppel, R.E., Peterson, W.T. and Casillas, E. (2008) Spatial distribution of ocean habitat of yearling Chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon off Washington and Oregon, USA. *Fish. Oceanogr.,* **17,** 463-476.

Bi, H., Peterson, W.T., Lamb, J. and Casillas, E. (2011a) Copepods and salmon: characterizing the spatial distribution of juvenile salmon along the Washington and Oregon coast, U.S.A. *Fish. Oceanogr.,* **20,** 125-138.

Bi, H., Peterson, W.T. and Strub, P.T. (2011b) Transport and coastal zooplankton communities in the northern California Current system. *Geophys. Res. Lett.,* **38**.

Blankenship, S.M., Campbell, M.R., Hess, J.E., Hess, M.A., Kassler, T.W., Kozfkay, C.C., Matala, A.P., Narum, S.R., Paquin, M.M., Small, M.P., Stephenson, J.J. and Warheit, K.I. (2011) Major lineages and metapopulations in Columbia River *Oncorhynchus mykiss* are structured by dynamic landscape features and environments. *Trans. Am. Fish. Soc.,* **140,** 665-684.

Bradford, M.J. (1995) Comparative review of Pacific salmon survival rates. *Can. J. Fish. Aquat. Sci.,* **52,** 1327-1338.

Bradford, M.J. and Irvine, J.R. (2000) Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. *Can. J. Fish. Aquat. Sci.,* **57,** 13-16.

Brodeur, R.D., Fisher, J.P., Teel, D.J., Emmett, R.L., Casillas, E. and Miller, T.W. (2004) Juvenile salmonid distribution, growth, condition, origin, and environmental and species associations in the Northern California Current. *Fish. Bull.,* **102,** 25-46.

Brodeur, R.D., Fisher, J.P., Emmett, R.L., Morgan, C.A. and Casillas, E. (2005) Species composition and community structure of pelagic nekton off Oregon and Washington under variable oceanographic conditions. *Mar. Ecol. Prog. Ser.,* **298,** 41-57.

Brodeur, R.D., Daly, E.A., Sturdevant, M.V., Miller, T.W., Moss, J.H., Thiess, M.E., Trudel, M., Weitkamp, L.A., Armstrong, J. and Norton, E.C. (2007) Regional comparisons of juvenile salmon feeding in coastal marine waters off the west coast of North America. *Am. Fish. Soc. Symp.,* **57,** 183-203.

Brodeur, R.D., Suchman, C.L., Reese, D.C., Miller, T.W. and Daly, E.A. (2008) Spatial overlap and trophic interactions between pelagic fish and large jellyfish in the northern California Current. *Mar. Biol.,* **154,** 649-659.

Brodeur, R.D., Ruzicka, J.J. and Steele, J.A. (2011) Investigating alternate trophic pathways through gelatinous zooplankton and planktivorous fishes in an upwelling ecosystem using end-to-end models. In: *Interdisciplinary Studies on Marine Environmental Modeling & Analysis.* K. Omori, X. Guo, N. Yoshie, N. Fujii, I.C. Handoh, A. Isobe and S. Tanabe (eds). TERRAPUB. pp. 57-63.

Budy, P., Thiede, G.P., Bouwes, N., Petrosky, C.E. and Schaller, H. (2002) Evidence linking delayed mortality of snake river salmon to their earlier hydrosystem experience. *N. Am. J. Fish. Manage.,* **22,** 35-51.

Burla, M., Baptista, A.M., Casillas, E., Williams, J.G. and Marsh, D.M. (2010a) The influence of the Columbia River plume on the survival of steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*): a numerical exploration. *Can. J. Fish. Aquat. Sci.,* **67,** 1671-1684.

Burla, M., Baptista, A.M., Zhang, Y.L. and Frolov, S. (2010b) Seasonal and interannual variability of the Columbia River plume: A perspective enabled by multiyear simulation databases. *J. Geophys. Res. (C Oceans),* **115**.

Cederholm, C.J., Kunze, M.D., Murota, T. and Sibatani, A. (1999) Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries,* **24,** 6-15.

Chawla, A., Jay, D.A., Baptista, A.M., Wilkin, M. and Seaton, C. (2008) Seasonal variability and estuary-shelf interactions in circulation dynamics of a river-dominated estuary. *Estuar. Coast.,* **31,** 269-288.

Claiborne, A.M., Fisher, J.P., Hayes, S.A. and Emmett, R.L. (2011) Size at Release, Size-Selective Mortality, and Age of Maturity of Willamette River Hatchery Yearling Chinook Salmon. *Trans. Am. Fish. Soc.,* **140,** 1135-1144.

CMOP (Center for Coastal Margin Observation & Prediction) (2012) Virtual Columbia River Climatological Atlas. Interactive data site of the Center for Coastal Margin Observation and Prediction. Available www.stccmop.org/datamart/ virtualcolumbiariver/simulationdatabases/climatologicalatlas (January 2012).

Coyle, K.O. and Pinchuk, A.I. (2003) Annual cycle of zooplankton abundance, biomass and production on the northern Gulf of Alaska shelf, October 1997 through October 2000. *Fish. Oceanogr.,* **12,** 327-338.

Coyle, K.O. and Pinchuk, A.I. (2005) Seasonal cross-shelf distribution of major zooplankton taxa on the northern Gulf of Alaska shelf relative to water mass properties, species depth preferences and vertical migration behavior. *Deep-Sea Res, Part II,* **52,** 217-245.

Coyle, K.O., Pinchuk, A.I., Eisner, L.B. and Napp, J.M. (2008) Zooplankton species composition, abundance and biomass on the eastern Bering Sea shelf during summer: The potential role of water-column stability and nutrients in structuring the zooplankton community. *Deep-Sea Res, Part II,* **55,** 1775-1791.

Cross, A.D., Beauchamp, D.A., Myers, K.W. and Moss, J.H. (2008) Early marine growth of pink salmon in Prince William Sound and the coastal Gulf of Alaska during years of low and high survival. *Trans. Am. Fish. Soc.,* **137,** 927-939.

Crossin, G.T., Hinch, S.G., Farrell, A.P., Higgs, D.A. and Healey, M.C. (2004) Somatic energy of sockeye salmon *Oncorhynchus nerka* at the onset of upriver migration: a comparison among ocean climate regimes. *Fish. Oceanogr.,* **13,** 345-349.

Daly, E., Brodeur, R., Fisher, J., Weitkamp, L., Teel, D. and Beckman, B. (2011) 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. *Environ. Biol. Fishes***,** 1-18.

Daly, E.A., Brodeur, R.D. and Weitkamp, L.A. (2009) Ontogenetic Shifts in Diets of Juvenile and Subadult Coho and Chinook Salmon in Coastal Marine Waters: Important for Marine Survival? *Trans. Am. Fish. Soc.,* **138,** 1420-1438.

Daly, E.A., Benkwitt, C.E., Brodeur, R.D., Litz, M.N.C. and Copeman, L.A. (2010) Fatty acid profiles of juvenile salmon indicate prey selection strategies in coastal marine waters. *Mar. Biol.,* **157,** 1975-1987.

Dawley, E.M., Ledgerwood, R.D. and Jensen, A. (1985) Beach and purse seine sampling of juvenile salmonids in the Columbia River estuary and ocean plume, 1977-1983. Vol. I: Procedures, sampling effort and catch data. Seattle, WA, U.S. Dep. Comm. NOAA Tech. Memo. NMFS F/NWC no.74. 260 pp.

Ebel, W.J., Park, D.L. and Johnson, R.C. (1973) Effects of transportation on survival and homing of Snake River Chinook salmon and steelhead trout. *Fish. Bull.,* **71,** 549–563.

Ebel, W.J. (1980) Transportation of Chinook salmon, *Oncorhynchus tshawytscha*, and steelhead, *Salmo gairdneri*, smolts in the Columbia River and effects on adult returns. *Fish. Bull.,* **78,** 491–506.

Elliott, D.G., Pascho, R.J. and Bullock, G.L. (1989) Developments in the control of bacterial kidney disease of salmonid fishes. *Dis. Aquat. Org.,* **6,** 201-215.

Emmett, R.L., Miller, D.R. and Blahm, T.H. (1986) Food of juvenile Chinook, *Oncorhynchus tshawytscha*, and coho, *Oncorhynchus kisutch*, salmon off the Northern Oregon and Southern Washington coasts, May - September 1980. *Calif. Fish Game,* **72,** 38-46.

Emmett, R.L. (2006) The relationships between fluctuations in oceanographic conditions, forage fishes, predatory fishes, predator food habits, and juvenile salmonid marine survival off the Columbia River. Fisheries and Wildlife. Corvallis, OR, Oregon State University, Ph.D. Thesis, 312 pp.

Emmett, R.L., Krutzikowsky, G.K. and Bentley, P. (2006) Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998-2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. *Prog. Oceanogr.,* **68,** 1-26.

Emmett, R.L. and Sampson, D.B. (2007) The relationship between predatory fish, forage fishes, and juvenile salmonid marine survival off the Columbia River: a simple trophic model analysis. *CALCOFI Rep,* **48,** 96-105.

Emmett, R.L. and Krutzikowsky, G.K. (2008) Nocturnal feeding of Pacific hake and jack mackerel off the mouth of the Columbia River, 1998-2004: Implications for juvenile salmon predation. *Trans. Am. Fish. Soc.,* **137,** 657-676.

English, K.K., Glova, G.J. and Blakley, A.C. (2008) *An Upstream Battle: Declines in 10 Pacific Salmon Stocks and Solutions for Their Survival.* David Suzuki Foundation, Vancouver, B. C., 49pp.

Farley, E.V., Starovoytov, A., Naydenko, S., Heintz, R., Trudel, M., Guthrie, C., Eisner, L. and Guyon, J.R. (2011) Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. *ICES J. Mar. Sci.,* **68,** 1138-1146.

Ferguson, J. (2011) Preliminary survival estimates for passage during the spring migration of juvenile salmonids through Snake and Columbia River reservoirs and dams, 2011. Memorandum to Bruce Suzumoto. Seattle, WA, NOAA Northwest Region, dated September 13, 2011. Available from NOAA's Northwest Fisheries Science Center.

Ferguson, J.A., Rossignol, P.A., Jacobson, K.C. and Kent, M.L. (2011) Mortality in coho salmon (*Oncorhynchus kisutch*) associated with burdens of multiple parasite species. *Int. J. Parasitol.,* **41,** 1197-1205.

Fisher, J.P. and Pearcy, W.G. (1990) Spacing of scale circuli versus growth rate in young coho salmon. *Fish. Bull.,* **88,** 637-643.

Fisher, J.P. and Pearcy, W.G. (1995) Distribution, migration, and growth of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, off Oregon and Washington. *Fish. Bull.,* **93,** 274-289.

Fisher, J.P., Trudel, M., Ammann, A., Orsi, J.A., Piccolo, J., Bucher, C., Casillas, E., Harding, J.A., MacFarlane, R.B., Brodeur, R.D., Morris, J.F.T. and Welch, D.W. (2007) Comparisons of the coastal distributions and abundances of juvenile Pacific Salmon from central California to the Northern Gulf of Alaska. In: *The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons.* C.B. Grimes, R.D. Brodeur, L.J. Haldorson and S.M. McKinnell (eds). American Fisheries Society, Symposium 57, Bethesda. pp. 31-80.

Fisher, J.P., Hinton, S.A., Teel, D.J., Trudel, M., Weitkamp, L.A., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Orsi, J.A. and Farley, E.V. (In revision) Patterns of early ocean dispersal and growth among Columbia River Chinook and coho salmon stock groups. *Trans. Am. Fish. Soc.*

Francis, R.C. and Hare, S.R. (1994) Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: A case for historical science. *Fish. Oceanogr.,* **3,** 279-291.

Fryer, J.L. and Sanders, J.E. (1981) Bacterial kidney diesease of salmonid fish. *Annu. Rev. Microbiol.,* **35,** 273-298.

Gargett, A.E. (1997) The optimal stability 'window': a mechanism underlying decadal fluctuations in North Pacific salmon stocks? *Fish. Oceanogr.,* **6,** 109-117.

Garza, J.C. and Anderson, E. (2007) Large scale parentage inference as an alternative to coded-wire tags for salmon fishery management. *In*: PSC Genetic Stock Identification Workshop (May and September 2007): Logistics Workgroup final report and recommendations. Vancouver, British Columbia, Canada. Available at http://www.psc.org/info_genetic_stock_id.htm#REPORTS, Pacific Salmon Commission. 48-55pp.

Greene, C.M., Hall, J.E., Guilbault, K.R. and Quinn, T.P. (2010) Improved viability of populations with diverse life-history portfolios. *Biol. Lett.,* **6,** 382-386.

Hallowed, A.B. and Wooster, W.S. (1992) Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. *ICES Mar. Sci. Symp.,* **195,** 433-444.

Hare, S.R., Mantua, N.J. and Francis, R.C. (1999) Inverse production regimes: Alaska and West Coast Pacific salmon. *Fisheries,* **24,** 6-14.

Hartt, A.C. and Dell, M.B. (1986) Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Int. N. Pac. Fish. Comm, 46. 105pp.

Healey, M.C. (1991) Life History of Chinook Salmon (*Oncorhynchus tshawytscha*). In: *Pacific salmon life histories.* C. Groot and L. Margolis (eds). University of British Columbia Press, Vancouver, Canada. pp. 311-394.

Hickey, B., McCabe, R., Geier, S., Dever, E. and Kachel, N. (2009) Three interacting freshwater plumes in the northern California Current System. *J. Geophys. Res. (C Oceans),* **114**.

Hickey, B.M., Kudela, R.M., Nash, J.D., Bruland, K.W., Peterson, W.T., MacCready, P., Lessard, E.J., Jay, D.A., Banas, N.S., Baptista, A.M., Dever, E.P., Kosro, P.M., Kilcher, L.K., Horner-Devine, A.R., Zaron, E.D., McCabe, R.M., Peterson, J.O., Orton, P.M., Pan, J. and Lohan, M.C. (2010) River Influences on Shelf Ecosystems: Introduction and synthesis. *J. Geophys. Res. (C Oceans),* **115**.

Hilborn, R., Quinn, T.P., Schindler, D.E. and Rogers, D.E. (2003) Biocomplexity and fisheries sustainability. *Proc. Nat. Acad. Sci. USA,* **100,** 6564-6568.

Holsman, K.M., Scheuerell, M.D., Buehle, E. and Emmett, R.L. (In prep) Interacting management practices modify subsequent effects of biotic and abiotic factors on marine survival of threatened Chinook salmon. *Conserv. Biol.*

Hooff, R.C. and Peterson, W.T. (2006) Copepod biodiversity as an indicator of changes in ocean and climate conditions of the northern California current ecosystem. *Limnol. Oceanogr.,* **51,** 2607-2620.

Hurst, T.P. (2007) Causes and consequences of winter mortality in fishes. *J. Fish Biol.,* **71,** 315-345.

Independent Scientific Advisory Board (ISAB) (2007) Latent Mortality Report. Review of Hypotheses and Causative Factors Contributing to Latent Mortality and their Likely Relevance to the "Below Bonneville" Component of the COMPASS Model.: Northwest Power and Conservation Council., Document No. ISAB 2007-1, http://www.nwcouncil.org/fw/isab/Default.asp

Intergovernment Panel on Climate Change (IPCC) (2007) Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernment Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds). Cambridge University Press, Cambridge.

Jacobson, K.C., Teel, D., Van Doornik, D.M. and Casillas, E. (2008) Parasite-associated mortality of juvenile Pacific salmon caused by the trematode *Nanophyetus salmincola* during early marine residence. *Mar. Ecol. Prog. Ser.,* **354,** 235-244.

Jenkins, E. (2011) Trophic niche and foodweb dynamics within and among juvenile salmon in years of contrasting ocean conditions. Victoria, British Columbia, University of Victoria, M.Sc. Thesis, 129 pp.

Kareiva, P., Marvier, M. and McClure, M. (2000) Recovery and management options for spring/summer chinook salmon in the Columbia River Basin. *Science,* **290,** 977-979.

Keister, J.E., Di Lorenzo, E., Morgan, C.A., Combes, V. and Peterson, W.T. (2011) Zooplankton species composition is linked to ocean transport in the Northern California Current. *Global Change Biol.,* **17,** 2498-2511.

Lee, R.F., Hagen, W. and Kattner, G. (2006) Lipid storage in marine zooplankton. *Mar. Ecol. Prog. Ser.,* **307,** 273-306.

Levin, P.S., Zabel, R.W. and Williams, J.G. (2001) The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. *Proc. R. Soc. Lond., Ser. B: Biol. Sci.,* **268,** 1153-1158.

Lindley, S.T., Grimes, C.B., Mohr, M.S., Peterson, W.T., Stein, J., Anderson, J.T., Botsford, L.W., Bottom, D.L., Busack, C.A., Collier, T.K., Ferguson, J., Garza, J.C., Grover, A.M., Hankin, D.G., Kope, R.G., Lawson, P.W., Low, A., Mcfarlane, R.B., Moore, K., Palmer-Zwahlen, M., Schwing, F.B., Smith, J., Tracy, C., Webb, R., Wells, B.K. and Williams, T.H. (2009) What caused the Sacramento River fall Chinook stock collapse? , NOAA Technical Memorandum: NOAA-TM-NMFS-SWFSC-447. 61pp.

Litz, M.N.C., Brodeur, R.D., Emmett, R.L., Heppell, S.S., Rasmussen, R.S., O'Higgins, L. and Morris, M.S. (2010) Effects of variable oceanographic conditions on forage fish lipid content and fatty acid composition in the northern California Current. *Mar. Ecol. Prog. Ser.,* **405,** 71-85.

Litz, M.N.C., Phillips, A.J., Brodeur, R.D. and Emmett, R.L. (2011) Seasonal occurrences of Humboldt squid (*Dosidicus gigas*) in the northern California Current System. *CALCOFI Rep,* **52,** 97-108.

Logerwell, E.A., Mantua, N., Lawson, P.W., Francis, R.C. and Agostini, V.N. (2003) Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. *Fish. Oceanogr.,* **12,** 554-568.

Losee, J.P., Baldwin, R.E., Fisher, J., Teel, D.J. and Jacobson, K.C. (In prep) Growth of juvenile coho salmon (*Oncorhynchus kisutch*) relates to species richness of trophically-transmitted parasites. *Proc. R. Soc. Lond., Ser. B: Biol. Sci.*

Mackas, D.L., Thomson, R.E. and Galbraith, M. (2001) Changes in the zooplankton community of the British Columbia continental margin, 1985-1999, and their covariation with oceanographic conditions. *Can. J. Fish. Aquat. Sci.,* **58,** 685-702.

Mackas, D.L., Peterson, W.T. and Zamon, J.E. (2004) Comparisons of interannual biomass anomalies of zooplankton communities along the continental margins of British Columbia and Oregon. *Deep-Sea Res, Part II,* **51,** 875-896.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M. and Francis, R.C. (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Am. Meterol. Soc.,* **78,** 1069-1079.

Marcogliese, D.J. (1995) The role of zooplankton in the transmission of helminth parasites to fish. *Rev. Fish Biol. Fish.,* **5,** 336-371.

Marin Jarrin, J.R., Miller, D.R. and Teel, D.J. (In Review) Distribution and densities of juvenile Chinook salmon in sandy beach surf zones. *Mar. Ecol. Prog. Ser.*

Marin Jarrin, J.R., Shanks, A.L. and Banks, M.A. (2009) Confirmation of the presence and use of sandy beach surf-zones by juvenile Chinook salmon. *Environ. Biol. Fishes,* **85,** 119–125.

Marmorek, D. and Peters, C. (2001) Finding a PATH towards scientific collaboration: Insights from the Columbia River Basin. *Conserv. Ecol.,* **5(2),** 8.

Matthews, S.B. (1984) Variability of marine survival of Pacific salmonids: A review. In: *The Infleunce of Ocean Conditions on the Production of Salmonids in the North Pacific.* W.G. Pearcy (ed.) Oregon State University Sea Grant Program, Corvallis, OR. pp. 161-182.

Mazumder, A., Brodeur, R.D., Eisner, L.B., Farley, E.V., Harding, J.A., Moss, J.H. and Trudel, M. (2011) Continental-scale comparative analyses of foodweb feeding and resource ecology of juvenile Chinook salmon along the coastal North Pacific, presented at the American Fisheries Society Annual Meeting, Seattle, WA, Available at: http://afs.confex.com/afs/2011/webprogram/Paper3999.html.

Middleton, K.R. (2011) Factors affecting overwinter mortality and early marine growth in the first ocean year of juvenile Chinook salmon in Quatsino Sound, British Columbia. University of Victoria, M.Sc. Thesis, 116 pp.

Miller, D.R., Williams, J.G. and Sims, C.W. (1983) Distribution, abundance and growth of juvenile salmonids off the coast of Oregon and Washington, summer 1980. *Fish. Res.,* **2,** 1-17.

Miller, T.W. and Brodeur, R.D. (2007) Diets of and trophic relationships among dominant marine nekton within the northern California Current ecosystem. *Fish. Bull.,* **105,** 548-559.

Miller, T.W., Brodeur, R.D., Rau, G. and Omori, K. (2010) Prey dominance shapes trophic structure of the northern California Current pelagic food web: evidence from stable isotopes and diet analysis. *Mar. Ecol. Prog. Ser.,* **420,** 15-26.

Morris, J.F.T., Trudel, M., Thiess, M.E., Sweeting, R.M., Fisher, J., Hinton, S.A., Ferguson, J.A., Orsi, J.A., Farley, E.V. and Welch, D.W. (2007) Stock-specific migrations of juvenile coho salmon derived from coded-wire tag recoveries on the continental shelf of western North America. In: *The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons.* C.B. Grimes, R.D. Brodeur, L.J. Haldorson and S.M. McKinnell (eds). American Fisheries Society, Symposium 57, Bethesda, MD. pp. 81-104.

Moss, J.H., Beauchamp, D.A., Cross, A.D., Myers, K.W., Farley, E.V., Murphy, J.M. and Helle, J.H. (2005) Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. *Trans. Am. Fish. Soc.,* **134,** 1313-1322.

Mueter, F.J., Peterman, R.M. and Pyper, B.J. (2002) Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (*Oncorhynchus* spp.) in northern and southern areas. *Can. J. Fish. Aquat. Sci.,* **59,** 456-463.

Muir, W.D., Marsh, D.M., Sandford, B.P., Smith, S.G. and Williams, J.G. (2006) Post-hydropower system delayed mortality of transported snake river stream-type Chinook salmon: Unraveling the mystery. *Trans. Am. Fish. Soc.,* **135,** 1523-1534.

Myers, K.W., Aydin, K.Y., Walker, R.V., Fowler, S. and Dahlberg, M. (1996) Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956-1995. University of Washington, Fisheries Research Institute, Seattle, Rep. FRI-UW-9614.

Nickelson, T.E. (1986) Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon production area. *Can. J. Fish. Aquat. Sci.,* **43,** 527-535.

Northwest Power Act (1996) No. 5093 July 26, 1996 Amendment to the Pacific Northwest Electric Power Planning and Conservation Act. Section (4)(g)(4)(vi) of U.S. Code Chapter 12H (1994 and Supplement/1995). Statute 2697. Public Law No. 96-501, S. 885.

Northwest Power and Conservation Council (NPCC) (2000) Columbia River Basin Fish and Wildlife Program. Council Document 2000-19. Northwest Power and Conservation Council, Portland, Oregon. 76pp.

Northwest Power and Conservation Council (NPCC) (2009) Columbia River Basin Fish and Wildlife Program: 2009 Amendments. Council Document 2009-09. Northwest Power and Conservation Council, Portland, Oregon. 98pp.

Orsi, J.A., Harding, J.A., Pool, S.S., Brodeur, R.D., Haldorson, L.J., Murphy, J.M., Moss, J.H., Farley, J.E.V., Sweeting, R.M., Morris, J.F.T., Trudel, M., Beamish, R.J., Emmett, R.L. and Fergusson, E.A. (2007) Epipelagic fish assemblages associated with juvenile Pacific salmon in neritic waters of the California Current and the Alaska Current. In: *The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons.* C.B. Grimes, R.D. Brodeur, L.J. Haldorson and S.M. McKinnell (eds). American Fisheries Society, Symposium 57, Bethesda. pp. 105-155.

Overland, J., Rodionov, S., Minobe, S. and Bond, N. (2008) North Pacific regime shifts: Definitions, issues and recent transitions. *Prog. Oceanogr.,* **77,** 92-102.

Pascual, S., Gonzales, A., Arias, C. and Guierra, A. (1996) Biotic relationships of *Illex condetii* and *Todaraposis eblana* (Cephalopoda, Ommastrephidae) in the Northeast Atlantic: evidence from parasites. *Sarsia,* **81,** 265-274.

Payne, J.C., Andrews, K., Chittenden, C., Crossin, G., Goetz, F.A., Hinch, S.G., Levin, P., Lindley, S.T., McKinley, S., Melnychuk, M.C., Nelson, T., Rechisky, E.L. and Welch, D.W. (2010) Tracking Fish Movements and Survival on the Northeast Pacific Shelf. In: *Life in the World's Oceans: Diversity, Distribution, and Abundance.* A.D. McIntyre (ed.) Blackwell Publishing Ltd. pp. 267-290.

Pearcy, W.G. and Fisher, J.P. (1988) Migrations of coho salmon, *Oncorhynchus kisutch*, during their 1st summer in the ocean. *Fish. Bull.,* **86,** 173-195.

Pearcy, W.G. and Fisher, J.P. (1990) Distribution and abundance of juvenile salmonids off Oregon and Washington, 1981-1985. NOAA Tech. Rep. NMFS. 83pp.

Pearcy, W.G. (1992) *Ocean ecology of North Pacific salmonids.* Washington Sea Grant Program, University of Washinton Press, Seattle, WA, 179pp.

Pearcy, W.G. and McKinnell, S.M. (2007) The ocean ecology of salmon in the northeast Pacific Ocean - an abridged history. *Am. Fish. Soc. Symp.,* **57,** 7-30.

Peterman, R.M. and Dorner, B. (2011) Fraser River sockeye production dynamics. Vancouver, B.C., Cohen Commission. Tech. Rep. 10. 134pp.

Peterson, W.T. and Keister, J.E. (2003) Interannual variability in copepod community composition at a coastal station in the northern California Current: a multivariate approach. *Deep-Sea Res, Part II,* **50,** 2499-2517.

Peterson, W.T. and Schwing, F.B. (2003) A new climate regime in northeast pacific ecosystems. *Geophys. Res. Lett.,* **30**.

Peterson, W.T. and Hooff, R.C. (2005) Long term variations in hydrography and zooplankton in coastal waters of the northern California Current off Newport Oregon, *In* Proceedings of International Symposium on Long-term variations in the Coastal Environments and Ecosystems. 27-28 September 2004, Matsuyama, Japan, pp. 36-44.

Peterson, W.T., Morgan, C.A., Fisher, J.P. and Casillas, E. (2010) Ocean distribution and habitat associations of yearling coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*) salmon in the northern California Current. *Fish. Oceanogr.,* **19,** 508-525.

Peterson, W.T., Morgan, C.A. and Fisher, J.P. (In prep) Habitat characteristics of sub-yearling Chinook salmon during their first summer at sea in continental shelf waters off Washington and Oregon U.S.A.

Petric, M., Mladineo, I. and Sifner, S.K. (2011) Insight into the short-finned squid *Illex coindetii* (Cephalopoda:Ommastrephidae) feeding ecology: is there a link between helminth parasites and food composition? *J. Parasitol.,* **97,** 55-62.

Pool, S., Reese, D. and Brodeur, R. (2012) Defining marine habitat of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, and coho salmon, *O. kisutch*, in the northern California Current System. *Environ. Biol. Fishes,* **93,** 233-243.

Porter, A.D., Welch, D.W., Rechisky, E.L., Jacobs, M.C., Lydersen, H., Winchell, P.M., Kroeker, D.W., Neaga, L., Robb, J.D. and Muirhead, Y.K. (2010a) 2006-09 Multiyear Summary & Key Findings from the Pilot-Stage Acoustic Telemetry Study on Hydrosystem and Early Ocean Survival of Columbia River Salmon. . Fish & Wildlife (ed.) Portland, Oregon: Report to the Bonneville Power Administration by Kintama Research Corporation. p. 46 pages.

Porter, A.D., Welch, D.W., Rechisky, E.L., Jacobs, M.C., Lydersen, H., Winchell, P.M., Kroeker, D.W., Neaga, L., Robb, J.D. and Muirhead, Y.K. (2010b) Marine and freshwater measurement of delayed and differential-delayed mortality of Snake River spring Chinook smolts using a continental-scale acoustic telemetry array, 2009. Report to the Bonneville Power Administration by Kintama Research Corporation, Contract No. 46389, Project No. 2003-114-00. 361 pages.pp.

Porter, A.D., Welch, D.W., Rechisky, E.L., Challenger, W.O., Scott, M.C.J., Lydersen, H., Winchell, P.M., Neaga, L., Robb, J.D. and Muirhead, Y.K. (2011) Marine and freshwater measurement of delayed and differential-delayed mortality of Columbia & Snake River yearling Chinook smolts using a continental-scale acoustic-telemetry array, 2010. Portland, Oregon: Report to the Bonneville Power Administration by Kintama Research Services Ltd., Contract No. 46389, Project No. 2003-114-00. p. 492 pp.

Post, D.M., Layman, C.A., Arrington, D.A., Takimoto, G., Quattrochi, J. and Montana, C.G. (2007) Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. *Oecologia,* **152,** 179-189.

Quinn, T.P., Vollestad, L.A., Peterson, J. and Galluci, V. (2004) Influence of freshwater and marine growth on egg size-egg number tradeoffs in coho and Chinook salmon. *Trans. Am. Fish. Soc.,* **133,** 55-65.

Rand, P.S., B., B., Bidlack, A., Bottom, D.L., Gardner, J., Kaeriyama.M., Lincoln, R., Nagata, M., Pearsons, T., Schmidt, M., Smoker, W., Weitkamp, L.A. and Zhivotovsky, L.A. (In press) Ecological interactions between wild and hatchery salmon and key recommendations for research and management actions in selected regions of the North Pacific. *Environ. Biol. Fishes*.

Rechisky, E.L., Welch, D.W., Porter, A.D., Jacobs, M.C. and Ladouceur, A. (2009) Experimental measurement of hydrosystem-induced delayed mortality in juvenile Snake River spring Chinook salmon (*Oncorhynchus tshawytscha*) using a large-scale acoustic array. *Can. J. Fish. Aquat. Sci.,* **66,** 1019-1024.

Rechisky, E.L., Welch, D.W. and Porter, A.D. (Submitted) A test of the Differential-delayed mortality theory that transportation reduces survival of Snake River Spring Chinook. *Nat. Commun.*

Reese, D.C. and Brodeur, R.D. (2006) Identifying and characterizing biological hotspots in the northern California Current. *Deep-Sea Res, Part II,* **53,** 291-314.

Ruggerone, G.T. and Rogers, D.E. (1993) Predation on sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: implications for salmon management. *N. Am. J. Fish. Manage.,* **12,** 87-102.

Ruggerone, G.T. and Nielsen, J.L. (2004) Evidence for competitive dominance of Pink salmon (*Oncorhynchus gorbuscha*) over other Salmonids in the North Pacific Ocean. *Rev. Fish Biol. Fish.,* **14,** 371-390.

Ruggerone, G.T., Peterman, R.M., Dorner, B. and Myers, K.W. (2010) Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. *Mar. Coast. Fish.,* **2,** 306-328.

Rupp, D.E., Wainwright, T.C., Lawson, P.W. and Peterson, W.T. (2011) Marine environment-based forecasting of coho salmon (*Oncorhynchus kisutch*) adult recruitment. *Fish. Oceanogr.,* **21(1),** 1-19.

Ruzicka, J.J., Brodeur, R.D. and Wainwright, T.C. (2007) Seasonal food web models for the oregon inner-shelf ecosystem: Investigating the role of large jellyfish. *CALCOFI Rep,* **48,** 106-128.

Ruzicka, J.J., Wainwright, T.C. and Peterson, W.T. (2011) A model-based meso-zooplankton production index and its relation to the ocean survival of juvenile coho (*Oncorhynchus kisutch*). *Fish. Oceanogr.,* **20,** 544-559.

Scheuerell, M.D. and Williams, J.G. (2005) Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). *Fish. Oceanogr.,* **14,** 448-457.

Schindler, D.E., Hilborn, R., Chasco, B., Boatright, C.P., Quinn, T.P., Rogers, L.A. and Webster, M.S. (2010) Population diversity and the portfolio effect in an exploited species. *Nature,* **465,** 609-612.

Seeb, L.W., Antonovich, A., Banks, A.A., Beacham, T.D., Bellinger, A.R., Blankenship, S.M., Campbell, A.R., Decovich, N.A., Garza, J.C., Guthrie, C.M., III, Lundrigan, T.A., Moran, P., Narum, S.R., Stephenson, J.J., Supernault, K.J., Teel, D.J., Templin, W.D., Wenburg, J.K., Young, S.E. and Smith, C.T. (2007) Development of a standardized DNA database for Chinook salmon. *Fisheries,* **32,** 540-552.

Shaul, L., Weitkamp, L.A., Simpson, K. and Sawada, J. (2007) Trends in abundance and size of coho salmon in the Pacific Rim. *N. Pac. Anadrom. Fish Comm. Bull.,* **4,** 93-104.

Smith, E.P., Orvos, D.R. and Cairns, J. (1993) Impact assessment using the before-after-control-impact (BACI) model: concerns and comments. *Can. J. Fish. Aquat. Sci.,* **50,** 627-637.

Steele, C., Ackerman, M., McCane, J., Cambell, M., Hess, M., Cambell, N. and Narum, S. (2011) Parentage Based Tagging of Snake River Hatchery Steelhead and Chinook salmon. Annual Report of research to Bonneville Power Administration, contract No. 4838, Project No. 2010-031-00. Available at http://efw.bpa.gov/searchpublications/.

Stocking, R.W., Holt, R.A., Foott, J.S. and Bartholomew, J.L. (2006) Spatial and Temporal Occurrence of the Salmonid Parasite *Ceratomyxa shasta* in the Oregon–California Klamath River Basin. *J. Aquat. Anim. Health,* **18:3,** 194-202.

Teel, D.J., Van Doornik, D.M., Kuligowski, D.R. and Grant, W.S. (2003) Genetic analysis of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington reveals few Columbia River wild fish. *Fish. Bull.,* **101,** 640-652.

Teel, D.J. (2004) Genetic mixed stock analysis of juvenile Chinook salmon in coastal areas of western North America. N. Pac. Anadrom. Fish Comm, Tech. Rep. 47-48pp.

Tomaro, L.T., Teel, D.J., Peterson, W.T. and Miller, J.A. (In revision) Early marine residence of Columbia river spring Chinook salmon: when is bigger better? *Mar. Ecol. Prog. Ser.*

Trudel, M., Tucker, S., Zamon, J.E., Morris, J., Higgs, D.A. and D.W. Welch, D. (2002) Bioenergetic response of coho salmon to climate change. N. Pac. Anadrom. Fish Comm, Tech. Rep. 59-61pp.

Trudel, M., Welch, D.W., Morris, J.F.T., Candy, J.R. and Beacham, T.D. (2004) Using Genetic Markers to Understand the Coastal Migration of Juvenile Coho (*Oncorhynchus kisutch*) and Chinook Salmon (*O. tshawytscha*). N. Pac. Anadrom. Fish. Comm., Tech Rep, 5. 52-54pp.

Trudel, M., Jones, S.R.M., Thiess, M.E., Morris, J.F.T., Welch, D.W., Sweeting, R.M., Moss, J.H., Wing, B.L., Farley, E.V., Jr., Murphy, J.M., Baldwin, R.E. and Jacobson, K.C. (2007a) Infestations of motile salmon lice (Lepeophtheirus salmonis) on Pacific salmon along the west coast of North America. In: *The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons.* C.B. Grimes, R.D. Brodeur, L.J. Haldorson and S.M. McKinnell (eds). American Fisheries Society, Symposium 57, Bethesda, MD. pp. 157-182.

Trudel, M., Thiess, M.E., Bucher, C., Farley, E.V., Jr., MacFarlane, R.B., Casillas, E., Fisher, J., Morris, J.F.T. and Murphy, J.M. (2007b) Regional variation in the marine growth and energy accumulation of juvenile Chinook salmon and coho salmon along the west coast of North America. In: *The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons.* C.B. Grimes, R.D. Brodeur, L.J. Haldorson and S.M. McKinnell (eds). American Fisheries Society, Symposium 57, Bethesda, MD. pp. 205-232.

Trudel, M., Thiess, M.E., Morris, J.F.T., Candy, J.R., Beacham, T.D., Higgs, D.A. and Welch, D.W. (2007c) Overwinter mortality and energy depletion in juvenile Pacific salmon off the west coast of British Columbia and Alaska. *N. Pac. Anadrom. Fish Comm. Tech. Rep.,* **7,** 61-63.

Trudel, M., Fisher, J.P., Orsi, J.A., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Fergusson, A. and Welch, D.W. (2009) Distribution and migration of juvenile Chinook salmon derived from coded wire tag recoveries along the continental shelf of western North America. *Trans. Am. Fish. Soc.,* **138,** 1369-1391.

Trudel, M., Tucker, S. and Candy, J.R. (2010) Ocean distribution of two depressed stocks of sockeye salmon stocks. Canadian Science Advisory Research Document 2010/053. 94-95pp.

Trudel, M., Thiess, M.E., Morris, J.F.T., Zubkowski, T. and Mackas, D.L. (2011a) Canada-USA Salmon Shelf Survival Study. Annual Report submitted to the Bonneville Power Administration. 117pp.

Trudel, M., Thiess, M.E., Tucker, S., Zubkowski, T., Jung, Y. and Baillie, S. (2011b) Reduced caches of juvenile salmon off WCVI in 2010 relative to 2009, but improved growth. Canadian Science Advisory Research Document 2010/054. 72-75pp.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C., Teel, D.J., Crawford, W., Farley, E.V. and Beacham, T.D. (2009) Seasonal Stock-Specific Migrations of Juvenile Sockeye Salmon along the West Coast of North America: Implications for Growth. *Trans. Am. Fish. Soc.,* **138,** 1458-1480.

Tucker, S., Trudel, M., Welch, D.W., Morris, J.F.T., Candy, J.R., Wallace, C. and Beacham, T.D. (2011) Life-history and seasonal stock-specific ocean migration of juvenile Chinook salmon. *Trans. Am. Fish. Soc.,* **140,** 1101-1119.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C. and Beacham, T.D. (In press) Annual coastal migration of juvenile Chinook salmon; static stock-specific patterns in a highly dynamic ocean. *Mar. Ecol. Prog. Ser.*

Tuomikoski, J., McCann, J., Berggren, T., Schaller, H., Wilson, P., Haeseker, S., Petrosky, C.E., Tinus, E., Dalton, T., Ehlke, R. and DeHart, M. (2009) Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook and Summer Steelhead-2009 Annual Report: Portland, Oregon, Fish Passage Center. 265pp.

Valtonen, E.T., Marcogliese, D.J. and Julkunen, M. (2010) Vertebrate diets derived from trophically transmitted fish parasites in the Bothnian Bay. *Oecologia,* **162,** 139-152.

Van Doornik, D.M., Teel, D.J., Kuligowski, D.R., Morgan, C.A. and Casillas, E. (2007) Genetic analyses provide Insight into the early ocean stock distribution and survival of juvenile coho salmon off the coasts of Washington and Oregon. *N. Am. J. Fish. Manage.,* **27,** 220–237.

Walters, C.J. (1987) Nonstationarity of production relationships in exploited populations. *Can. J. Fish. Aquat. Sci.,* **44(Suppl. 2),** 156-165.

Ward, B.R. (2000) Declivity in steelhead (*Oncorhynchus mykiss*) recruitment at the Keogh River over the past decade. *Can. J. Fish. Aquat. Sci.,* **57,** 298-306.

Ward, D.L., Boyce, R.R., Young, F.R. and Olney, F.E. (1997) A review and assessment of transportation studies for juvenile Chinook salmon in the Snake River. *N. Am. J. Fish. Manage.,* **17,** 652–662.

Ware, D.M. and McFarlane, G.A. (1989) Fisheries production domains in the Northeast Pacific Ocean. In: *Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models.* R.J. Beamish and G.A. McFarlane (eds). Canadian Special Publications of Fisheries and Aquatic Sciences, 108. pp. 359–379.

Ware, D.M. and Thomson, R.E. (2005) Bottom-up ecosystem trophic dynamics determine fish production in the northeast Pacific. *Science,* **308,** 1280-1284.

Welch, D.W., Ishida, Y. and Nagasawa, K. (1998) Thermal limits and ocean migrations of sockeye salmon (Oncorhynchus nerka): long-term consequences of global warming (vol 55, pg 937, 1998). *Can. J. Fish. Aquat. Sci.,* **55,** 1996-1996.

Welch, D.W., Ward, B.R., Smith, B.D. and Eveson, J.P. (2000) Temporal and spatial responses of British Columbia steelhead (*Oncorhynchus mykiss*) populations to ocean climate shifts. *Fish. Oceanogr.,* **9,** 17-32.

Willette, T.M., T., C.R., Patrick, V., Mason, D.M., Thomas, G.L. and Scheel, D. (2001) Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. *Fish. Oceanogr.,* **10(suppl 1),** 14-41.

Williams, J.G., Smith, S.G., Zabel, R.W., Muir, W.D., Scheuerell, M.D., Sandford, B.P., Marsh, D.M., McNatt, R.A. and Achord, S. (2005) Effects of the federal Columbia River power system on salmonid populations. *NOAA Technical Memorandum NMFS-NWFSC,* **63**.

Zamon, J.E., Phillips, E.M. and Guy, T.J. (Submitted) Marine bird aggregation at tidally-driven plume fronts of the Columbia River. *Deep Sea Res (Part II, Top.Stud. Oceanogr., Fronts, Fish, and Top Predators).*

Appendices

This document contains appendices (A - J) that contain supplementary materials referred to in the report:

The Marine Ecology of Juvenile Columbia River Basin Salmonids: A Synthesis of Research 1998-2011

Kym Jacobson, Bill Peterson, Marc Trudel, John Ferguson, Cheryl Morgan,
David Welch, Antonio Baptista, Brian Beckman, Richard Brodeur, Edmundo Casillas,
Robert Emmett, Jessica Miller, David Teel, Thomas Wainwright, Laurie Weitkamp,
Jeannette Zamon and Kurt Fresh

Report of the U.S. National Marine Fisheries Service,
National Oceanic and Atmospheric Administration
Fisheries and Oceans Canada
Kintama Research Services, Ltd.
and Oregon State University

to

Northwest Power and Conservation Council
851 S.W. Sixth Avenue, Suite 1100
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January 2012

Table of Contents

Appendix A. Region, periods, and metrics covered by NOAA and DFO ocean projects

Feature	NOAA	DFO
Geographic area	45-48ºN (Columbia River Estuary and Plume, Oregon and Washington Coasts)	48-56ºN (West coast of Vancouver Island to Southeast Alaska, including inlets and straits)
Years	1998-2011	1998-2011
Sampling Period	May June September --	-- June-July October-November February-March
Oceanography		
- T, S, D, pH, O2, Trans, Fluoro	CTD @ 0-200m	CTD @ 0-250m
- Nutrients	Niskin Bottle @ 3m	Niskin Bottle @ 10m
- Chlorophyll	Niskin Bottle @ 3m	Niskin Bottle @ 10m
- Zooplankton	Bongo net @ 20-30m Vertical net @ 0-100m	Bongo net @ 0-150m
Trawl		
- Manufacturer	Nordic 264	Cantrawl
- Dimension	30 m wide x 20 m high	30 m wide x 12 m high
- Tow speed	4 knots (~7.4 km/h)	5 knots (~9.3 km/h)
- Tow duration	30 min	30 min
Stock ID Baseline		
- Chinook*	GAPS[1]	DFO[4]
- Coho	NOAA[2]	DFO[5]
- Sockeye	NOAA[3]	DFO[6]
Diet	Stomachs, Stable Isotopes, Fatty Acids, Parasites	Stomachs, Stable Isotopes, Fatty Acids
Growth	Otolith microscruture IGF-1	IGF (since 2007 in collaboration with NOAA Fisheries), Size-based
Food consumption rates	--	Mass balance model of inert chemical tracers
Modeling	Linear/non-linear regressions PATH Analyses Structural Equation Modeling Bayesian Beliefs Network Green-Yellow-Red light traffic system	Linear/non-linear regressions PATH Analyses Structural Equation Modeling Bayesian Beliefs Network Green-Yellow-Red light traffic system
Marine Survival	Adult count to Bonneville[7] Adult count Lower Granite[7] Smolt released above Bonneville[7] Smolt count at Lower Granite[7] OPI Coho SAR	Adult count to Bonneville[7] Adult count Lower Granite[7] Smolt released above Bonneville[7] Smolt count at Lower Granite[7] OPI Coho SAR

* The microsatellite DNA baselines used by NOAA and DFO provide similar allocation at the ESU level (Hanson et al., 2010; S. Tucker, unpublished). References: [1](Seeb et al., 2007); [2](Van Doornik et al., 2007); [3](Iwamoto et al., In press); [4](Beacham et al., 2006b); [5](Beacham et al., In press) ; [6](Beacham et al., 2011); [7]See Appendices B

Appendix B. Joint Publications

2004

Mackas, D.L., Peterson, W.T., and Zamon, J.E. 2004. Comparisons of interannual biomass anomalies of zooplankton communities along the continental shelf margins of British Columbia and Oregon. *Deep-Sea Res.* II 51: 875-896.

2006

Brodeur, R.D., Ralston, S., Emmett, R.L., Trudel, M., Auth, T.D., and Phillips, A.J. 2006. Recent trends and anomalies in pelagic nekton abundance, distribution, and apparent recruitment in the Northeast Pacific Ocean. *Geophys. Res. Let.* Doi:10.1029/2006GL026614.

2007

Trudel, M., Thiess, M.E., Bucher, C., Farley, E.V., Jr., MacFarlane, B., Casillas, E., Fisher, J., Morris, J.F.T., Murphy, J.M., and Welch, D.W. 2007. Regional variation in the marine growth and energy accumulation of juvenile Chinook salmon and coho salmon along the west coast of North America. *Am. Fish. Soc. Symp. Ser.* 57: 205-232.

Brodeur, R.D., Daly, E.A., Studervant, M.V., Miller, T.W., Moss, J.H., Thiess, M., Trudel, M., Weitkamp, L.A., Armstrong, J., and Norton, E.C. 2007. Regional comparisons of juvenile salmon feeding in coastal marine waters off the West Coast of North America. *Am. Fish. Soc. Symp. Ser.* 57: 183-203.

Trudel, M., Jones, S.R.M., Thiess, M.E., Morris, J.F.T., Welch, D.W., Sweeting, R.M., Moss, J.H., Wing, B.L., Farley, E.V., Jr., Murphy, J.M., Baldwin, R.E., and Jacobson, K.C. 2007. Infestations of motile salmon lice on Pacific salmon along the west coast of North America. *Am. Fish. Soc. Symp. Ser.* 57: 157-182.

Orsi, J.A., Harding, J.A., Pool. S.S., Brodeur, R.D., Haldorson, L.J., Murphy, J.M., Moss, J.H., Farley, E.V., Jr., Sweeting, R.M., Morris, J.F.T., Trudel, M., Beamish, R.J., Emmett, R.L., and Fergusson, E.A. 2007. Epipelagic fish assemblages associated with juvenile Pacific salmon in neritic waters of the California Current and Alaska Current. *Am. Fish. Soc. Symp. Ser.* 57: 105-155.

Morris, J.F.T., Trudel, M., Thiess, M., Sweeting, R.M., Fisher, J., Hinton, S., Ferguson, E.A., Orsi, J.A., Farley, E.V., Jr., and Welch, D.W. 2007. Stock-specific migrations of juvenile coho salmon derived from coded-wire tag recoveries on the continental shelf of western North America. *Am. Fish. Soc. Symp. Ser.* 57: 81-104.

Fisher, J., Trudel, M., Ammann, A., Orsi, J., Piccolo, J., Bucher, C., Harding, J., Casillas, E., MacFarlane, B., Brodeur, R., Morris, J., and Welch, D. 2007. Regional comparisons of distribution and abundance of juvenile salmon along the West Coast of North America. *Am. Fish. Soc. Symp. Ser.* 57: 31-80.

2009
Trudel, M., Fisher, J., Orsi, J., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Hinton, S., Fergusson, E., and Welch, D.W. 2009. Distribution and migration of juvenile Chinook salmon derived from coded-wire tag recoveries along the continental shelf of western North America. *Trans. Am. Fish. Soc.*138: 1369-1391.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R, Morris, J.F.T., Thiess, M.E., Wallace, C., Teel, D.J., Crawford, W., Farley, E.V. Jr., and Beacham, T.D. 2009. Seasonal stock-specific migrations of juvenile sockeye salmon along the west coast of North America: Implications for growth. *Trans. Am. Fish. Soc.* 138: 1458-1480.

2010
Nance, S.L., Riederer, M.m Zubkowski, T., Trudel, M., and Rhodes, L.D. 2010. Interpreting dual ELISA and qPCR data for bacterial and kidney disease of salmonids. *Dis. Aquat. Org.* 91: 113-119.

Accepted with Revisions
Fisher, J.P., S.A. Hinton, D.J. Teel, M. Trudel, L. Weitkamp, J.F.T. Morris, M.E. Thiess, R.M. Sweeting, J.A. Orsi, and E.V. Farley, Jr. Patterns of early ocean dispersal and growth among Columbia River Chinook and coho salmon stock groups. *Trans. Am. Fish. Soc.* (submitted in June 2011).

In prep
Morgan, C.A., W. T. Peterson, M.V. Sturdevant, J.A. Keister, M. Galbraith, J.F. Lamb, D.L. Mackas, J.A. Orsi, M.E. Thiess, M. Trudel, B.L. Wing, and D.W. Welch. Latitudinal comparisons of copepod community composition in the Northern California Current and S. Gulf of Alaska during years of varying ocean conditions. *Mar. Ecol. Prog. Ser.*

Appendix C. Technical feasibility of using acoustic telemetry for assessing the mortality and migration of Spring Chinook salmon

1. Accuracy of Survival Estimates

The use of a telemetry system critically hinges on whether the data is credible; if post-release survival is compromised by surgical tagging procedures or if the implanted tag is too big, then survival may be reduced relative to untagged smolts. Alternatively, if larger smolts have different (higher) survival rates, the results for larger "taggable" smolts may be inaccurate for the entire population. Detailed assessment of the accuracy and precision of the telemetry-based survival estimates are reported in (Porter et al., 2011); we report here just the key biological findings.

The statistical experiments reported in document rely on comparing the relative proportion of two groups (Treatment and Control) that are detected after release, and an absolute estimate of survival is not in principle necessary. However, in practice having highly accurate data is desirable. To assess these questions we examined the relative survival of acoustic tagged smolts with independent releases of PIT-tagged smolts (Figure C-1). In 2006 and 2008-09 PIT and acoustic tagged smolts had indistinguishable survival rates with distance (see also Rechisky & Welch, 2010), while in 2007 (a year when smolts were repeatedly drugged and handled to find sufficient individuals meeting the size criteria), acoustic tagged smolt survivals differed from that of PIT-tagged spring Chinook. In 2010, when tagging was moved to the dams and smolts were handled and anaesthetized in

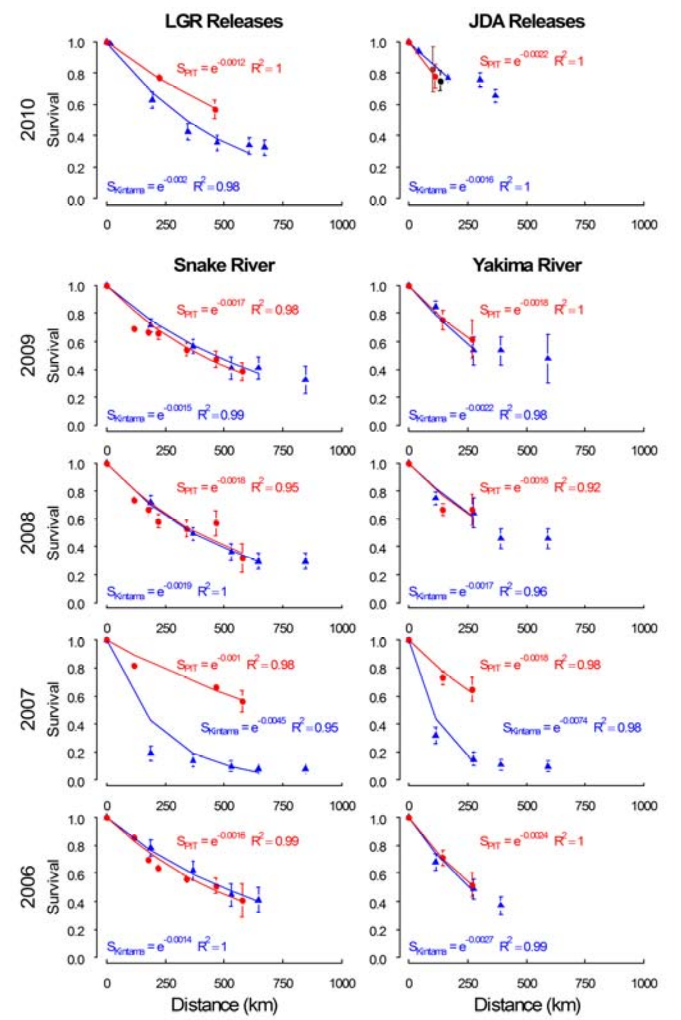


Fig. C-1. Survival of Snake and Columbia In-River yearling Chinook smolts tagged with PIT-tags (red circles) and acoustic-tags (blue triangles). The solid red line shows survival rate per unit distance for PIT-tagged smolts. Each comparison was between acoustic-tagged and PIT-tagged smolts from the same or similar population(s) and was restricted to areas both groups migrated in-common. PIT-tag-based survival estimates are from Steve Smith (NOAA) 2006-2009; David Lind (Yakima Fisheries) 2006-2009, and (Faulkner et al., 2010).

the bypass collection systems before being provided to Kintama for repeat anesthesia and surgical implantation, some reduction in survival relative to PIT tags is again evident, suggesting handling stress contributed to reducing survival after release. These results are consistent with previous findings on handling-related stress for BC smolts (Welch et al., 2004), and indicate that when smolt handling can be minimized, survival estimates are accurate (unbiased).

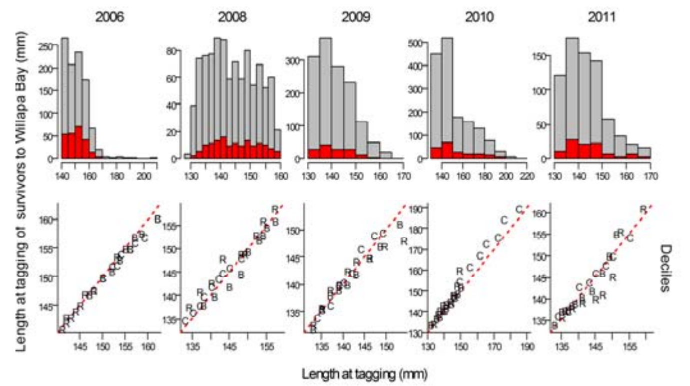


Fig. C-2. Evaluation of possible size-dependent effects of downstream and early marine survival. Plots show annual comparisons of lengths of tagged smolts at release and of the survivors reaching Willapa Bay. All lengths are at time of tagging. (Top) Frequency distribution of fork length for released animals (gray) and survivors (red), all groups combined. (Bottom) Quantile-quantile (qq) plots of the deciles of the empirical length distributions of released smolts and the survivors. 1:1 lines are indicated. R=Snake IR; C=Columbia IR; B=Snake Transported.

***2.** Size-dependent effects of acoustic tagging*

The second biological consideration is whether smolts of different sizes survive at different rates, because larger smolts may either be better able to avoid predators or because the implanted tag is a smaller burden. Figure C-2 compares the size at release of tagged smolts and the size at release of the smolts surviving to reach the Willapa Bay sub-array ca. one month later. No distortion is seen in the mean, variance, or higher order moments of the two size distributions, as shown by the QQ plots (Porter et al., 2011), so tagging did not distort survival characteristics, at least for the size range of smolts tagged (FL≥14 cm in 2006; FL≥13 cm in 2008-11).

***3.** Cross-shelf distribution of tagged smolts*

If smolts permanently emigrate off-shelf after entering the ocean until adult return then survival estimates using a shelf-based array will be biased low, because progressive disappearance of smolts as they migrate north will reflect both off-shelf emigration and along-shelf mortality. On the other hand, if off-shelf emigration is only temporary and smolts simply move north in a migration extending further offshore than the sub-arrays, survival estimates will be unaffected because the degradation of the sub-array detection efficiency will be identified at the subsequent sub-array smolts encounter and survival estimates will be adjusted upwards to reflect this degradation when analysis is done within a CJS framework. (This statement assumes that the smolt's off-shelf movements are random and that they migrate back far enough inshore to be detected by subsequent sub-arrays; smolts that migrate on-shelf but consistently offshore of all array elements will be classed as permanent emigrants).

To date, our results (Figure C-3) indicate that off Willapa Bay the smolt distribution extends farther offshore than our array extends (≤200m in 2006, ≤280 m bottom depths in 2008-10; ≤500m in 2011) indicating a more extensive offshore distribution in this region of the shelf than either the NOAA or CDFO surveys have documented. However, both the NOAA and CDFO trawl surveys and the acoustic tagged smolt distribution at Lippy Point (NWVI; Figure C-3) indicate that north of

Willapa Bay the distribution is clearly shelf-bound. Additional analysis using NOAA catches of Chinook smolts off SE Alaska indicates that the Chinook distribution also remains strongly shelf-bound here as well (Porter et al., 2011). As a result, it seems likely that smolts may move farther offshore in the Columbia River plume before turning north after exiting the river; the location of the Willapa Bay sub-array just 40 km to the north of the Columbia River mouth and at the head of a significant submarine canyon also means that the shelf extends farther offshore both north and south of the sub-array (See Porter et al., 2011 for further discussion). An additional piece of evidence, (not available when the Porter et al., 2011 was prepared) is that in 2011 the extended Willapa Bay sub-array had a ca. 75% detection efficiency based on the proportion of smolts detected at Lippy Point; this estimate of detection efficiency for V7-tagged smolts is almost identical to estimates made for BC-tagged smolts exiting over the northern Strait of Georgia where the migration path is bounded on both sides by land. In summary, the available evidence indicates that Chinook smolts remain shelf-bound and that the numerical decrease in smolt numbers as the migration progresses reflect mortality processes and not off-shelf emigration. This conclusion is, however, important to continue to evaluate because one of the key findings from the telemetry array work is that mortality rates are closely similar in the hydrosystem and the coastal ocean.

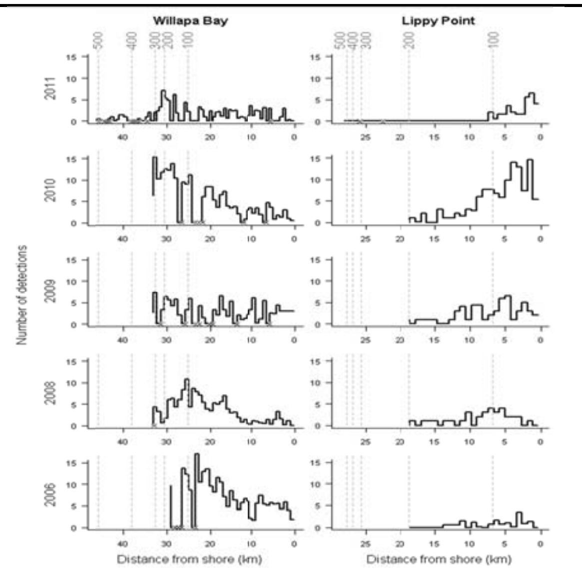


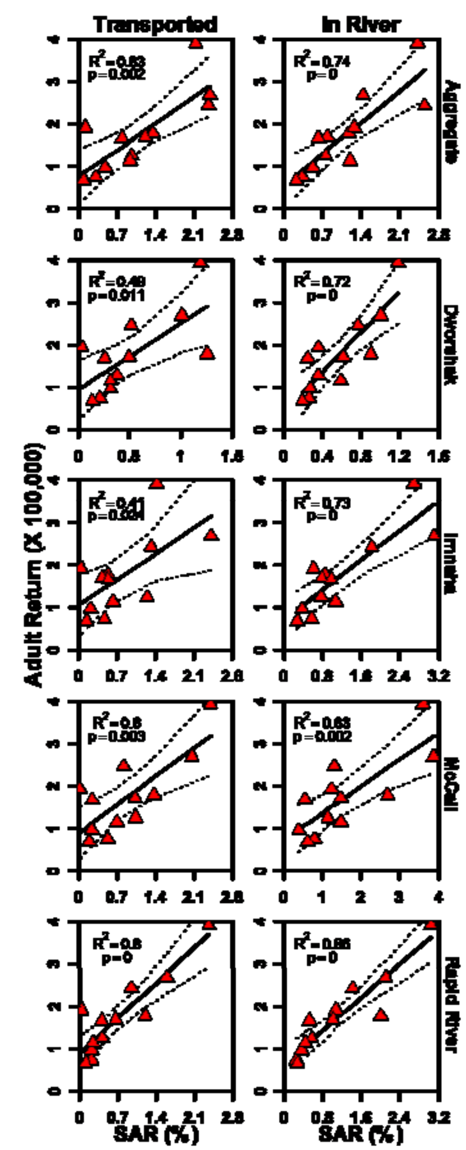
Fig. C-3. Distribution of acoustic-tagged Columbia River smolts on the Willapa Bay and Lippy Point sub-arrays (dashed lines show depths); land is to the right. Both sub-arrays were extended further offshore with additional receivers in 2008 (Willapa Bay only) and 2011 (all marine sub-arrays). When a smolt was detected on more than one receiver per sub-array, it was allocated equally across all receivers. An X indicates no date (lost or displaced receiver); dashed vertical lines indicate depth (m).

Appendix D. Smolt-to-Adult Return Indices

To examine the response of Columbia River salmon to changes in ocean conditions, it is necessary to use an appropriate response variable for Columbia River salmon. The marine survival of yearling Chinook salmon derived by Kintama using acoustic tags is likely the most promising response variable that could be integrated with the ocean conditions measured by the NOAA and DFO studies and used to evaluate the effects of ocean conditions on Columbia River salmon. However, the Kintama time series is currently too short to derive any meaningful relationships between survival and ocean conditions. An alternative would be to use smolt-to-adult returns (SAR) as a response variable. However, they are available for a limited number of stocks. Furthermore, to get a representative sample of each of these stocks in the marine environment, sampling effort would need to be increased considerably and the DNA baselines currently used by NOAA and DFO would need to be extended to include all the stocks of salmon within the Columbia River basin. Both of these strategies would incur significant costs to the ocean project.

As a result, the NOAA and DFO studies have attempted to use holistic response variables for Columbia River salmon in their ocean projects to reflect the common response of the majority of the Columbia River salmon stocks. Two indices of Columbia River salmon production are currently used by these ocean projects: 1) adult counts to Bonneville dam, and 2) a Bonneville-Bonneville survival index.

Adult counts at Bonneville dam are lagged by 1-3 years to reflect the time it takes for a smolt[1] to become adult. Because the Columbia River salmon fishery has been severely curtailed during the last 10-20 years to allow the recovery of ESA listed stocks, adult counts are expected to be a reasonable indicator of salmon production in the Columbia River during

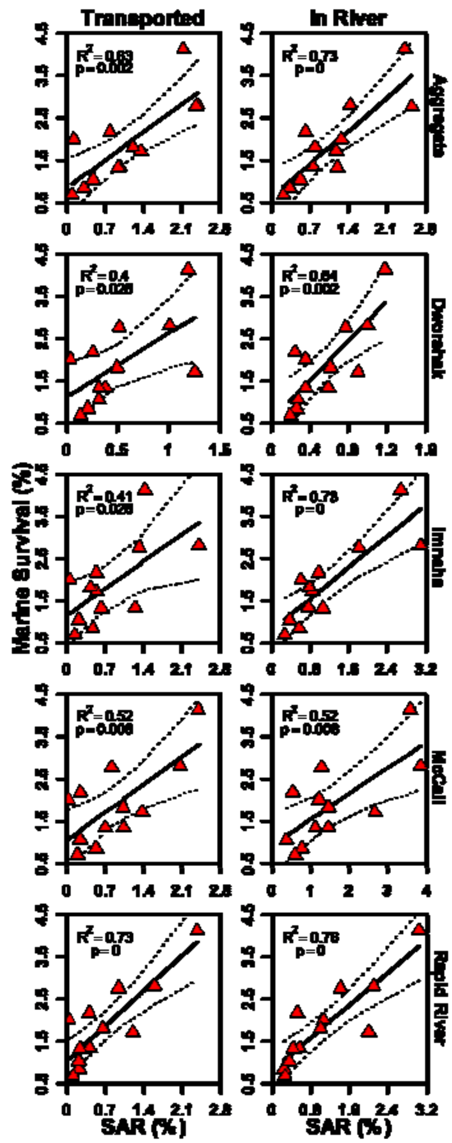


D-1. Relationship between the adult count of spring Chinook salmon at the Bonneville dam and smolt-to-adult ratio (SAR) of Snake River spring Chinook salmon for transported fish (left column) and in-river migrants (right column). Adult counts were lagged by two years, as the majority of spring Chinook salmon mature after spending two years in the ocean. Adult counts and SAR were obtained from the Fish Passage Center website (**http://www.fpc.org**). Data were limited to the 1998-2009 ocean entry years to match the time period of the NOAA and DFO ocean projects.

[1] Lag differs among species: 1 year for coho, 2 years for sockeye and spring Chinook, and 2-3 years for fall Chinook

the time frame of the NOAA and DFO studies (1998 to present). To evaluate the performance of this indicator, we correlated the count of spring Chinook salmon at the Bonneville Dam with Snake River spring Chinook salmon SAR for both transported fish and in river migrants. Adult return correlated positively and significantly with all the SAR values (Figure D-1), suggesting that adult count at Bonneville dam is a reasonable holistic indicator for the production of Columbia River salmon.

A Bonneville-Bonneville survival index has also been derived by dividing adult counts to Bonneville dam by the number of smolts released by the hatcheries above the Bonneville dam. This index attempts to correct adult counts for variable smolt outputs in the Columbia River. As the 75-95% of the juvenile Columbia River salmon caught in the research surveys conducted by NOAA and DFO are of hatchery origin (Teel et al., 2003, Abdul-Aziz et al., 2011, Litz et al., 2011, Trudel et al., 2011), the number of smolts produced by hatcheries is expected to be a reasonable surrogate for the number of smolts produced within the Columbia River. To evaluate the performance of this indicator, we correlated Bonneville-Bonneville survival index of spring Chinook salmon with Snake River spring Chinook salmon SAR for both transported fish and in river migrants. The Bonneville-Bonneville survival index correlated positively and significantly with all the SAR values (Figure D-2), suggesting that the Bonneville-Bonneville survival index is a reasonable holistic indicator for the production of Columbia River salmon.



D-2. Relationship between the Bonneville-Bonneville survival index (referred to as Marine Survival) for spring Chinook salmon and smolt-to-adult ratio (SAR) of Snake River spring Chinook salmon for transported fish (left column) and in-river migrants (right column). Adult counts were lagged by two years, as the majority of spring Chinook salmon mature after spending two years in the ocean. Adult counts and SAR were obtained from the Fish Passage Center website (**http://www.fpc.org**). Data were limited to the 1998-2009 ocean entry years to match the time period of the NOAA and DFO ocean projects.

Appendix E. Basin-Wide Hatchery Chinook Releases, 1998 - 2009

Number of Chinook salmon smolts released into the Columbia River Basin above the Bonneville Dam between 1998 and 2009. Release data compiled from the Regional Mark Processing Center database (www.rmpc.org). Adult return data obtained from the Columbia River DART website (www.cbr.washington.edu/dart/adult_annual.html).

Release Year	Smolt Releases Above Bonneville Dam	Return Year	Adult Returns to Bonneville Dam	Estimated Marine Survival (%)
		Spring Chinook salmon		
1998	10,422,024	2000	178,336	1.71
1999	9,494,912	2001	391,818	4.13
2000	9,584,032	2002	269,428	2.81
2001	9,607,395	2003	195,671	2.04
2002	9,402,576	2004	170,291	1.81
2003	8,763,791	2005	74,052	0.84
2004	9,230,612	2006	96,457	1.04
2005	9,812,051	2007	66,644	0.68
2006	9,393,292	2008	125,582	1.34
2007	8,620,951	2009	114,548	1.33
2008	8,821,245	2010	244,418	2.77
2009	7,698,007	2011	167,146	2.17
		Summer Chinook salmon		
1998	3,652,469	2000	30,616	0.84
1999	3,110,214	2001	76,156	2.45
2000	2,703,997	2002	127,436	4.71
2001	4,300,349	2003	114,808	2.67
2002	3,550,929	2004	92,143	2.59
2003	2,980,069	2005	79,208	2.66
2004	3,501,855	2006	97,519	2.78
2005	3,469,099	2007	47,882	1.38
2006	3,914,208	2008	78,271	2.00
2007	2,834,424	2009	81,936	2.89
2008	3,764,044	2010	97,604	2.59
2009	3,267,245	2011	108,279	3.31
		Fall Chinook salmon**		
1998	37,995,720	2000	192,815	0.51
1999	32,893,073	2001	400,410	1.22
2000	39,738,186	2002	474,648	1.19
2001	32,232,995	2003	610,336	1.89
2002	37,352,702	2004	583,493	1.56
2003	34,767,456***	2005	417,142	1.20
2004	33,877,257	2006	299,637	0.88
2005	33,381,571	2007	161,550	0.48
2006	31,947,590	2008	315,080	0.99
2007	35,620,573	2009	283,787	0.80
2008	29,826,072	2010	467,732	1.57
2009	31,613,299	2011	401,704*	1.27*

* Incomplete record ** Includes Fall and Late Fall runs. *** Includes Hybrid runs.

Appendix F. Comparison with other telemetry systems

In the early 2000s, only HTI, LOTEK, and VEMCO acoustic components were available to potentially build large-scale telemetry systems. VEMCO's technology was found to be clearly superior to the other two systems in terms of low per-unit cost, long deployment capability (low current consumption, limiting battery changes), and long tag detection range (& lifespan), and was thus adopted for the transmit & receive components of the POST/COAST array. The receivers were also lower cost than any of the alternatives (and still are), permitting a more extensive telemetry infrastructure to be built for a given cost. The initial trade-off was that the original V9 acoustic tag was larger and could only be implanted into larger smolts (≥14 cm). In 2006, however, the smaller V7 tag (which operates on the same frequency as the V9 tag, 69 kHz) became commercially available. This tag can be implanted into smolts ≥12.5 cm, and was implemented by Kintama beginning in 2008.

Since then, JSATS technology has developed, and produced impressively small tags now nearly rivaling PIT tags in size, but with the engineering trade-off of moving to an even higher frequency (417 KHz). McMichael et al (2010) provide a readable comparison of different manufacturer's equipment from a JSATS perspective, and emphasize the importance of using a smaller tag (the comparison uses VEMCO V9 tags used in 2006, not the V7 used since 2008). However, acoustic attenuation decreases higher frequency signals even more rapidly in seawater than freshwater, therefore tag detection ranges are substantially lower than for the POST/COAST design. The shorter ranges inherent to JSATS is partially compensated for by using more expensive high power receivers to boost detection range, but this also reduces operational lifespan of the receivers to 30-60 days, raising operational costs for maintaining receivers year-round (a goal of POST/COAST). Therefore the use of JSATS for estimating survival in the coastal ocean would likely be logistically and economically infeasible for Columbia River smolts.

Thus, although in principle telemetry arrays can be constructed from any tag and receiver combination, the deployment of the POST array using VEMCO equipment provided relatively high detection rates of migrating smolts implanted with V7 and V9 transmitters in both freshwater and coastal ocean waters using a relatively modest number of receivers with a low false positive detection rate[2] (Table 5). As Table 5 also shows, the use of JSATS receivers in the ocean to construct a telemetry array would likely require both an unfeasibly large number of receivers and result in high operational costs.

---

[2] *McMichael et al. (2010) report detection ranges for different vendor's equipment, but the technical definition of range has an arbitrary component because a tag which is distant from a receiver may still be logged but at the cost of recording false detections as well. Thus range may be high in theory, but lower in practice because elevating the receiver's gain also amplifies the acoustic noise. In addition, the JSATS signal transmission scheme used by JSATS, which allows transmission of the ID code in a shorter period of time to reduce tag transmission collisions (about 1/5th of VEMCO's, for example), also inherently has a higher false positive recording rate than coding schemes used by the other acoustic tag manufacturers Ehrenberg & Steig (2009). High false positive rates cause complications for telemetry studies, because algorithms used for data exclusion will falsely pass some detections. The POST/COAST array has false positive rates typically <0.25% of all logged detections (see Kintama's annual reports to BPA).*

Appendix G. Ocean conditions off the west coast of Vancouver Island and returns of Columbia River salmon to the Bonneville Dam

To assess the effects of ocean conditions on the production of Columbia River salmon, DFO started to explore the relationship between the return of Columbia River salmon and the ocean conditions observed off the west coast of Vancouver Island by DFO during the 2007 fiscal year and have been updated annually since then (Trudel et al. 2011a). Simple linear regression models showed that the return of Columbia River summer and fall Chinook salmon and coho salmon to Bonneville Dam were related to zooplankton community composition: high returns occurred in years when large and lipid-rich northern copepods were abundant and small and lipid-poor copepods were sparse in coastal waters when Columbia River smolts entered the ocean (Figure. G-1).

These analyses suggest that ocean conditions off the west coast of Vancouver Island could be used to predict adult return 1-2 years following ocean entry of Columbia River salmon smolts. However, given the limited predictive power of these simple regression models, the best that can probably be achieved at this time is a qualitative prediction, such as low, medium, and high, or below average, average, and above average. As a result, DFO adopted the "stoplight" system developed by NOAA to characterize the ocean conditions measured as part of the *Canada-USA Salmon Shelf Survival Study* (Table G-1). With the exception of 2004, the ranking of ocean conditions examined by NOAA and DFO are very similar. Preliminary analyses indicate that the mean rank of these conditions out performed single metrics for Columbia River spring Chinook salmon, but not for summer and fall Chinook or coho salmon. A more comprehensive analysis of these data will be completed in FY12.

Table G-1. Stoplight chart illustrating annual variations in the indices of ocean conditions used in to salmon forecasting efforts by the *Canada-USA Salmon Shelf Survival Study*. Red indicates poor ocean conditions; yellow, average; green, good. Note that ocean conditions in 2008 were mostly "good" whereas the years 1998 and 2005 were mostly poor.

RANK SCORES													
Environmental Variables	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***
Online data													
Mean SST - WCVI (Amphitrite) - Mar-Jun	12	1	6	2	3	9	11	13	8	4	5	7	10
Survey data - Zooplankton													
C:N Zooplankton Ratio (WCVI)	12	5	11	6	4	7	2	13	9	8	1	10	3
Northern (Boreal) Copepods	13	3	6	8	4	9	10	12	11	5	1	2	7
Southern Copepods	13	6	7	5	4	12	9	11	10	3	2	1	8
Survey data - Fish													
Coho Growth	12	1	3	7	2	8	4	13	9	10	6	11	5
WCVI CR CK CPUE - Jun-Jul	4	2	7	10	5	9	11	12	6	13	1	8	3
WCVI sockeye CPUE - Jun-Jul	8	5	4	11	13	2	3	12	9	6	1	7	10
WCVI coho CPUE - Jun-Jul	9	4	2	6	7	12	13	11	3	8	5	1	10
Mean Rank	10.1	3.7	5.7	7.6	5.6	8.4	7.4	12.0	8.1	7.6	2.4	5.7	6.8
Rank of Mean Ranks	12	2	4	8	3	11	7	13	10	8	1	4	6

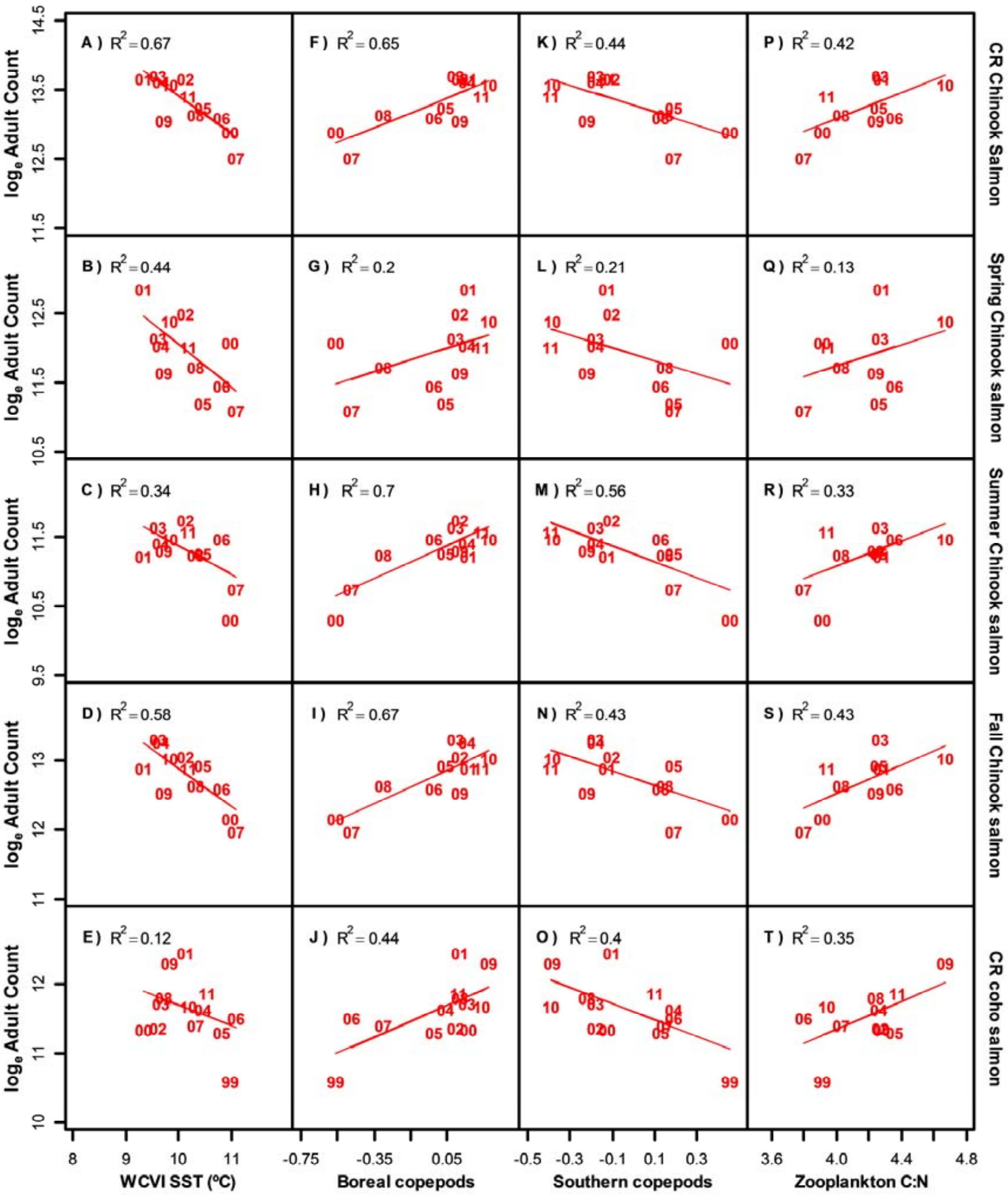


Fig. G-1. Number of adult Chinook and coho salmon returning to the Bonneville Dam in relation to environmental variables observed during their smolt year of the west coast of Vancouver Island (WCVI) in 1998-2011. Environmental variables include: WCVI sea surface temperature (SST in ºC), Boreal and southern copepod anomalies, and WCVI zooplankton carbon to nitrogen (C/N) ratio in summer. Points are labeled according to their respective return year. Adult counts were offset by two years for Chinook salmon (Columbia River Chinook spend 2-3 years at sea before maturing), and by one year for coho salmon. Adult return data obtained from www.fpc.org website, January 2011. (Updated from Trudel et al., 2011)

Appendix H. NOAA's response to ISRP comments on the *Ocean Survival of Salmonids Study* (Project 199801400) submitted to the Northwest Power and Conservation Council on November 15, 2010

199801400 - Ocean Survival of Salmonids

Proponents: National Oceanic and Atmospheric Administration (NOAA)

Short description: A study to evaluate the role of changing ocean conditions on growth and survival of juvenile salmon from the Columbia River Basin as they enter the Columbia River plume and PNW coastal habitats. Adult returns vary dramatically (over 10 fold) as a result of changing (good or bad) ocean conditions that juveniles experience. Evaluating the benefit of restoration efforts in the Columbia River to restore endangered salmon populations needs to consider ocean conditions as a contributing factor to recovery.

ISRP recommendation: Meets Scientific Review Criteria (Qualified)

Comment:

Qualification: A synthesis of this project, as proposed by the proponents, should be completed and reviewed by the ISRP in 2011.

This is a productive and worthwhile project that has made significant contributions to understanding relationships between Chinook and coho salmon survival and ocean and plume conditions. The ISRP commends the proposed new research on abundance, distribution, timing and migration of smolts through the estuary. Another important new feature of the project is the proposed analysis of factors affecting sockeye, chum, and steelhead. However, the proposal was not clear on the extent to which data on these species were collected in previous years but not analyzed or reported. Rapid gains in knowledge could be accomplished if previous data on these species were collected, although the ISRP recognizes that these species may not be abundant in coastal research trawl samples. An important outcome of the project has been a qualitative method for forecasting salmon runs that appears to be an improvement over past methods. It is refreshing to see a project that directly addresses management concerns. The ISRP strongly concurs with the proponents that a major synthesis of this work should be completed in 2011.

Response to the section of this comment regarding sockeye, chum, and steelhead: We have been recording and collecting data on steelhead, chum, and sockeye from almost every year we have been doing field sampling. The catches of these salmonids are reported in our cruise reports. We agree that collating our findings would be most useful for these other salmon important to the Columbia River basin. We are presently summarizing data on marine distributions, size, clipping rates, and diets. We also have some limited data on parasite infestation and growth and ocean residence from otolith increment analysis. We have been collecting other biological material from these fish as well but until this round of funding have not

asked for the funds necessary for processing. Additional future analysis will examine genetic composition (once baselines are available), migration rates from CWT recoveries, and detailed comparison with steelhead caught in purse seines in the estuaries. A poster based on the preliminary analysis of the steelhead data was presented at the Salmon Ocean Ecology meeting in Santa Cruz in March 2010. This can be provided if it would be useful. We also have substantial data on pink and chum salmon ocean distributions which was presented by L. Weitkamp at the 2005 and 2008 Pink and Chum Workshops and published in their proceedings (Weitkamp & Emmett, 2006, Weitkamp & Bentley, 2009). These analyses indicate that most pink and chum salmon caught by the Plume Study do not originate from the Columbia River, but instead have immigrated from the Salish Sea (pink salmon) or likely originate from large populations in Willapa Bay and Grays Harbor (chum salmon).

As stated above, we have examined some diets (summarized in Brodeur et al., 2007 for the early years) and hope to continue this in the future, along with examining other aspects of their biology. Sockeye have been rare in most of our surveys but have been increasing since 2007 and we have been collecting data and samples from these fish. A preliminary analysis of 95 sockeye stomachs from 2007 show that they are feeding mainly on fish eggs, which may be important in regulating recruitment of some marine fish should sockeye numbers continue to increase.

Some important issues to be considered during the contracting process and in the synthesis are listed below:

1. Strategic plan. The ISRP recommends the use of synthesis results to develop a strategic plan that prioritizes project hypotheses and management objectives. The current approach is exploratory and observational, including numerous hypotheses and investigations of trails of evidence dealing with limiting factors ranging from lipids to parasites to bird predation. When arguing for an observational rather than experimental approach, the proponents state that each year/sampling season can be considered an "independent observation." It seems unlikely that the quantitative values of physical and biological variables are independent between years, that is, there is no between-year autocorrelation. The proponents need to justify this assertion or adjust for it in their statistical analyses, as described in the synthesis objective. The strategic plan should explain in greater detail how interaction issues arising from studying four elements (bottom-up, top-down, food-web, and plume structure) at the same time will be addressed.

Response: We agree that with 12 years of data, a more strategic plan could now be made from a synthesis of current observations and findings to help focus the effort on the hypotheses that are testable. We are planning to develop a strategic plan in 2011 to incorporate in the 2012 SOW the findings from the analysis. Current findings support the notion that bottom up control greatly influences the success of juvenile salmon and their eventual return. We suspect that testing this hypothesis more directly will reveal how ocean conditions influence growth capacity and habitat structure in the California Current ecosystem that enable juvenile salmon to

grow and survive and how the plume interacts with the CC to facilitate this outcome. The 2012 SOW should reflect the emphasis on confirming and testing bottom up control as the primary ecological factor through enhanced ocean conditions that foster improved adult returns back to the Columbia River basin.

2. Achievable objectives. Consider whether stated objectives are achievable. For example, can the objective (discussed in proposal's introduction) to determine decadal-scale cycles in ocean productivity be achieved? If so, when will the periodic wave length in cycles be known? If changes are periodic events without a fixed wave length or chaotic events, then how will this objective be achieved?

Response: We agree that a more focused synthesis that can identify what objectives are likely testable. See our response to item #1 above. It turns out that decadal cycles may have been anomalous as we have observed cycles of 3 to 4 years of differing ocean productivity over the past 12 years providing the natural experiments for evaluation. The outcome, as has been reported, is that the ocean conditions can change very quickly to reflect the influence of the large scale forcing on the productivity of the local ocean environment that affect the growth and survival of juvenile salmon leaving the Columbia River basin during their first spring and summer in the ocean landscape.

3. Fishing operation effects. Consider important sources of variation in research trawl and other fishing operations and fishing efficiency with respect to what is known about diel, horizontal, vertical, and seasonal distribution of juvenile salmon that might affect time-series observational data on species composition, abundance, distribution, growth, etc., of juvenile salmon in the survey area.

Response: This is a good comment and one that we have made some progress in but perhaps need to focus a bit more on. We did an extensive study of diel vertical distribution using two research vessels that has been published (Emmett et al., 2004). Our cruises have consistently sampled May, June and September of each year which is as much as our funding levels permit but we have been able to use ships of opportunity to add broad-scale cruises in August and November. For this coming February, we have been planning to collaborate with DFO and use their Research Vessel W.E. Ricker to sample off of Washington and Oregon for up to two weeks. This will be the first attempt ever to examine overwintering juveniles in terms of their habitat, growth and ecology. We acknowledge that the distribution of juvenile salmon can be quite patchy in the ocean and we have been examining this through retrospective analysis of our catch data (Peterson et al., 2010) and special cruises. In June of 2010, we had some additional shiptime on the NOAA ship Miller Freeman where we were able to occupy a fine-scale grid of 16 stations about 1 km apart to examine finer patterns of salmon patchiness in relation to their prey organisms. The salmon from these surveys have been processed and analysis of the data is proceeding.

4. Cruise planning and coordination. The ISRP recommends that the proponents provide annual cruise plans to other related projects. The plans should include sufficient detail on how cruises in the plume, estuary, and ocean will be organized and coordinated with these other projects. For example, the current proposal lacks details on how far upstream the estuary sampling will occur. It seems the sampling will occur only in the lower reaches, and this may not be sufficient to tie in with other work, e.g., POST tagging at Sand Island, LCREP work in the marshes, etc.

Response: We have an established 'cruise protocol' that we can make available to any interested group. Cruises have been ongoing for 12 years and cruise planning currently is focused on process studies rather than on the monitoring which is the same year to year. These items are added to the cruise protocols as appropriate. The cruise SOPs can be ascertained from the Cruise Reports which are accessible from BPA.

With respect to the estuary comment, there appears to be some confusion as to its role in this project as we infer from the ISPR comments. The estuary sampling is directed at comparing the type and condition of salmonids leaving the CR estuary to the juveniles we observe in the ocean; it is not directed at identifying relationships to juveniles in other parts of the estuary. Although the findings from this study can be used by other investigators who are working on estuarine habitat issues and the role of the estuary in the salmon landscape to their success, it is not our intent to make these evaluations. We can easily make our findings available to any of the investigators working directly on estuarine studies. We are not planning on changing the estuary purse seine sampling stations or extend the seining further upstream as suggested in the ISPR comments. By sampling at our two current stations, we know [based on genetics (Chinook salmon), CWTs (all species), and PIT tags (all species)] we are catching juvenile salmon from all parts of the Columbia River basin: lower, middle and upper Columbia, and Snake and Willamette tributaries. Because being able to catch this diversity of salmon is one of our primary objectives to compare the stock composition and condition at the location in the estuary just prior to ocean entry to what we actually observe in the ocean, moving our stations further upstream isn't warranted at this time.

5. Monitoring ocean conditions. Consider greater use of ocean monitoring data collected by other (non-BPA funded) projects for developing indices of ocean conditions, such as hydroacoustics, remote sensing, oceanographic buoys and floats, and robotic vehicles. The ISRP recommends improved coordination and collaboration with other projects and programs collecting these data.

Response: We agree and have been evaluating our findings on this project in relation to other indices from the ocean monitoring data collected by others. In reviewing many of the indices on our ocean indicators hosted on the NWFSC website, a number of the indices included in the ocean indicators page include these other ocean monitoring data which compliments data accumulated from this project.

6. Hatchery vs. wild salmon. Consider a detailed comparison of differences in condition, growth, and survival between hatchery and wild salmon of each species. The Endangered Species Act protects many salmon and steelhead ESUs in the Columbia Basin, yet this study does not address hatchery versus wild salmon issues. Hatchery salmon are released at a large size and have high lipid content, therefore hatchery fish may respond differently to environmental factors compared with wild salmon. In earlier years, many hatchery salmon were not marked and could not be readily identified. However, in recent years, including 2010, nearly all hatchery Chinook and coho salmon and steelhead, with the exception of some tribal and conservation hatchery fish, will receive an adipose fin clip. Relatively small numbers of hatchery Chinook raised in conservation hatcheries will not be marked. The ISRP recommends a detailed comparison of hatchery versus wild salmon of each species.

Response: We agree with the comment and already have made progress in this regard to comparing hatchery to wild fish; we just did not highlight this sufficiently in the proposal. For example, we published a paper in 2008 that highlighted the differences in infection levels of the parasite *Nanophyetus salmincola*, with respect to parasite-associated mortality, in marked vs. unmarked juvenile coho salmon (Jacobson et al., 2008). In addition, we have made a detailed comparison of differences in marine spatial overlap, physical characteristics, diet overlap and growth (2006-2009 only) between hatchery and unmarked (presumed wild) spring Chinook salmon from the Columbia River Basin (1999-2009). We have presented the findings at the State of the Salmon Wild and Hatchery Ecological Interactions Symposium (see presentation by Daly et al. at conference web site http://www.stateofthesalmon.org/conference2010/presentations.html) and have submitted a manuscript to Environmental Biology of Fishes which is presently in review. A summary of some important finding are as follows: 1) spatial overlap was high between unmarked and hatchery fish, although catches of unmarked fish were minor compared to those of marked hatchery salmon, 2) 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, 3) hatchery salmon were characteristically longer and had a greater condition factor by June. Small-scale (by station) diet composition showed significant overlap (62.8 ±13.5%) between unmarked and hatchery fish, 4) feeding intensity and growth were not significantly different between unmarked and hatchery fish, and 5) there were synchronous interannual fluctuations in catch, length, body condition, feeding intensity, and growth for unmarked and hatchery fish, indicating that both groups were responding similarly to ocean conditions. With high spatial and trophic overlap, potential competition for food resources during years of low prey abundance may result in density-dependent growth suppression for both natural and hatchery-produced salmon. We also explored analyzing coho salmon but the tagging rates for the years we looked at were too low (~ 60%) to allow a reasonable criteria to distinguish between hatchery and wild fish caught in the ocean. We hope to follow up this study with other species and stock groups in the future, if clipping rates increase or if we have other methods to reliably distinguish hatchery and wild fish

in our catches. At present (i.e., during years 2007-2010), average clip rates for Columbia River hatchery salmon range from 67.8% (coho) to 91.9% (yearling Chinook), with subyearling Chinook (75.8%) and steelhead (85.4%) at intermediate levels. Although these clip rates are much higher than they have been, it still results in the release of almost 30 million unclipped hatchery fish annually: 16.7 million subyearling Chinook, 7.2 million coho, 2.6 million yearling Chinook, and 2.2 million steelhead.

7. Genetic stock identification. The ISRP recommends standardization of genetic stock identification methods used by BPA-funded estuary and ocean survival projects so that results are directly comparable among projects. Different projects may currently be using different methods, but this was not clearly explained in the proposal.

Response: We agree on standardization. The microsatellite evaluation of genetic origins that is used at the NWFSC is comparable to the approach used by DFO and the methods have been cross validated. We are not sure what method is being used, if any, by David Welch's project. With respect to projects in the estuary, four of the projects that we are aware of use the NWFSC genetics lab for stock identification, thus on balance the majority of projects in the ocean and estuary are using genetic analyses that have been cross validated and have been used to compare across projects already.

8. Otolith microchemistry. The ISRP considers the value of otolith microchemistry research uncertain. The proponents need to consider specifically how this method can provide new information without extensive baseline data collection. The validity of the proposed use of genetic methods to identify stock origin of individual fish sampled for otoliths needs to be demonstrated. Use of daily otolith increments to estimate estuary and plume residence times is also uncertain. For example, project results to date have estimated that yearling Chinook salmon spend several months in the estuary/plume, which is contrary to evidence from trawl survey and tagging research. Hatchery fish are known to have high Sr/Ca ratios because of their feed. Is this another factor that will confound the proposed microchemistry work? Also the Sr/Ca transition cannot distinguish between estuary and plume habitats, an issue that was not clearly described in the proposal. A useful reference is: Elsdon, T.S. and 9 others. 2008. Otolith chemistry to describe movements and life-history parameters of fishes: hypotheses, assumptions, limitations and inferences. Oceanography and Marine Biology: An Annual Review, 2008, 46, 297-330.

Response: Space for project description in the proposal was somewhat limited so perhaps some of the lack of clarity is related to the level of detail presented. We reply to each point raised below:

1) ***'Otolith microchemistry. The ISRP considers the value of otolith microchemistry research uncertain. The proponents need to consider***

specifically how this method can provide new information without extensive baseline data collection.'

a. There are no specifics associated with this statement; therefore it is not clear what baseline information the ISRP deems necessary. However, the potential gain of combining genetic stock identification (GSI) with otolith structural and chemical analysis is that stock-specific information on migration patterns will be generated at temporal scales unattainable using fish scale analyses (daily vs. 7-10 d resolution for otoliths vs. scales, respectively). Furthermore, this information can be generated for all individuals collected – not solely fish with CWT or PIT tags, which can generate biased estimates due to the dominance of hatchery fish. We have gathered fairly extensive baseline information, including: (1) the completion of otolith chemical and structural analysis on >200 Columbia River juvenile Chinook salmon including pre- and post-release hatchery, CWT- and PIT-tagged, and adipose fin-clipped individuals as well as those with no external or internal marks; (2) the completion of a laboratory validation study quantifying the effects of temperature (7, 9, 12°C), salinity (0 to 15), and water Ba:Ca levels on the otolith incorporation of Sr:Ca and Ba:Ca in juvenile Chinook salmon; and (3) collection of water chemistry data from various locations throughout the Columbia River basin. It is worth noting that our laboratory validation study builds upon a previous study confirming positive relationships between water and otolith Sr:Ca in five species, including Chinook salmon (Zimmerman, 2005). The complete presentation of the laboratory analysis of Chinook salmon otolith elemental incorporation is in preparation but the approach is very similar to those presented in Miller (2009) and DiMaria et al. (2010) and some of the results are presented in Miller et al. (2010a). Details of most aspects of the analytical approach can be found in Miller et al. (2010a). It is not clear what additional, extensive baseline collection the ISRP considers essential to complete the basic interpretation of otolith structure and timing of brackish/ocean entrance.

2) ***The validity of the proposed use of genetic methods to identify stock origin of individual fish sampled for otoliths needs to be demonstrated.***

a. Several researchers have formally evaluated the accuracy of individual assignment in Pacific salmonids using highly polymorphic markers (Beacham et al., 2006c, Seeb et al., 2007, Narum et al., 2008, Barnett-Johnson et al., 2010, Miller et al., 2010b). Furthermore, some of these assessments are focused on, or include, the assignment of Chinook salmon using the Genetic Analysis of Pacific Salmonids (GAPs) baseline (Seeb et al., 2007, Miller et al., 2010b). Results of these syntheses were previously summarized by the proponents as follows:

> **'Microsatellite datasets also can provide accurate information on the source of an individual fish. Beacham et al. (2006c) reported 84%**

assignment accuracy using 13 microsatellite loci in a Pacific Rim Chinook salmon analysis. Narum et al. (2008) tested the GAPS microsatellite dataset and found that individuals from 10 Columbia River Basin populations were assigned to the correct source population (tributary or hatchery) with 79% accuracy. Similar tests of the more comprehensive 45 population Columbia River baseline we are using in this study, show that individuals can be assigned to the correct regional genetic stock group with a mean accuracy of 88% (D.Teel, unpublished data).'

Additionally, Dr. Michael Banks, OSU, is completing a power analysis for individual-based assignment applications using GSI. He reports that 'Crude individual-based assignment results with no probability stringency were modest: 89.9% and 84.6% correct for c-Bayes and ONCOR [two software programs/statistical approaches used to assign individuals], respectively, for the known origin non-baseline samples and 87.1% and 77.8% correct for c-Bayes and ONCOR respectively for coded wire tags samples. Applying higher probability stringency, however increased correct assignment results to greater that 90% correct (ONCOR) for both and greater than 95% (C-Bayes) for both known sample data sets and assignment methods'.

There is also an extensive collection of Chinook salmon of known origin (based on CWT and PIT tags) that have been assigned to a stock using GSI. These collections can be more formally analyzed to generate regional estimates of accuracy; quantification of the error in stock assignment can be generated and specific probabilities of assignment included in formal presentations. Additional details regarding these types of error analysis could be incorporated into any standardization procedures developed for collaborating partners using GSI on Columbia River stocks. However, the value of completing stock-specific analyses cannot be understated. Given the extensive life history variation in salmon, stock-specific analyses are much more likely than mixed stock analyses to provide the resolution needed to elucidate migratory or behavioral patterns and identify specific mechanisms of mortality.

3) ***Use of daily otolith increments to estimate estuary and plume residence times is also uncertain.***

a. It appears that we did not adequately present the details of our methodological approach and would like to clarify an important point - we do not claim to be able to estimate 'estuary and plume residence times'. We are identifying 'brackish/ocean' residence times. Although we qualified our determination as 'brackish/ocean' residence within the proposal, we did not provide details regarding why this approach cannot be used to differentiate among salinities greater than approximately 8 PSU. This issue has been in the literature for some time (e.g., Kraus & Secor, 2004) and is further

detailed for Chinook salmon in Zimmerman et al. (2005) and Miller et al. (2010a). However, otolith structural and chemical analysis has been used to identify individual transitions from fresh to marine waters in a variety of diadromous fishes for >15 yr (Limburg, 1995, Secor et al., 1995). Due to the widespread application of these methodologies, there was a recent review manuscript (Elsdon et al., 2008, as noted by the ISRP) that summarized conceptual approaches and considerations for reconstructing migratory history of diadromous fishes using otolith structure and chemistry; an approach that, in many respects, has become a standard methodology. Furthermore, this approach has been applied previously in field studies of Chinook salmon (Miller et al., 2010a, Volk et al., 2010) and specifically for populations within the Columbia River basin (Campbell, 2010).

Two of the primary considerations for reconstructing migratory history in juvenile Columbia River Chinook salmon are: (1) determination that relevant water masses display distinct water chemistry (i.e., fresh vs. brackish/ocean waters); and (2) some knowledge of the lag time between individual movement to chemically distinct habitat and detectable change in otolith composition. We have compiled existing data and collected additional water chemistry from throughout the Columbia River basin to validate the primary assumption that freshwater Sr:Ca levels are significantly different (lower) than marine waters (Fig. 1 and Table 1). In regard to the lag time, we have completed a species-specific laboratory validation of the otolith incorporation of Sr:Ca and Ba:Ca in Chinook salmon and determined that the initial change in otolith composition (i.e., increase in Sr:Ca) occurred within 2-3 d after exposure to saline waters (5 PSU). Equilibration, however, required 7-10 d. Therefore, given that we are identifying the initial increase in otolith Sr:Ca (Fig. 2 and 3), there is an approximate lag time of 2-3 d. Furthermore, we adopt a dual marker approach (Sr:Ca and Ba:Ca) to provide further confidence in our determination of the habitat transition from fresh to brackish/salt waters (see Miller et al., 2010a for additional details). Additionally, in the case of hatchery-reared salmonids, the influence of hatchery feed, which is typically dominated by marine protein, should be examined. We have also examined pre- and post-release hatchery fish and evaluated the effects of hatchery rearing, including analysis of the Sr, Ca, and Ba content of five types of hatchery feed, on the otolith Sr:Ca in spring Chinook salmon within the system. There are complex patterns in the otolith chemistry associated with hatchery rearing, likely due to a combination of feed, growth rate, and temperature, but they do not lead to a misinterpretation of brackish/ocean entry (see Fig. 2 vs. 3 for representative examples). Additional details on this point are presented in below (see '5').

4) ***For example, project results to date have estimated that yearling Chinook salmon spend several months in the estuary/plume, which is contrary to evidence from trawl survey and tagging research.***

a. We would like to clarify this important point: we did not use the term 'estuary/plume' to describe our results and apologize for any confusion on this point. We do not think that our data necessarily indicate that individuals reside for 'several months in the estuary/plume'. The proposal states, "When we evaluate residence time of juvenile yearling interior basin spring Chinook that are captured on the Columbia River transect (which is typically centered in the plume), residence time is measured in months rather than a few days. Residency is measured as the number of daily growth rings (days) apparent in otoliths after a strontium signal is evident, a measure of saltwater entry. Average residence time for juvenile spring Chinook on the Columbia River transect is 25 days, ranging from 5 to 60 days whereas residence time for juvenile spring Chinook captured at our more northerly transects (Queets and La Push) is 35 days (range of 5 to 75 days).' Figure 28 in the original proposal, which presumably is the source of the ISRP conclusion, indicates that 2% of the Mid and Upper Columbia River spring Chinook juveniles collected on the Columbia River transect resided in *brackish/ocean waters* for 60 d; it is important to realize that these individuals may have travelled south prior to capture. The mean estimates of brackish/ocean residence times generated for the mid- and upper Columbia River spring Chinook salmon are, in fact, very similar to estimates based on CWT analyses of individuals from the Mid and Upper Columbia region collected along the same Columbia River transect (J. Fisher, unpublished data). Preliminary data indicate a mean ocean residence time of 20 d for individuals from the Mid-Columbia and means of 0 and 30 d for individuals from the Upper Columbia River region (Fig. 4). It is important to remember that many previous estimates are based on CWT individuals, which are not necessarily a representative sample of the entire population. Our mean estimate for the stock group (which combines Mid and Upper Columbia River fish) is 25 d. Our approach samples all individuals, including hatchery and naturally-spawned, and therefore may be more representative of the entire population. This example underscores the need for, and value, of stock-specific analyses to avoid over generalizations of observations based on mixed stock groups.

5) *Hatchery fish are known to have high Sr/Ca ratios because of their feed. Is this another factor that will confound the proposed microchemistry work? Also the Sr/Ca transition cannot distinguish between estuary and plume habitats, an issue that was not clearly described in the proposal.*

a. There are good data on the Sr contribution of hatchery feed (Kennedy et al., 2002, Weber, 2002, Miller et al., 2010b); a mean of 32% of the otolith Sr in Chinook salmon during their freshwater residence represents a food contribution. We have also quantified the maternal influence on otolith Sr:Ca patterns in hatchery fish (Miller & Kent, 2009) and examined Central Valley fall and Columbia River spring Chinook hatchery juveniles (Miller et al., 2010a). As noted earlier, there are some interesting patterns within the

Mid and Upper Columbia River yearlings that may actually serve as an indicator of hatchery origin. However, when examining otolith Sr:Ca and Ba:Ca, entrance into brackish/ocean waters is distinct from the period of hatchery residence. We include figures to illustrate this point (Fig. 2 vs. Fig. 3). Finally, the point regarding distinction between estuary and plume habitats was addressed above and is presented in more detail in Kraus and Secor (2004), Zimmerman (2005), and Miller et al. (2010a).

Table 1. Riverine Sr (ppb) and Sr:Ca (mmol·mol^{-1}) data for various locations in the Columbia River basin. River kilometer = RK. Samples below mainstem dams were collected within 5 km of the dam unless otherwise noted. Samples sites are identified by letters; see Fig. 1 for approximate locations. '—' indicates no data. Note oceanic Sr:Ca is approximately 8.0 to 8.5 mmol·mol^{-1}.

ID	Location	Sr (ppb)	Sr:Ca (mmol·mol^{-1})
A	Columbia River mainstem, below Bonneville Dam	66.0	2.35
B	Columbia River mainstem, below Dalles Dam	62.6	2.32
C	Columbia River mainstem, below John Day Dam	73.0	2.36
D	Columbia River mainstem, below McNary Dam	66.9	2.30
E	Columbia River mainstem, above Priest Rapids Dam	81.5	—
F	Columbia River mainstem, (~12 RK downstream of Chief Joseph Dam)	76.6	2.07
G	Columbia River mainstem, below Chief Joseph Dam	72.4	1.94
H	Columbia River mainstem, below Grand Coulee Dam	73.0	1.95
J	Columbia River mainstem, above Grand Coulee Dam	67.3	1.93
K	Columbia River mainstem, below Pend Oreille River	74.0	1.78
L	Snake River, above confluence with Columbia River	53.3	3.06

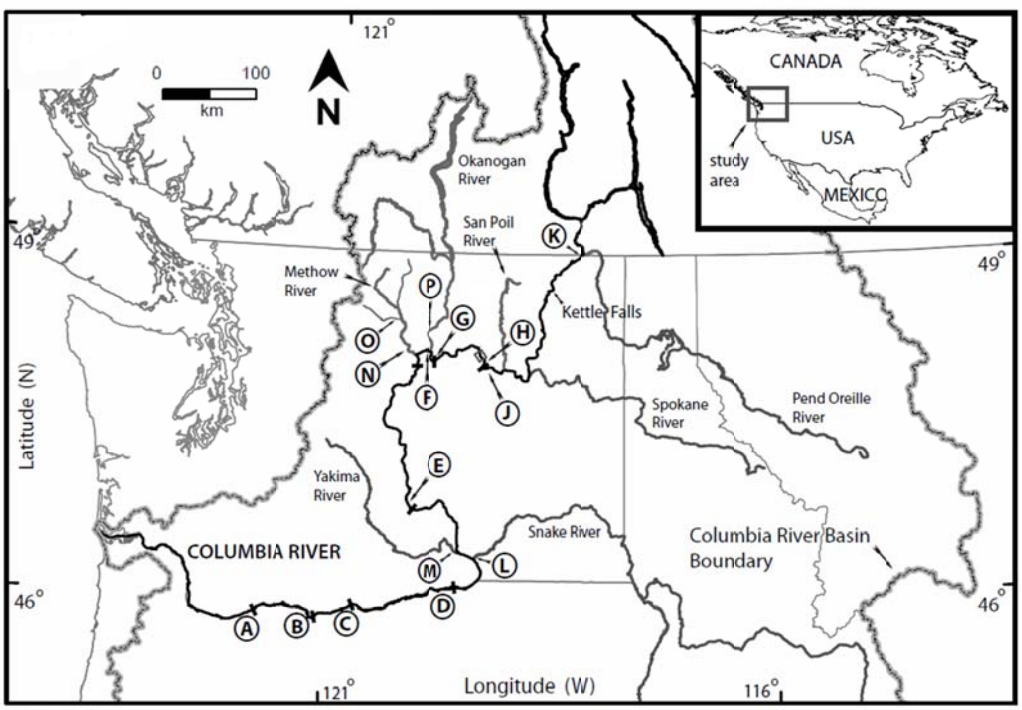


Fig. 1. Map of Columbia River and tributaries. (a) Majority of the Columbia River watershed, including the Snake (SNR), Yakima (YKR), Methow (MR), Similkameen (SKR), Okanogan (OKR), San Poil (SR), Pend Oreille (POR), Spokane (SPR), and Snake (SN) rivers. Approximate locations where riverine Sr (ppb) and Sr:Ca (mmol·mol^{-1}) data were collected are identified by letters (data are presented in Table 1).

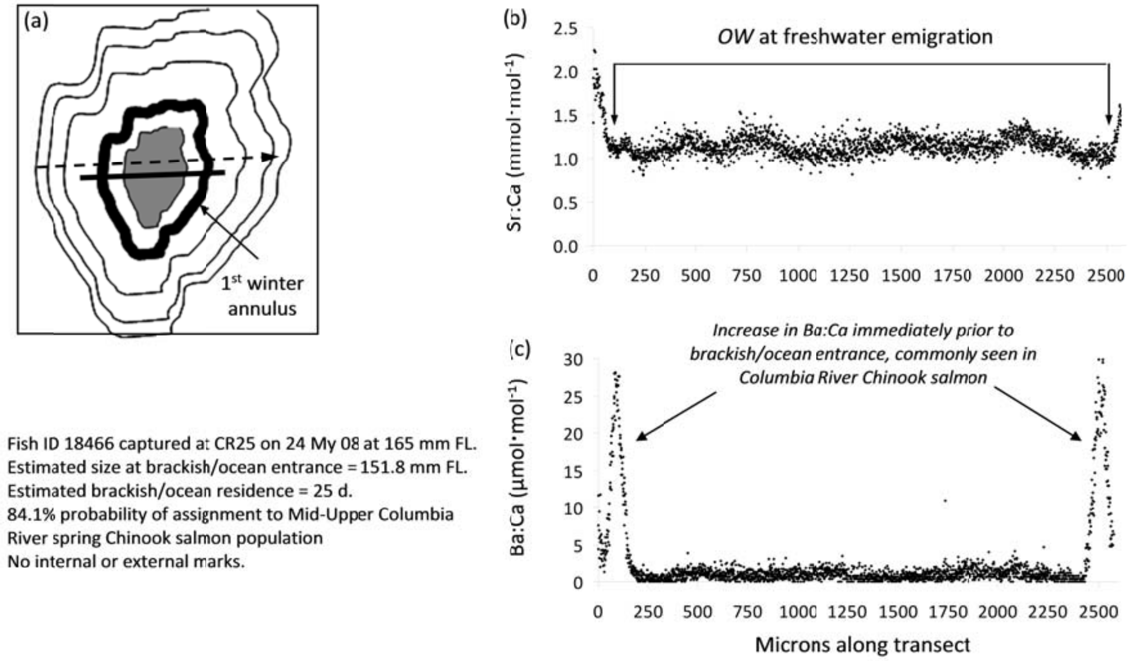


Fig. 2. (a) Schematic (sagittal section) of a sagittal otolith of a juvenile yearling Chinook salmon. Dashed line indicates laser path for elemental analysis and solid line represents otolith width (*OW*) at freshwater emigration. The core, which represents the egg and early juvenile life history, is shaded and the first winter annulus is labelled. (b) Sr:Ca across an otolith from a yearling Chinook salmon. (c) Ba:Ca across the same otolith. Measurements of otolith width (*OW*, µm) at freshwater emigration are identified. Note there is no evidence of maternal contribution to core strontium likely due to spring return of mother and length of maternal migration (see Donohoe et al. 2008 & Miller and Kent 2009 for more detail on maternal signatures).

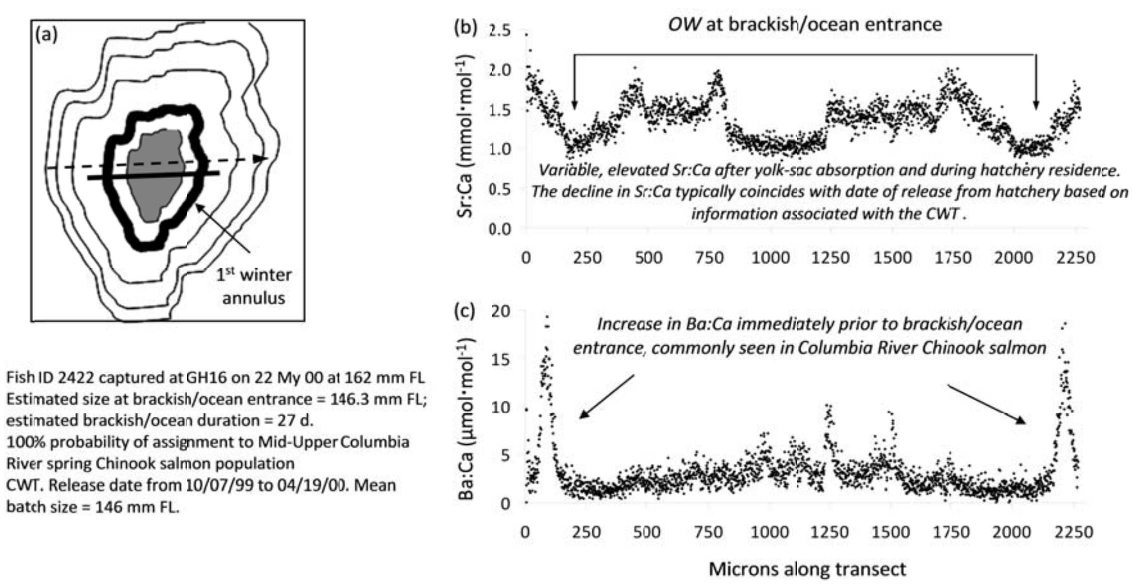


Fig. 3. (a) Schematic (sagittal section) of a sagittal otolith of a juvenile yearling Chinook salmon. Dashed line indicates laser path for elemental analysis and solid line represents otolith width (*OW*) at freshwater emigration. The core, which represents the egg and early juvenile life history, is shaded and the first winter annulus is labelled. (b) Sr:Ca across an otolith from a yearling Chinook salmon. (c) Ba:Ca across the same otolith. Measurements of otolith width (*OW*, µm) at freshwater emigration are identified.

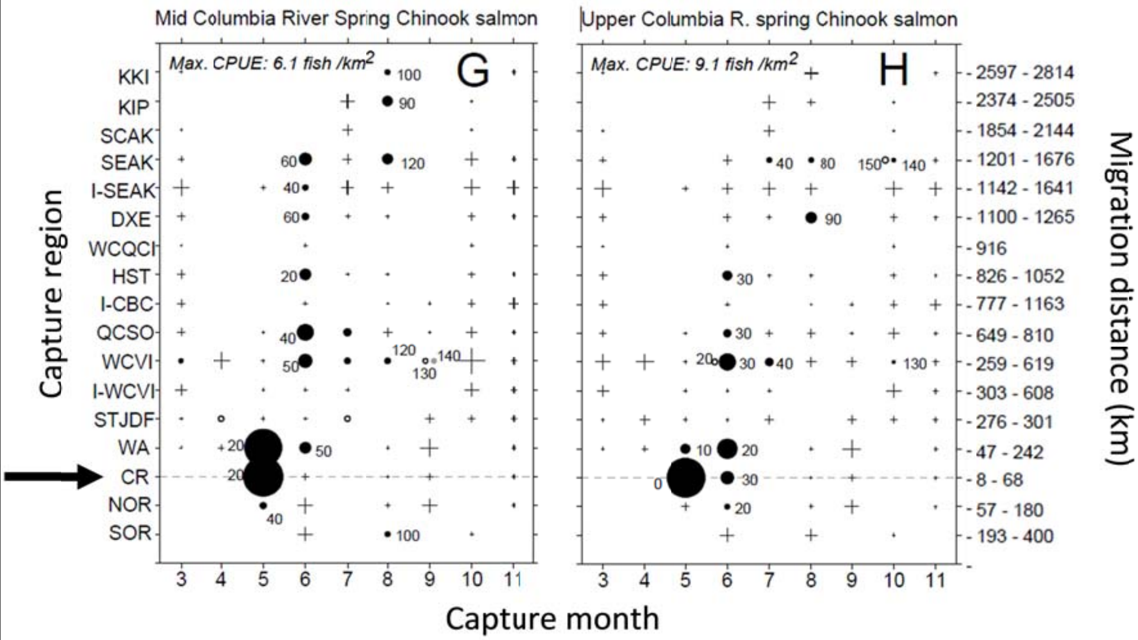


Fig. 4 (from Fisher et al. In revision.) . Summary of CWT collections. Catch per effort in surface trawls of age 1.0 fish by stock group, capture region, and month. Within stock groups, areas of circles are directly proportional to CPUE. The maximum CPUE is indicated at the top. The average estimated number of days (to the nearest 10) since ocean entry of fish in each region/month is shown near each circle. Cross size in each region/month indicates total surface trawl effort (only shown when catch = 0). Ranges in distance from the Columbia River mouth of capture locations in each region are also shown. The Columbia River transect is indicated by the filled arrow.

9. Avian predation and alternative prey. The ISRP recommends that the effects of Caspian terns be considered in proposed research on avian predation and alternative prey (anchovy). In the estuary, Caspian tern predation is known to be related to river flows and the Pacific Decadal Oscillation. Proponents need to demonstrate collaboration with other avian predation studies.

Response: Collaboration with existing avian predation studies was required to develop and test the sampling protocols for proposed new work on ocean bird predation. Therefore, we have already established connections with ongoing research on Columbia River estuary avian predation impacts (Oregon State University, Roby et al.; and NOAA Fisheries, Ledgerwood/Sebring) and the availability of forage fishes in the estuary/plume/ocean (NOAA Fisheries; Emmett, Brodeur, Weitkamp and others). If ocean bird diet work is fully funded, then our expectation is to make explicit comparisons between ocean bird diet, estuary bird diet, and forage fish availability. We agree with the reviewers that the proposal narrative should have clearly stated that coordination of new work with existing programs is already in place.

For example, to insure we can make valid comparisons between ocean and estuary bird diet, we shall use methods for collection, processing, and analysis of ocean diet samples which are identical to those used for estuary samples. The same avian diet technician (Reinalda) and salmon geneticists (Teel, Kuligowski) who analyzed tern/cormorant estuary samples worked with us to develop and test protocols for treatment of soft tissue, hard parts, and genetic identification of salmon remains. In some cases, we suggested improvements to existing methods, and those improvements are now being used by not only by our program and the tern predation group, but also by another project investigating murre diet near the Yaquina River, OR.

Additionally, the proposed location of ocean bird predation research at Pt. Adams Research Station provides significant strategic advantages for coordinating sampling efforts. Four of the five existing field programs addressing estuary bird predation or alternative prey availability are currently based out of Pt. Adams, and therefore the PIs has ongoing knowledge of field sampling schedules and preliminary results in these programs. The research program addressing effects on Caspian terns on juvenile salmon survival consists of two primary components: East Sand Island colony monitoring by Oregon State University biologists immediately before and during the nesting season (Roby), and PIT tag recovery after the nesting season by NOAA Fisheries staff at Pt. Adams Research Station in Hammond, OR (Ledgerwood/Sebring). The three research programs addressing variation in alternative prey (i.e. forage fish community composition and abundance) in the estuary and ocean are all led by NOAA Fisheries investigators. All three field programs which directly sample alternative prey (estuary purse seining, daytime trawl surveys in May/June/September, nighttime forage fish sampling) are sponsored by BPA as part of this proposal, and all three are staged out of Pt. Adams Research Station.

The only effort not based at Pt. Adams is the colony-based fieldwork with terns and cormorants on East Sand Island during the breeding season. NOAA has an established correspondence with Roby for coordination between estuary and ocean bird work. NOAA has also developed a communication channel with the program coordinator for East Sand Island fieldwork (Marcella). Maintaining these communications links will facilitate coordination and collaboration among the two programs.

Sampling ocean birds (shearwaters, murres) is necessarily a separate research effort from sampling estuary birds (terns, cormorants). It is not possible to collaborate directly on sample collection because the ocean birds rarely enter the estuary, and neither shearwaters nor murres nest anywhere in the estuary. Conversely, existing estuary fieldwork does not operate outside the river mouth. This is why there is a need for new field programs.

10. Tag recovery. In addition to collection of coded-wire tags (CWT), all salmon and steelhead sampled during fishing and tagging operations should be examined for recovery of PIT tags and acoustic tags, if this is not already being done. The ISRP recommends using a handheld wand detector, V-Detector, or tunnel detector onboard the survey vessels to examine all salmon and steelhead in survey catches for CWTs, as some Columbia River hatcheries release coded-wire tagged fish that do not have an adipose fin clip.

Response: We do check all juvenile salmon for the presence of CWT and PIT tags and also examine them for fin clips (adipose, ventral, caudal), visible implant elastomer (i.e., latex) marks, and internal tags (radio, acoustic, archival, etc.). Because all juvenile salmon caught in the Plume Study are retained (i.e. lethally sampled), we check for non-visual tags (i.e., PIT, CWTs) in the lab with a hand-held CWT wand and Biomark PIT tag reader. By contrast, many juvenile salmon caught by the estuary purse seine study are released after identification and measurement. Nevertheless, we accordingly check them in the field for visual marks and non-visual tags with the appropriate electronic detectors.

11. Tagging effects. New proposed research involves acoustic tagging of juvenile Chinook salmon smolts in the Columbia River estuary with VEMCO and JSATS tags and tracking them as they cross several acoustic listening-lines and with mobile units in the estuary to estimate site-specific survival during outmigration. An evaluation of the effects of tagging stress on fish that are smolting is needed, as stress may be considerable and could affect behavior and survival of tagged fish. Although the proponents think survival will be high because of positive test results in 2010, up-estuary release above the receivers at Astoria and Sand Island may be an added stress to smolts that could be evaluated.

Response: The effects of JSATS tags on survival of yearling Chinook salmon during migration through the basin has been documented (recently by McMichael et al., 2010). We are aware of the effects on tagged fish those will be included in analyses as we examine interactions of fish tagged through other programs with hydrographic conditions in the lower estuary.

Proposed tagging in the estuary with VEMCO tags.

With regard to tag effects, we plan to only tag fish > 130 mm, which will result in a tag/fish mass ratio of < 5%, which is consistent with suggested protocol (e.g., Giorgi et al., 2010). We will use the smallest tags available that are compatible with the POST array. We are hoping that the POST capability will be enhanced in the near future to accommodate smaller tags. We will collect fish from the freshwater lens and release them into freshwater, so the tagging and fish conditions will be quite similar to those at Bonneville Dam, the site of other acoustic tag studies.

Nonetheless, we agree concerns about tagging fish in the estuary environment and transporting them to an upstream release site are valid. Thus, we propose to modify our study design as follows.

First, we will conduct a pilot tag effects study in the first year of our study. During one of the sampling periods in the peak of the run, when we have ample numbers of fish captured, we will collect an additional 40 fish. We will randomly assign 20 fish to treatment and control groups. For the treatment group, we will surgically implant sham tags, which have the same dimensions and mass as the acoustic tags, into each individual. The treatment group will be handled in a similar manner, but will have no surgery. We will hold the fish for two weeks at NOAA's facility in Hammond, Oregon in holding tanks with flow through water. We will conduct a Kaplan-Meir survival analysis and use a log-rank test (□ = 0.05) to test for significant differences between groups. If we detect significant difference, we will seek funds to conduct a larger scale experiment involving more fish and longer holder periods, likely conducted at the Bonneville Dam facilities.

Second, we will modify our release strategy to have paired releases throughout the season – one near the tagging site and one upstream of the Astoria Bridge array. We will then test whether survival in common segments differs between the two groups. The first common segment is the one between the river mouth and the first array along the coast, at Willapa Bay. We will test for differences by building alternative models of the survival process, one of which has separate survival probabilities (that can vary throughout the season) for each group in the common segments, and one that has equal survival probabilities in these segments. We will determine which model is more consistent with the data using AICc. We believe releasing fish above the Astoria Bridge array is important because it allows us to detect any mortality that occurs shortly after release, which would be lumped with the lower estuary survival estimate when fish are released below this array.

12. Collaboration. This project is collaborating with the CDFO Salmon Shelf Survival Study (#200300900) and the Pacific Ocean Survey Tracking (#200311400, POST, re-named COAST) studies. The ISRP appreciates recent improvements in coordination with these projects. Linkages between these and others studies (e.g., JSATS tagging research) in the estuary, plume, and ocean are established, but the degree of coordination needs further explanation and development. For example, the approaches by NOAA and CDFO are somewhat similar, and integration of data collection and analyses to a greater extent would strengthen results. Likewise, the proponents should consider how data from the NOAA, COAST, and JSATS tagging projects can be integrated to provide a more comprehensive analysis of factors affecting salmon survival.

Response: We have increased our level of collaboration with the DFO group (led by Trudel) in recent years. In addition to many papers that compared results on salmon distribution, growth, community structure, feeding and parasite incidence described in the AFS Volume published in 2007 (Grimes et al., 2007), we have studies ongoing looking at growth comparisons using IGF-1 (led by Beckman), diets (led by Brodeur) and stable isotope analysis (led by Trudel). We also have plans outlined in Comment 3 earlier to collaborate with DFO on a February cruise off Washington and Oregon. We plan to make available space on board our cruises as well this coming summer for their scientists to participate. We have greatly increased our collaborative efforts with the NOAA Santa Cruz Laboratory to extend our normal sampling transects all the way to central California. During a cruise last summer, we provided logistical and manpower support to help in this cruise and are working with this lab to share data and samples. Further, it should be noted that we are directly collaborating in this proposal with COAST and Dr. David Welch as we have a specific task to incorporate VEMCO tags in juveniles collected during our estuary sampling that will be tracked along the receivers placed along the shelf by Dr. Welch's project.

13. Scientific workshop. The ISRP recommends a scientific workshop in 2011 focused on estimation of estuarine and ocean survival, forecasting of adult returns, and adaptive estuary, plume, and ocean environmental assessment for Columbia River Basin salmon and steelhead. Perhaps the proposal should include this workshop. A workshop would help to improve coordination and collaboration, standardization of methods (e.g., genetic stock identification), development of simulation and predictive models, and integration of results among Columbia River Basin estuary and ocean projects. One aspect of all projects that needs work is how to include more detail on sub-stock structure, including hatchery versus wild fish, hatchery release time, area comparisons, in-river migration and associated ocean migration, and more in the models. CDFO and NOAA seem to be taking somewhat different approaches to salmon forecasting, i.e., stoplight charts (red, yellow, and green) with a Bayesian belief network approach by CDFO versus ecosystem indicators by NOAA. Can this be reconciled?

Response: We agree that a workshop would be useful for investigators from the Columbia basin region to become more familiar with the findings from our ocean related research on how ocean and plume conditions affect growth and survival of

juvenile salmon from the CR basin. It should be noted that we have participated in two Science and Policy Exchanges hosted by the NPPC in the past three years and we host an annual Salmon Ocean Ecology workshop, initiated in 1998, for west coast researchers from California to Alaska, which is now including salmon researchers from the east coast. This workshop is open to all interested parties and at the workshop we have conducted an evaluation of forecasting approaches and actually compared forecasts for the past 4 years. In addition, in the past 5 years we have made numerous presentations to the NPPC, on a nearly annual basis, and to the Federal Executive Board and Caucus numerous times. We have also briefed the TAC on using our ocean indicators to improve their forecasts for adult returns to the Columbia River basin, and this is showing promise. Our forecasts are maintained on the NWFSC website and we endeavor to inform the widest audience to view the website, which is updated twice yearly. Further in our 2011 project meeting, we have scheduled a discussion with CDFO investigators to compare and contrast our forecasting approaches to identify areas of synchrony that we can advance in order to minimize confusion. We will continue to work with BPA on the best venues to improve science exchange with other BPA investigators.

14. Adaptive management. Consider how to better implement adaptive management to forecasted changes in ocean survival in the Columbia River system. Consider experiments designed in concert with hatchery, hydrosystem, and harvest managers to test specific hypotheses related to estuarine and early ocean survival. Proponents have indicated that management could respond to release timing and barging vs. in-river releases based on predictions from their 16 indicators and timing of upwelling, but what do managers say about the feasibility? How can managers respond to pathogen problems identified during this project? Or is this strictly an explanatory variable?

Response: We agree that we are at a stage where we could entertain scientific assessments or experiments to consider and implement adaptive management strategies to improve juvenile growth and survival and improve adult return rates under varying ocean conditions. This requires more participants than our scientific research team to initiate. To this end though, we are beginning discussions in 2011 with our NOAA Regional Office to talk with hatchery managers, for instance, to inform them of the role of the ocean in their success of the fish they produce and how they might use the information we provide to test scenarios of altering release amounts and timing to improve overall returns. The tests of scenarios could lead to effective adaptive management options in the future.

With respect to the specific question regarding pathogens, it is currently being evaluated as an explanatory variable but we could envision, if our hypothesis is correct, that eventual altering of release strategies relative to ocean conditions and pathogen loads could be an appropriate management strategy to employ.

15. Sources of variation in forecasts. Consider whether ocean survival forecasts could be improved by integration of additional sources of variation in freshwater and ocean survival (e.g., ocean harvests of immatures, jacks, and adults in Alaska and Canada;

bycatch in commercial groundfish fisheries; and climate and ocean conditions in offshore rearing areas)?

Response: We agree with this recommended approach and will consider additional metrics relating to climate and ocean conditions in offshore rearing areas and ocean harvest. It should be noted that knowledge of offshore rearing areas for all stocks is not clearly known (e.g interior basin spring Chinook salmon) and thus we would recommend efforts to identify stock specific rearing areas in the ocean be a special directed effort in future planning.

16. Quantitative forecasts. Qualitative methods of forecasting are helpful, but difficult for managers to apply and rely upon. That being said, proponents need to exercise caution in promoting the idea that their monitoring data will eventually lead to reliable, quantitative forecasts of ocean survival of salmon. Clearly, it is a goal of their agency to provide scientific forecasting tools to improve fishery management, but to date all quantitative ocean forecasting tools for salmon have failed, and thus expensive, long-term research vessel monitoring surveys are necessary.

Response: We understand the concern. We continue to advocate for improving our quantitative forecasting skills while acknowledging for the time being long term vessel monitoring surveys be supported.

17. Communicating results. Consider developing more effective approaches for communicating project results and forecasts of ocean survival of salmon directly to hatchery, hydrosystem, and harvest managers. The websites, scientific meetings, and peer-reviewed scientific publication are excellent methods for communicating with other scientists, government agencies, educational institutions, and conservation organizations, but are likely not effective tools for communicating directly with hydro, harvest, and hatchery managers.

Response: We agree and will work with BPA and the NPPC to identify venues to inform Columbia River basin researchers and managers of our findings. Also, see response to item #13.

18. Online proposal. Consider improvements to the online proposal form. Descriptions of methods in the online proposal were overly brief for some reviewers. Methods should provide sufficient stand-alone detail in the online form to enable evaluation of scientific and technical merit. The proposal could be improved if methods and metrics were explicitly stated for each objective. This is a complex proposal with six general objectives, both broad and narrow hypotheses, and "Studies" that provide metrics and methods that are intended to address multiple objectives, but the association between each specific objective and the metrics and methods that are intended to address it are unclear. For example, Study One provides methods and metrics that the proponents indicate address objectives one through six, but it is not entirely clear what methods and metrics presented in Study One address which of the six general objectives. The discussion of results in the online form would benefit from an ecosystem diagram

depicting important physical and biological variables and their known or hypothesized interactions (perhaps indicated by arrows between variables). Such a diagram would provide a synopsis of the proponent's current view of the system and how it might work, and would be beneficial in understanding the proposal. More complete details are needed on sampling methodology and analyses, along with a format that reduces the redundancies. Information on the percent of salaries for the PIs and what outside support they have would also help.

Response: We agree that with the new online format detailed methods were not included to the extent that they have been in past submissions and objectives and studies became more complicated. The online proposal process was not entirely clear and easy to follow and did provide a compatible format. Unfortunately, this is largely not an issue that we can solve from the applicant's perspective. We hope that feedback arrived from all who submitted proposals and will give insight to the developers of the online proposal forms on how to improve the process. If not, we will make an even greater effort in the future to best incorporate and clarify our information.

Appendix I. DFO's response to ISRP comments on the Canada-USA *Salmon Shelf Survival Study* (Project 200300900) submitted to the Northwest Power and Conservation Council in November 2010

200300900 - Salmon Shelf Survival Study

Proponents: Canada Department of Fisheries and Oceans
Short description: The Salmon Shelf Survival Study is an ongoing research and monitoring program jointly funded by CDFO and BPA aimed at understand the factors limiting the production of Columbia River salmon in the ocean environment, a key gap identified in the 2009 Fish and Wildlife Program. This research provides baseline data that can assist managers to discern climatic and oceanographic factors from the effects of habitat restoration, hatchery releases, hydrosystem operation, and harvest regulation.

ISRP final recommendation: Meets Scientific Review Criteria (Qualified)

Comment:
This project provides an important link to NOAA project #199801400 (Ocean Survival of Salmonids) for coastwide investigations of survival of northward-migrating Columbia River salmon distributed over the continental shelf off British Columbia and Southeast Alaska. The results benefit Columbia River salmon by potentially enabling managers to understand mechanisms of ocean survival and adaptively manage for changes in ocean conditions. The working hypothesis of this project is that "marine survival of salmon is mediated by the effects of ocean conditions on salmon growth during their first year at sea." Overall, the project has made good progress on evaluating factors that affect early ocean growth and survival of Columbia River salmon. The ISRP believes it is highly important to keep building on the existing time series of data. The investigators continue to examine new ideas that develop through analyses of existing data. This project examines all species and races of salmon, and it is apparent that hatchery and wild fish are identified when possible. A major accomplishment of ongoing research is the identification of a potential growth/survival bottleneck (in some years) for juvenile Columbia River salmon related to ocean conditions off the west Coast of Vancouver Island. Another import result is the observation that the majority of Columbia River fish caught off British Columbia during summer are of hatchery origin. During the last three to four years the proportion of hatchery fish relative to wild fish has decreased despite fairly stable releases, which may indicate increased production of wild Columbia River salmon. Although the ISRP is not requesting a response to this proposal, we have one major qualification.

Qualification: Address the issues listed below during the contracting process and in the project's 2011 annual report, which will be reviewed by ISRP.

Response: We thank the ISRP committee for providing valuable comments that will help to improve the research and monitoring proposal and plan submitted by

CDFO as part of the *Shelf Salmon Survival Study*, as well as improve the collaboration among BPA-funded ocean survival projects.

Comment #1: Strategic Plan. As noted by the ISRP in previous reviews, the project would benefit from a strategic plan that prioritizes objectives in the event that only partial funding is available for this project.

Response: In the event that only partial funding was available for the *Shelf Salmon Survival Study*, the proposed research and monitoring could be divided into three tiers that represent incremental level of funding:

Bronze package:
The first priority will be to process the remaining archived samples of salmon that have been collected during the last twelve years (with three surveys a year, samples accumulate faster in the freezer than we can process in the laboratory with the current technical support we have for this project). This will allow us to address most of the biological objectives of this project, with the exception of the monitoring of invasive species. This project would be limited to a retrospective analysis of past data, and will thus not be able to track ongoing changes in the oceans. This will require funding to support one technician to process the samples in the laboratory analyses. Funding for genetic analyses, salmon bioenergetics (i.e. food consumption rates), and stables isotopes are considered the highest priorities, as they will provide the baseline data that are understanding of the processes regulating the growth and survival of Columbia River salmon. Due to limited support for data analysis and reporting, publications would be limited to those pertaining to ocean migration and bioenergetics of Columbia River salmon.

Silver package:
In addition to processing the archived samples of salmon described above, processing of the archived zooplankton samples as well as a complete analysis of the data collected to date are considered the second priority of this project. This would require funding to support one research biologist to analyze the data collected as part of this project and communicate the results through primary publications, as well as to cover the identification of the archived samples of zooplankton. As with the previous priority, this project would be limited to a retrospective analysis of past data, and will thus not be able to track ongoing changes in the oceans. However, the added support would allow CDFO to produce a series of publications on the effects of ocean conditions on Columbia River salmon in a timely fashion.

Gold package:
The final priority is to continue the ongoing research and monitoring sampling at sea, so that new field data can be collected and used to track changes in the ocean environment and their effects on Columbia River salmon. This would allow a better integration of the research conducted by NOAA Fisheries and Kintama Research on the ocean survival of Columbia River salmon.

Comment #2a: Linkages between CDFO and NOAA Sampling. The linkages between CDFO sampling off British Columbia and Alaska relative to NOAA sampling off Washington and Oregon need to be clarified. Can one project proceed without the other or are the two sampling programs interlinked so tightly that incomplete understanding would result if one project did not go ahead?

Response: The surveys conducted by CDFO and NOAA Fisheries are highly complementary, and allows a broader coverage of the ocean environment exploited by Columbia River salmon, notably spring Chinook salmon and Redfish Lake sockeye salmon. These ESUs quickly migrate out of the area covered by NOAA Fisheries (Trudel et al., 2009, Tucker et al., 2009, Tucker et al., 2011), and would be missed if sampling was only conducted off Washington and Oregon. Both CDFO and NOAA Fisheries recognize the necessity of coordinating these sampling programs and exchanging data and tissues to provide a comprehensive understanding of the processes regulating the survival of different Columbia River salmon ESUs in the ocean. For instance, NOAA Fisheries have been participating in CDFO surveys since 2007 to collect blood plasma for IGF-I measurements. These analyses will allow CDFO and NOAA Fisheries to map habitat quality (with respect to growth) for juvenile Columbia River salmon over a broad geographic area, and help to understand the limit to their production during their early marine life. CDFO has also performed DNA analyses on the juvenile sockeye salmon collected by NOAA Fisheries off Washington (Tucker et al., 2009), as CDFO has developed the only comprehensive coast-wide DNA baseline that can discriminate all the stocks of sockeye salmon within the Columbia River baseline (Beacham et al., 2005; Beacham, unpublished data) [Note: The SNP baseline developed by Habicht et al **(2007)** does not discriminate sockeye salmon stocks located between the Columbia River and Southeast Alaska**]. The timing of the summer and fall surveys are comparable, and both research programs collect similar data to facilitate comparisons among the regions covered by these projects. Hence, neither project by themselves can fully address the Ocean Strategies of the Columbia River Basin Fish and Wildlife Program. But combined, they increase our ability to predict the response of Columbia River salmon to changing climate and ocean conditions.**

Comment #2b: The proponents state, "In addition, CDFO and NOAA Fisheries are planning to extend the CDFO winter survey to the Washington and Oregon coasts to provide additional information on the distribution of Columbia River salmon and to describe the biophysical environment they encounter in these waters during winter. This area has never been sampled for juvenile salmon at that time of the year due to inclement weather." However, this survey is not described as an objective, and the CDFO work is only to "complement" NOAA work. Presumably similar methods will be used in both CDFO and NOAA surveys, but this needs further explanation. Does NOAA now have a vessel that can handle heavier weather or is there some other reason why the winter survey is now feasible? Have the data from CDFO winter surveys been used to evaluate the winter starvation hypothesis (Beamish & Mahnken, 2001)?

Response: As winter has been hypothesized to be a critical period for juvenile salmon (i.e. Beamish & Mahnken, 2001), conducting field surveys during winter is necessary to evaluate this hypothesis. To date, the data collected by CDFO in the Alaska Coastal Current system are consistent with the starvation hypothesis, but not in Northern California Current (except under extremely poor ocean conditions, such as in 2005). However, this hypothesis remains to be tested on Columbia River salmon.

NOAA Fisheries do not currently have a vessel capable of performing winter surveys. Although no formal plans have been established, CDFO and NOAA Fisheries are currently discussing the possibility of using the *CCGS WE Ricker* in FY11-FY12 to sample the ocean environment from the Oregon coast to the west coast of Vancouver Island during winter. CDFO has been using this vessel to conduct winter surveys off British Columbia and Southeast Alaska since 2001, and hence has the necessary expertise to sample when inclement weather conditions prevail on the continental shelf. As Columbia River fall Chinook appear to remain primarily off coastal Washington and Oregon during their first year at sea (Trudel et al., 2009, Tucker et al., 2011), this joint survey would allow CDFO and NOAA Fisheries to directly test the winter starvation hypothesis on Columbia River salmon.

Comment #2c: NOAA is now proposing to look at sockeye salmon (assuming they have a few fish in their samples). Sockeye is a specific species that the two projects need to collaborate on since Columbia sockeye increased during a period when Fraser River sockeye collapsed (the 2005 & 2007 Fraser smolt years produced very low adult returns compared to what was expected from the long-term Ricker relationships).

Response: CDFO and NOAA Fisheries have collaborated to develop a microsatellite DNA baseline that can be used to discriminate all the sockeye stocks within the Columbia and Snake River basins and to describe the migration routes and behavior of sockeye salmon (Tucker et al., 2009). Both agencies anticipate pursuing their collaboration to understand the processes affecting juvenile sockeye in the marine environment. This will not only help to explain the recent increase in the returns of adult sockeye salmon to the Columbia River, as well as the decline of Fraser River sockeye during the last two decades, as well as the exceptionally high returns observed in 2010.

Comment #3: Interannual Variations in Salmon Distribution. The proponents state, "This project will be successful if interannual variations in the marine distribution of Columbia River salmon are detected." Proponents should keep in mind that even if interannual variations are detected and significant, we need to know about the mechanisms that determine the variations and how much they vary in time and space. How many years will it take before success can be determined or will this go on forever? The proponents need to consider important sources of variation in research trawl fishing operations and fishing efficiency with respect to what is known about diel, horizontal, vertical, and seasonal distributions of juvenile salmon. How might these sources of variation affect time-series observational data on species composition, abundance, distribution, growth, etc., of juvenile salmon in the survey area?

Response: The purpose of that project is actually to determine the factors and mechanisms that affect the variability in the ocean distribution of juvenile Columbia River salmon. The statement quoted by the ISRP should have read instead: "This project will be successful if interannual variations in the marine distribution of Columbia River salmon can be modeled as a function of the physical, chemical, and biological condition encountered by these fish". In addition to temperature, salinity, phytoplankton, and zooplankton biomass, this analysis will consider the time of year (i.e. season) and fish community structure (i.e. species composition and abundance). Growth may be also incorporated in the analyses using either the IGF-I measurements that have been performed by Dr. Beckman on our surveys or otolith microstructure, though it is important to note that IGF-I measurements were only initiated in 2007. Sampling is generally restricted during daylight hours. Hence, it will not be possible to consider diel changes in horizontal and vertical distribution in this study.

The ability of these models to predict changes in salmon distribution over time will depend on the range of variation observed for each of the explanatory variables (e.g. temperature, phytopkanton biomass, smolt production, etc ...). The abiotic and biotic conditions monitored by CDFO during the last decade have varied considerably. Hence the habitat models that will develop by CDFO as part of the *Shelf Salmon Survival Study* are expected to be valid over a broad range of climate and ocean conditions experienced by Columbia River salmon.

Comment #4a: Invasive Species (Objective 3). No details were provided in Objective 3 of the proposal, although section 3.4 of the Major Accomplishments section mentions Humboldt squid. What invasive species will be investigated? How will this information be used?

Response: It is difficult to predict which species will invade the area currently sampled by the *Shelf Salmon Survival Study*, though Humboldt squid is an obvious candidate. However, as all the species collected in the trawl net and bongo nets are identified at the species level, the occurrence of unusual species and range expansion of non-native species will be documented and reported. We will continue to work with other groups at CDFO to document the distribution and abundance of unusual and invasive species.

Their impacts on salmon and marine ecosystems are more difficult to assess: a concomitant change in salmon survival with the appearance of these unusual species may be indicative that they have a significant effect on salmon; though these results will have to be interpreted carefully. For instance, some have argued that the low

return of Fraser River sockeye salmon in 2009 may be linked to the high abundance of Humboldt squid on the continental shelf, despite the lack of direct evidence of predation on Humboldt squid on sockeye salmon. This hypothesis is interesting in itself, but fails to explain why Chinook jack reached a historical high level in the Columbia River for the fall runs in 2009. Predation by Humboldt squid on these fish is expected to be higher, as Columbia River fall Chinook most likely remain on the continental shelf for most of the marine life (Trudel et al., 2009, Tucker et al., 2011), and are therefore expected to interact with Humboldt squid for an extended period of time. They are also smaller than Fraser River sockeye, and potentially more vulnerable to predators (i.e. slower swimming speed).

Comment #4b: Pacific whiting migrations and potential predation could be integrated with estimates to the south. Nothing is mentioned in the proposal about forage fish as a buffer to smolt predation, although the proponents note that a subset of the pelagic forage fish caught in the trawl is sampled. The ISRP encourages proponents to assess the availability, size, and abundances of forage and predatory fishes and squids in their trawl survey catches.

Response: Although not explicitly stated in the proposal, we are planning to examine how adult returns and marine survival of Columbia River salmon are affected by the abundance of forage fish (i.e. predation buffer or competition) and predator using correlations, path analyses, and Bayesian Beliefs Network. We will not only use the catch data from our surveys for these analyses (counts and biomass estimates have been systematically recorded for all species since 2005, and size is available for a subsample of the catch at each station), but also biomass data available from stock assessment surveys and publications.

Comment #5: Coordination with Other Projects. This project benefits greatly from in-kind match support from CDFO, which funds two of the three project surveys each year. The effort includes analysis of stocks from other regions, and this provides for interesting comparisons with Columbia River salmon. The project also has shared information with NOAA's Ocean Survival of Salmonids Project. Still, it would be good for the BPA-funded CDFO, NOAA, and Kintama investigators to coordinate and integrate their efforts and their findings to a greater extent than shown in the proposals. Also, consider greater use of ocean monitoring data collected by other (non-BPA funded) projects for developing indices of ocean conditions, such as hydroacoustics, remote sensing, oceanographic buoys and floats, and robotic vehicles. The ISRP recommends improved coordination and collaboration with other projects and programs collecting these data.

Response: Although significant progress has been achieved during the last five years with respect to collaboration among BPA-funded ocean survival research through joint publications and workshops, sample and data exchange, further effort is certainly required to increase the coordination and integration of these projects. As a first step, NOAA Fisheries, CDFO, and Kintama Research are convening a

meeting in February 2011 to discuss recent findings and upcoming field work in order to improve the collaboration among these projects. All these projects also plan to use monitoring data obtained via remote sensing and buoys, and test fisheries for groundfish and pelagic fish as additional source of ocean and climate data. Although floats are primarily restricted to the open waters of the Pacific Ocean (i.e. Argo floats), they may help to better characterize the boundaries of coastal domains and sources of plankton to the shelf (Batten & Freeland, 2007) where Columbia River salmon spend the first few months of their lives.

Comment #6. Genetic stock identification. The ISRP recommends standardization of genetic stock identification methods used by BPA-funded ocean survival projects so that results are directly comparable among projects. Different projects may currently be using different methods but this was not clearly explained in the proposal.

Response: All the BPA-funded ocean survival projects currently use microsatellite DNA to determine the origin of the fish caught in their study, as microsatellites have consistently been showed to provide a considerably higher degree of accuracy in GSI analyses than Single Nucleotide Polymorphism (SNPs) in Chinook salmon (Narum et al., 2008, Beacham et al., In review), sockeye salmon (Beacham et al., 2010), and chum salmon (Beacham et al., 2008), at least with the SNPs that are currently available for these species.

Chinook salmon: CDFO uses the CDFO microsatellite baseline (Beacham et al., 2006a), whereas NOAA Fisheries and Kintama use the GAPS microsatellite baseline (Seeb et al., 2007, Narum et al., 2008, 2010). Although these baselines rely on different microsatellite loci, both baselines provide comparable assignments at the basin level (Hanson et al., 2010, Beacham et al., In review). Hence, the GSI results obtained by CDFO, NOAA Fisheries, and Kintama on Chinook salmon can be directly compared at the ESU level (i.e. Lower Columbia River, Willamette, Upper Columbia River spring, Upper Columbia River summer/fall, Snake River spring/summer, and Snake River fall). There is insufficient coverage with both baselines to adequately assign individual Chinook salmon at the stock level.

Coho salmon: NOAA Fisheries uses a microsatellite baseline that include populations ranging from Northern California to southern British Columbia (Van Doornik et al., 2007). This baseline is suitable for the "Ocean Survival of Salmonids Study", as it contains the ESUs that are likely to occur off Washington and Oregon. This baseline is not appropriate for the "Shelf Salmon Survival Study", as it lacks stocks originating from the regions sampled by CDFO such as the central and north coasts of British Columbia and Southeast Alaska. We are currently expanding and testing the performance of the coho salmon baseline developed at CDFO with fish of known origins.

Sockeye salmon: CDFO uses the microsatellite baseline developed at CDFO (Beacham et al., 2005). Redfish Lake sockeye salmon were added to the CDFO

baseline in 2010. As a result, we can now accurately discriminate individual sockeye salmon originating from Redfish Lake, Lake Wenatchee, and Lake Okanagan. Juvenile sockeye salmon samples collected by NOAA Fisheries as part of the "Ocean Survival of Salmonids Study" have been analyzed by CDFO (Tucker et al., 2009). Hence, in this case, the same baseline and laboratory has been used to determine the origin of juvenile sockeye salmon.

Chum salmon: None of the BPA-funded ocean survival projects are planning to conduct GSI analyses on chum salmon. The "coast-wide" microsatellite baseline developed by CDFO does not currently include any chum salmon from the Columbia River (Beacham et al., 2009), but can easily be updated if DNA analyses are required for juvenile chum salmon caught at sea.

Comment #7: Tag recovery and reporting. In addition to collection of coded-wire tags and PIT tags, all salmon and steelhead sampled during fishing operations should be examined for recovery of acoustic tags, if this is not already being done (no mention of this in the proposal). The ISRP recommends using a handheld wand detector, V-Detector, or tunnel detector onboard the survey vessels to examine all salmon and steelhead in survey catches for coded-wire tags (CWTs), as some Columbia River hatcheries release CWT fish that do not have an adipose fin clip. Apparently, data on CWT recoveries collected by this project have not been reported to the Pacific States Marine Fisheries Commission's (PSMFC) RMIS database since 2005. Are PIT tag recovery data reported in the PSMFC's PTAGIS database? The ISRP strongly recommends that reporting of recovered CWTs and PIT tags to the PSMFC's RMIS and PTAGIS databases should be done on an annual basis.

Response: All the Chinook, coho, sockeye, and steelhead salmon are systematically scanned on board the ship with a handheld wand detector to determine the presence of coded-wire tags (CWT), irrespective if their adipose fins have been clipped or not (Morris et al., 2004). In addition, all the Chinook salmon are scanned onboard the ship for the presence of PIT tags. The ISRP accurately pointed out that the CWT and PIT tag data collected during the Shelf Salmon Survival Study has not been submitted to RMIS and PSMFC's PTAGIS databases since 2005. We have experienced some difficulties in the past within CDFO to submit our CWT to RMIS. We plan to submit all our remaining CWT and PIT tag recoveries to these databases within the next year. As we experienced some difficulties in the past within CDFO to submit these data to external databases, we will be seeking advice from Dr. K. Myers who was instrumental in submitting our CWT recoveries to RMIS in the past (Note: The 2005-2009 CWT recovery data were recently sent to Dr. Myers so that the can be incorporated in the RMIS database).

Comment #8a: Forecast models. The proponents state, "With more than a decade of observations on the ocean conditions experienced by juvenile salmon on the west coast of BC, this CDFO-BPA study has started to develop simple forecasting models for the marine survival of Columbia River salmon 1-2 years prior to the return of adult salmon to their natal river." However no elaborations of these models are provided - can this be done? Can confidence intervals be placed on the qualitative information in the red-yellow-green traffic-light charts or some kind of probabilistic statistic?

Response: Yes this can be done, and we apologize for not explicitly stating how we were planning to achieve this. In this project, we propose to assess the effects of ocean conditions on the marine survival and adult returns of Columbia River salmon using linear correlations and regressions with a series of biotic and abiotic variables thought to regulate juvenile salmon growth and using Bayesian Beliefs Networks. These models use ocean conditions experienced by juvenile salmon, and hence, can be used as leading indicators for salmon returns.

Linear regression models can be used to quantitatively predict marine survival and adult returns, and confidence limits around these predictions can be derived using standard statistical textbooks (e.g., Sokal & Rohlf, 1995). However, as pointed by the ISRP, confidence limits around regression models can at times be large. Instead of focusing on quantitative predictions, Prairie (1996) argued that confidence limits around regression models may help to identify the number of distinct classes that a model can truly predict. He further derived a simple function based on the coefficient of determination (R2) that can be used to determine the number of classes regression models can distinguish. With R2 ranging from 65% to 85%, regression models can truly distinguish 2-3 classes, such as below average, average, and above average. We propose to use the mean plus or minus half a standard deviation (mean 0.5 s.d.) of marine survival and adult return to identify the limits for below average (survival < mean – 0.5 s.d.), above average (mean + 0.5 s.d.), and average (anything within 0.5 s.d. of the mean). In a normal distribution, approximately 34% of the observations are within half a standard deviation of the mean. Hence, these limits generate three classes of roughly the same size. This approach can therefore be easily transposed into red-yellow-green traffic-light charts (i.e. below average, average, and above average).

The Bayesian Beliefs Network (BBN) is an extension of the multiplied regression model applied to qualitative and quantitive relationships, and can be used to directly determine the probability that marine survival and adult return will be below average, average, and above average, and hence provide a direct probabilistic statistics for the red-yellow-green traffic-light charts. The advantage of the BBNs over linear regression models and principal component analyses is that BBNs can simultaneously take into account the relationships that are expected to occur among predictors (such as those depicted in Figure 1 of the proposed research), and examine how marine ecosystems respond to climate forcing.

Comment #8b: Forecast models. The proponents state, "Given that the C:N ratio is an indicator of lipids, and that prey size and lipid contents generally increase with trophic position in aquatic food webs (Rasmussen et al., 1990), salmon growth should also be positively correlated to the C:N ratio in plankton, their trophic position, and plankton biomass." Has this hypothesis been tested before?

Response: Relationships between the C:N ratio and lipids have been derived for fish and aquatic invertebrates for two decades (McConnaughey & McRoy, 1979), and has been confirmed by several studies (e.g., Post et al., 2007, Mintenbeck et al., 2008, Hoffman & Sutton, 2010; and several others, Tarroux et al., 2010). Prey size and lipid concentration have been showed to increase with trophic levels in aquatic food webs (Rasmussen et al., 1990, Fisk et al., 2001, Post et al., 2007). Model simulations suggest that prey quality can have strong effects on juvenile salmon growth (Trudel et al., 2002). Effects of prey quality on juvenile salmon growth have also been inferred for pink salmon in Prince William Sound based on their diet (Armstrong et al., 2005, 2008) as well for Oregon coho salmon based on copepod communities (Peterson & Schwing, 2003, Peterson, 2009). However, we are not aware of any studies that have attempted to empirically assess the effects of prey size and prey quality on juvenile salmon growth and survival in the same analysis, and to examine how changes in prey size and prey quality are linked to climate and ocean circulation affect.

Comment #8c: Forecast models. Why not correlate growth, boreal copepods, C/N of plankton with SARs of Chinook (as with Oregon Production Index Hatchery survival) rather than numbers returning? Consider whether ocean survival forecasts could be improved by integration of additional sources of variation in freshwater and ocean survival (e.g., ocean harvests of immatures, jacks, and adults in Alaska and Canada, bycatch in commercial groundfish fisheries, climate and ocean conditions in offshore rearing areas)?

Response: Harvest managers are generally interested in knowing how many fish will come back rather than the marine survival. A high marine survival during years of low smolt production may still lead to few adults returning to spawn, and hence, may still result in fishery closure. Conversely, a low marine survival in years of excessively high smolt production may lead to a good return (but see the low return of adult Fraser River sockeye salmon in 2009 despite one of the highest smolt production year on record). This is the primary reason we are attempting to focus on adult returns rather than marine survival; though this approach requires knowing how many smolts are produced in different systems. Nevertheless, for completeness of our analyses, we will attempt to examine how Chinook SARs vary in relation to ocean conditions.

Most of the mortality is expected to occur in coastal waters during their first year at sea (Pearcy, 1992). The strong correlations observed thus far between adult returns, marine survival, and the ocean conditions observed off the west coast of Vancouver Island strongly suggest that recruitment variability is determined early during their marine life. Hence, we are focusing most of our research on the marine ecology of juvenile salmon when they are on the continental shelf. Nevertheless,

significant mortality may be occurring elsewhere during their marine life. Hence, additional factors such as those listed by ISRP may be explored to provide more robust forecast to fishery managers.

Comment #8d: Forecast models. Are anoxic conditions considered in forecast models?

Response: Oxygen concentration in BC and Southeast Alaska waters have only been measured during the last 3-4 years. This time series is not sufficiently long at the moment to be of any use in predictive models of salmon survival, but may be considered in future iterations of the model. However, oxygen concentration is generally well above hypoxia or anoxia at the depth strata occupied by juvenile salmon, and hence is not expected to affect their survival. Nevertheless, continued monitoring of oxygen concentration is warranted given that anoxic waters have been observed off the Oregon coast (i.e. Dead Zones).

Comment #9: In-river versus ocean survival. In the proposal, the proponents state, "Finally, the in-river survival of salmon smolts is similar in large rivers with and without dams (Welch et al. 2008)." Is this a defensible generalization? For example, several organizations have said there were too few years in the Welch et al. study to reach this conclusion. This leads to the larger issue of whether proponents can deliver accurate quantitative forecasts of Columbia River salmon survival and adult returns without also considering in-river effects.

Response: We agree with the ISRP that the observations obtained by Welch et al. (2008) cannot be generalized beyond the years they studied. The extent to which in-river conditions will affect the ability of the Shelf Salmon Survival Study to accurately forecast Columbia River survival and adult returns is currently unknown. However, given that salmon stocks from the Columbia River and the west coast of Vancouver Island respond similarly to ocean conditions in the Northern California Current System (Fig. 38, 39, 40, and 42 from the annual report submitted to BPA by Trudel et al., 2011), it would appear that the returns of Columbia River salmon are driven to a large extent by changes in the ocean environment. However, continued monitoring of both the river and ocean conditions are necessary to tease apart their effects on Columbia River salmon.

Comment #10: Scientific workshop. ISRP recommends a scientific workshop in 2011 focused on estimation of estuarine and ocean survival, forecasting of adult returns, and adaptive estuary, plume, and ocean environmental assessment for Columbia River Basin salmon and steelhead. Perhaps the proposal should include this workshop. A workshop would help to improve coordination and collaboration, standardization of methods (e.g., genetic stock identification), development of simulation and predictive models, and integration of results among Columbia River Basin estuary/ocean projects. One aspect of all projects that needs work is how to include more detail on sub-stock structure, including hatchery versus wild fish, hatchery release time, area comparisons, in-river migration and associated ocean migration, and more in the models.

Response: A coordination meeting between BPA-funded ocean survival projects will be hosted by NOAA Fisheries in Newport in February 2011. The purpose of this meeting is to improve on coordination and collaboration, and standardization of methods among BPA-funded projects, and to integrate the results of these projects. It is expected that the field surveys of ocean conditions conducted by CDFO and NOAA Fisheries combined with the region-specific survival estimates derived by the *Coastal Ocean and Salmon Tracking* project will improve our ability to assess how the estuary, plume, and ocean provide the necessary data affect Columbia River salmon and steelhead.

A workshop focusing on the marine ecology of juvenile salmon and forecasting models will be hosted by NOAA Fisheries in Seattle on March 23-24 2011. Forecasting and simulation models structure and performance will be evaluated and compared at the workshop.

As with any scientific research, progress is achieved incrementally. Early attempts focused on large aggregation of stocks, without any discrimination of wild and hatchery fish. Now that we can identify wild and hatchery fish, and that tools are available to delineate major ESUs and track in-river migration, future efforts to relate Columbia River salmon to ocean conditions by CDFO and NOAA Fisheries will focus on ESUs and incorporate river conditions expected to affect the timing of ocean entry of these fish. Though, it is important to note that the ability to go beyond ESUs is limited by DNA baselines as well as by the number of fish that are and can be caught at sea, given sampling permit restrictions on ESA-listed stocks.

Comment #10b: CDFO and NOAA seem to be taking somewhat different approaches to salmon forecasting, i.e., stoplight charts (red, yellow, and green) with a Bayesian belief network approach by CDFO versus ecosystem indicators by NOAA. Can this reconciled?

Response: The approaches proposed by CDFO and NOAA have their strengths and weaknesses. For instance, the Bayesian Beliefs Network directly provides a probability estimate that returns or survival will be low, medium, or high (or red, yellow, green), is well suited for quantitative and qualitative data, takes into account the relationships that are expected to occur among explanatory variables (such as sea surface temperature, mixed-layer depth, current direction, ...), but is computationally more complex. The approach used by NOAA simply ranks the observations from lowest to highest with respect to their expected effects on salmon returns. However, some variables that are included are potentially redundant (for instance, sea surface temperature and PDO). Averaging the ranks will give this give more weights to redundant variables, which bias their forecast. Despite these differences, the results of both approaches can and will be compared directly.

Comment #11: Adaptive management. Project proponents might be overselling their ability to provide quantitative estimates of ocean conditions to help forecast runs. A case in point seems to be CDFO's recent failure to forecast near record returns of Fraser River sockeye salmon in 2010. A project focus directed toward use of information on ocean conditions for adaptive management of Columbia River hatchery operations, hydrosystem operations, and habitat restoration might be more appropriate.

Response: We agree with the ISRP that the proposed research is best suited to provide *qualitative* indicators on the state of ocean conditions with respect to salmon (favorable, unfavorable, or neutral) "for adaptive management of Columbia River hatchery operations, hydrosystem operations, and habitat restoration" due to the uncertainties in the correlational models derived in this project. Nevertheless, these models can still be used to provide *quantitative* predictions on salmon returns that help managers to make informed decisions on harvest rates. Notably, the growth indictors developed as part of this project have been incorporated into the CDFO stock assessment for west coast of Vancouver Island (WCVI) coho salmon in 2009. A comparison of the various methods used by CDFO to forecast the marine survival of WCVI coho salmon (e.g. coho jacks, euphausiid biomass, stock-recruitment models) have showed that the growth indicators derived in this project provided the most accurate estimates of marine survival for these fish. Preliminary data for the 2010 returns appear to be consistent with the predictions obtained from these growth indicators. Thus, these correlational models have the potential to inform managers on future returns of salmon, and guide harvest management decisions.

Notes concerning Fraser River sockeye: The methods currently used by CDFO to forecast the return of Fraser River sockeye are based on Ricker stock-recruitment curves and do not include any information on the ocean conditions experienced by these fish. This may explain, at least in part, why CDFO has been unable to forecast the unusually low and high returns of sockeye salmon to the Fraser River in 2009 and 2010, respectively.

Comment #12: Communicating results. Consider developing more effective approaches for communicating project results and forecasts of ocean survival of salmon directly to Columbia River Basin hatchery, hydrosystem, and harvest managers. The websites, scientific meetings, and peer-reviewed scientific publication are excellent methods for communicating with other scientists, government agencies, educational institutions, and conservation organizations, but are likely not effective tools for communicating directly with hydro, harvest, and hatchery managers.

Response: CDFO will work with their BPA COTR in FY11 and beyond to develop a more effective approach to effectively communicate the results of the *Shelf Salmon Survival Study* directly to Columbia River Basin hatchery, hydrosystem, and harvest managers.

Comment #13: Update Online Proposal Format. The format of this proposal was confusing and difficult to follow. Proponents should reformat their online proposal to better conform to the specific information requested in each section of the online form. The repetition of the same deliverables under several objectives seems unnecessarily repetitive. Objectives providing the same deliverables could be combined into one objective. Specific objectives need to be clearly stated as desired outcomes in the proponent's section 2.0 of the problem statement, instead of describing the methodological approaches. These should correspond to objectives in the objectives and deliverables part of the proposal form. At present, objectives are not stated as desired outcomes, for example, Objective 1 is "Ocean Conditions," and this might be better stated as, "Assess effects of ocean conditions on Columbia River salmon survival." The problem statement section is unnecessarily long, and describes the entire proposal including methods, timelines for deliverables, etc. This section could be shorted by moving methods, etc., to other more appropriate sections of the proposal. This proposal needs to address the online tailored questions for tagging as it involves recovery of CWTs and genetic stock identification.

Response: We attempted as much as possible to adhere to the online forms to develop this research proposal. Like the ISRP, we feel that there was some repetition among some sections, which made the proposal unnecessarily long. Given that this comment was raised by ISRP on several of the proposals submitted to BPA, we would be tempted to conclude that this occurred as a result of a lack of clarity on the online forms. For instance, in the Problem Statement section, the instruction indicates the following:

"In this section describe the specific problem or need your proposal addresses. Describe the background, history, and location of the problem. For projects doing research or monitoring, identify the management questions the work intends to address and include a short scientific literature review covering the most significant previous work related to the project. Also include the work of key project personnel on any past or current work similar to the proposal."

As this project is an ongoing Research, Evaluation, and Monitoring project, part of the scientific background requires that we discuss the issue that we are trying to address, which by necessity should also include a summary of the research conducted by the proponents (i.e. what have the proponents found to date, and what is currently missing), as well as a description of the management objectives pertaining to BPA. We opted to only provide a limited summary of the key findings of our past research on this topic in this section, as there was a much more detailed section where we were asked to present the major accomplishments of our project. Nevertheless, to reduce the length of the proposal, we eliminated the Methods and Timeline components of this section, as the methods section was described elsewhere in details.

We agree with the ISRP that two of the objectives were fairly similar (Ocean Conditions and Climate Change) and grouped them together. Also, as requested by the ISRP, we changed the rephrased the title of each objectives to reflect a desired outcome.

Finally, the intent of the BiOp RPAs that focus on recovery of CWTs and genetic stock identification RPA 62 appeared to be targeting adult fish more than juvenile salmon, which is why we did not include any specific information for these RPAs in the proposals.

Appendix J. Kintama's response to ISRP comments on the *Coastal Ocean And Salmon Tracking Study* (Project 200311400) submitted to the Northwest Power and Conservation Council on December 2010

200311400 - Coastal Ocean Acoustic Salmon Tracking (COAST)
Proponents: Kintama Research
Short description: By providing direct data on smolt movements and survival in the early ocean period, this proposal addresses a number of BiOp requirements and objectives in both the Fish and Wildlife Program and the MERR Plan. It also extends Kintama's 2006-2010 work and results. The intent is to inform FCRPS management with detailed data about listed Chinook stocks, including patterns of migration; seasonal changes in ocean survival relative to the hydrosystem and estuary; and survival correlations with ocean indicators.

ISRP recommendation: Meets Scientific Review Criteria (Qualified)

Comment:
This is one of three BPA-funded projects that address the critical uncertainty of ocean effects on survival of Columbia River salmon. The ISRP appreciates that project proponents have followed some of ISRP's past recommendations to develop approaches tailored specifically to Columbia River salmon in the estuary, plume, and ocean. Coordination with other ocean and estuary projects has improved. However, a number of past issues raised by ISRP and ISAB have not been addressed. In addition, there are new issues resulting from proposed changes in project design and methods that need to be addressed. Although the ISRP is not requesting a response at this time, we do have one major qualification.

Qualification 1: Address the issues listed below during the contracting process and in the project's 2011 annual report, which will be reviewed by the ISRP:

1. Feasibility of COAST Approach. How can the proposed objectives be achieved if the open-coast acoustic array is still being developed? Are there other approaches that would be more cost-effective for estimating life-stage specific open ocean distribution and survival of salmonids?

The proposed work could yield important new data on coastal and estuarine distribution of Columbia River Basin salmonids and endangered ESUs. However further information is requested on how the proponents view the strategic balance of this project between assessing broad "offshore" distributions (where it appears more development work is needed as mentioned below) versus detailed monitoring to estimate survival between closely spaced reaches in the estuary.

Response: Most technologies continuously evolve and few ever reach stasis without also becoming obsolete. We expect that we will continue to refine the array technology while also conducting salmon conservation research; the two are inseparable unless funding models change and large amounts of money are granted solely for engineering development work divorced directly from the salmon conservation issues; we view this as extremely unlikely.

When we developed the original pilot-scale design to demonstrate feasibility for Columbia River salmon issues in 2003~04, NOAA's trawl survey work indicated that essentially all Chinook smolts were caught in waters shallower than 200m; we thus set the outer limit to the array to this depth. Since then, based on the acoustic tagging results, we have found that in some years there is an essentially uniform distribution of Chinook smolts out to at least 280m, the current (2010) outer limit of the sub-array at Willapa Bay (however, smolt distribution farther north at Lippy Point is concentrated on the mid and inshore shelf area). Interestingly, NOAA's trawl surveys in the Willapa Bay area since 2007 have consistently captured smolts in 200 m water depths, so it is possible that smolts show wider cross-shelf distribution into deeper waters now than in the early years of the decade. However, the NOAA trawl results (Bi et al., 2007; Figure 3) do show that the probability of capturing juvenile Chinook or coho in the Washington coast trawl survey does go to zero by about 300-600 m bottom depths:

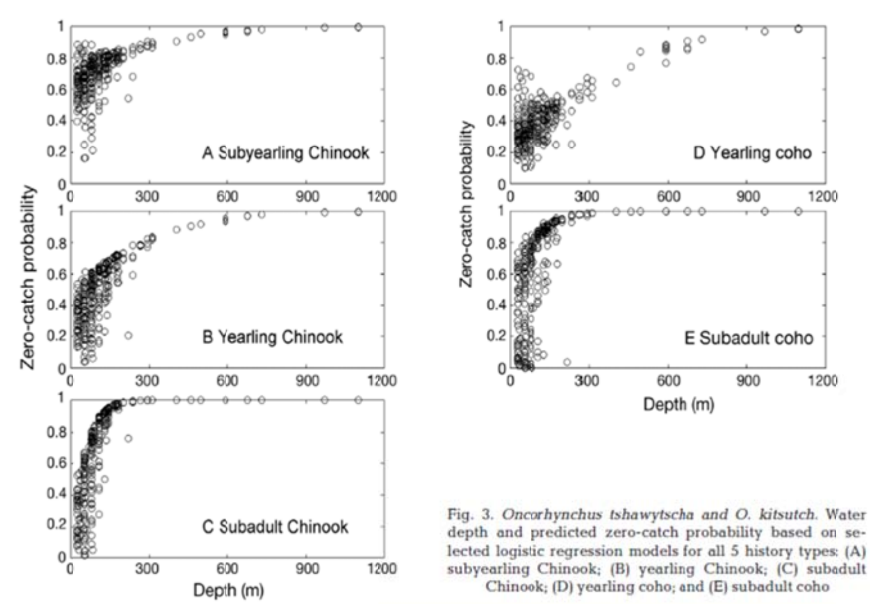


Fig. 3. *Oncorhynchus tshawytscha and O. kitsutch.* Water depth and predicted zero-catch probability based on selected logistic regression models for all 5 history types: (A) subyearling Chinook; (B) yearling Chinook; (C) subadult Chinook; (D) yearling coho; and (E) subadult coho

We suspect that our coastal arrays thus come close to covering most of the smolt migration corridor because the estimated detection probability of the Willapa Bay sub-array, as measured from the ratio of detected/not-detected smolts enumerated on the Lippy Point sub-array is quite close to the detection probability of the sub-arrays within the Salish Sea (Strait of Georgia) once receiver loss to trawlers is taken into account (Melnychuk, 2009, Welch et al., 2009, Melnychuk & Walters, 2010). This suggests that the unbounded outer coast arrays are detecting most migratory smolts; however, as we noted in our proposal, the return of several tagged smolts as adults that were not previously detected as smolts on the ocean array is a cause for concern. We cannot as yet reliably evaluate

whether the return of adults not detected as smolts represents smolts that (1) permanantly migrate off-shelf; (2) take up residence between arrays; or (3) migrated on the shelf but were not detected by the arrays.

We do not currently believe that there are other more cost-effective approaches that we could implement; both the JSATs and HTI technologies use acoustic tags whose frequencies are infeasible for use in the coastal ocean. Furthermore, other than acoustic telemetry, there are no other technoligies that can provide direct, and robust determinations of salmon movements and survival in the coastal ocean: acoustic receiver arrays sample 24x7x365 throughout the whole water column across migration corridors.

The project claims that its methodology is the only experimental technique available for addressing these issues, including early marine survival of salmon. While the approach is innovative and more direct, other studies have used incremental scale and otolith growth to examine size- and life-stage dependent mortality during specific periods at sea.

Response: Projects involving scale or otolith growth are focussed solely on the survivors that return as adults; as a result, it is unclear when (& therefore where) in the life history mortality occurs and how it relates to the growth patterns of the survivors seen in the early life history. In particular, if survival variation later in the life history is large, the interpretation of scale or otolith based early growth patterns may be distorted in complicated ways that confound survival effects later in the marine life history with survival in the early coastal phase. These are not separable if both life history periods are important to adult returns.

The low reported survival at sea is not surprising given the history of low survival rates of yearling and subyearling Chinook salmon based on CWT data. Chinook salmon are well-known to have lower ocean survival rates that other salmon species. The declining survival with distance from the Columbia is expected. For fisheries management, the key information is the evaluation of survival of in-river versus transported smolts. It would be of interest to compare results from CWT and PIT tagged salmon with those from this study and evaluate the benefit of the acoustic tag versus CWT and PIT tag for this management question because the acoustic tag approach is much more costly.

Response: We will attempt to do so in future. Because the number of tags needed to measure juvenile survival over the first few months at sea is much smaller than what is needed to estimate SARs (to adult return) using PIT tags, we believe that the cost of our early marine survival estimates may be roughly comparable - while the cost of the tags differs by approximately one-hundred fold, the acoustic tag sample size needed is only about 1/100th the number needed for PIT tag-based studies. Our ability to compare survivals is however, currently somewhat limited because it takes 3 years for al the adults to return from the sea and generate final SAR estimates; this means that the 2006 acoustic tag survival estimate can be compared with the 2009 SAR estimate, and the 2007 acoustic tag survival estimate can be compared with the 2010 SAR estimate. Although we have acoustic tag survival estimates for

2008, 2009, & 2010, it will be years before the SAR-based estimates are available for comparison.

2. Strategic Plan for COAST Array Location. Does COAST have a strategic plan for COAST array location, developed in cooperation with other Columbia River projects that use or plan to use BPA-funded arrays for their projects? If not, such a plan needs to be developed.

Response: We agree that such a plan would be beneficial. Kintama has developed a large-scale array design, and secured permits for the majority of these arrays (See Figure G-1). Dr. Rich Zabel & NOAA colleagues are proposing to use the exisiting array for acoustic tagging projects in 2012, LT also provides data from our telemetry array to both the POST and Hydra acoustic tag databases, which makes the data available for broader use. However, a broader strategic plan has not been developed, but we would certainly such a process.

We reiterate our suggestion in past reviews that the proponents coordinate development of the COAST acoustic array design with other projects in the Columbia River Basin and ocean, as this issue was inadequately addressed in the proponent's previous response. The proponents assume that Columbia River spring Chinook salmon migrate northward along a coastal corridor that is adequately sampled by the acoustic arrays. However, evidence exists for migratory patterns in other directions (southward, straight offshore). COAST proposes to remove the only listening line located south of the mouth of the Columbia River. The ISRP reiterates our previous recommendation that two ocean listening lines located to the south are needed to demonstrate the feasibility of this project. If COAST is to provide accurate estimates, arrays to the south of the Columbia River and additional tags to expand the proposed study to a 2-directional design are necessary. In addition, a closer examination of the location of arrays with respect to hypothesized locations of juvenile salmon survival bottlenecks is important to developing a strategic plan for potential future locations of arrays.

Response: We agree with the ISRP on the importance of the two southern sub-arrays (particularly for identifying which stocks of spring and fall Chinook move south) and that there are clear statistical benefits to additional tagging, as we

demonstrated in our proposal. However, the 2012-14 proposal request was clearly constrained to current funding levels which forced us to balance several research priorities. Since the ISRP review, we have also responded to an RME workgroup review with the benefit of more recent data, and we are now proposing to move one of our planned northerly sub-arrays to south of the Columbia for 2011 to re-examine southerly migration patterns. More generally, we can readily provide further detailed cost estimates in support of an expanded program incuding more sub-arrays and more tags if additional funding is available.

"A closer examination of the location of arrays. . . to develop a strategic plan" can certainly be developed. We note, however, that the location of sub-arrays is not dictated solely by purely scientific issues - it has taken many years to put together the coastwide permits required, plus much prior planning of locations that would be relatively effective. Factors that need to be taken into account in choosing locations include:

- **good physical locations to prevent gear loss due to natural events**
- **moderate shelf widths to reduce cost**
- **proximity to ports to more rapidly access data and reduce vessel time**
- **reduced impact from commercial fishers to minimize loss and maximize detection rate**

We would be pleased to present this material, but are uncertain as to how to organize this—perhaps as part of the suggested regional workshop?

3. Coordination with other projects. What specific process is used by COAST to coordinate with other projects to estimate survival of Columbia River salmon?

Coordination with other projects has improved, but it could be better. The proponents promise to tie in closely with the CDFO Shelf Survival proposal (#200300900) and the NOAA Ocean Survival of Salmonids proposal (#199801400). All three projects promise a key deliverable - survival. However, the coordination appears rather loose and further information on exactly how the three projects will work together is required.

Response: We have collectively discussed the ISRP's request with the NOAA & DFO groups and are proposing that we will add one specific day of additional coordination and planning to the end of the now annual Salmon Ocean Ecology meeting that all three parties attend. (The 2011 meeting is scheduled for 23-24 March in Seattle). We will use this venue to review our collective results and discuss possible additional collaborative work. Note that under Kintama's 2011 program of work, time is allocated specifically to develop a coordinated program with NOOA for 2012-14.

The only other formal co-ordination we have had was a collaborative effort to compare the survival rates of JSATs and Kintama-tagged smolts in 2010, which Dr Skalski's group at the University of Washington is undertaking. We would welcome suggestions from the ISRP as to additional mechanisms to develop further effective collaborative efforts.

The proposal presents a possibly unbalanced review of VEMCO tags relative to JSATS, and no discussion is provided in reference to McMichael et al. (2010) regarding their survival estimates. Nevertheless it is encouraging to see the increased discussions and joint work with USACE contractors and others working on survival estimates in the lower river and estuary. The ISRP recommends increased coordination with JSATs research in the estuary, since all COAST smolts are proposed to be released below Bonneville Dam. A component linking COAST to the nearshore studies and restoration work in the estuary, however, is missing. As well, the inner estuary proposals (e. g., LCREP, #200300700) should be tied in to the propose COAST work.

Response: Having seen close-up the work of our colleagues at PNNL during the 2010 field season, we have high regard for their professional competence. McMichael et al.'s (2010) paper devoted nearly 2 pages to comparing the strengths and weaknesses of the JSATs technology relative to VEMCO technology, with an emphasis on tag programming and size (Welch recused himself from review of the original manuscript owing to the conflict of interest issue). McMichael et al. (2010) cited tag specifications from our 2006 study (Rechisky et al., 2009), however since 2008 we have used a smaller tag than was used in 2006 (3.1g vs 1.6g), and thus the tag size comparison presented in McMicheal et al. (2010) is outdated.
In addition, we would respectfully suggest that McMichael et al's (2010) paper focussed on the strength of the JSAT's technology, which certainly has a tag burden advantage that allows for tagging smolts at the lowest end of the size distribution, and not on the weaknesses of the technology: it is certainly true that the frequency that the JSATs tag operates is significantly more highly attenuated in salt-water than that of the VEMCO tags which severely limits the use of the former in non fresh-water applications.

Because we have proposed to release smolts at or below Bonneville Dam for 2011 and in future years, we do plan to use JSATs acoustic survival estimates and NOAA PIT tag survival estimates to estimate total juvenile survial of yearling Chinook from the Snake and Columbia rivers to the northern end of Vancouver Island.

Multiple years of acoustic tracking data have demonstrated that spring Chinook from Dworshak and Cle Elum hatcheries migrate very rapidly through the estuary (~80km/day from Bonneville Dam to the Astoria Bridge), therefore residence time in the estuary is very short for these populations and estimated survival is high (80-100% - and PNNL results using JSATs have to date been in agreement with Kintama's). However, if the COAST project finds that smolt behavior in the estuary varies for different genetic stocks (genetic sampling being conducted for all tagged fish in 2011), we agree that the estuary may become a more important factor influencing survival and therefore may warrant an investigation into the sources of mortality in the estuary and the restoration work in progress.

5. Deliverable V. Testing the Delayed Mortality Theory. Can the proponents provide stronger justification for continuation of work on this deliverable? If the work continues, are there other more cost-effective methods for achieving the objective?

Response: The work we are proposing simply takes the data generated from our field work and compares the below Bonneville survival of stocks with low SARs against those with high SARs. Apart from the limited additional costs of analyzing the data this way and writing up the results, there are no additional costs beyond the genetic identification of the tagged fish ($40K)- we specifically laid out the experimental design so that multiple nested hypotheses can be examined simply by changing the animals within each of the groups under comparison.

The Independent Scientific Advisory Board (ISAB 2007-1) advised against continuing efforts to measure absolute latent mortality, suggesting instead that the focus should be on estimating processes such as in-river versus transport mortality that can be measured directly. Proponents acknowledge the ISAB recommendation but argue for continuation in part by citing Welch et al. (Welch et al., 2008), a comparison of the un-dammed Fraser/Thompson River with the dammed Columbia. The ISAB (2007-1) concluded that determining latent mortality relative to a damless reference is not measurable. The argument in the proposal does not convince the ISRP that this ISAB conclusion warrants reconsideration.

Response: In our view it seems prudent to develop common-sense comparisons of survival for different groups of spring Chinook because this perspective is otherwise lacking and we now have the technology to do so. Our published comparisons to date were for i) Fraser (no dams) versus Snake (8 dams), and ii) Yakima (4 dams) versus Snake (8 dams). It seems unlikely that the climate will continue to favour high (and sometimes record) returns of Chinook to the Snake River for much longer, given the predictions from global warming models, so any sensible comparative survival studies that we can develop by contrasting the survival of different groups of Chinook provide valuable information - in the absence of accurate baseline measurements of Snake River Chinook survival prior to the construction of the hydrosystem, this seems to be the next best choice.

Can acoustic tags provide a more accurate and precise estimate of differential delayed (latent) mortality than a similar study approach that used greater numbers of coded wire tagged fish (at a much lower cost)? The acoustic tags estimate survival after a few months, but CWTs measure survival to adults. Has a comparison of the two approaches been made? If research on this objective continues, it would be important to incorporate survival of hatchery versus wild fish into the analysis. Will Chinook salmon tagged by COAST below Bonneville be identified as hatchery versus wild fish? The proposal notes that wild salmon tend to have higher survival rates; therefore, the ratio may affect the survival findings. What is the expected hatchery/wild tagging ratio? It would be interesting to compare data of tagged and untagged Chinook. Also, the study might compare survival rates with those from CWT salmon. This could tell us the fraction of mortality that occurs during early versus late marine life.

Response: As the ISRP notes, acoustic tags estimate survival within the first several months after tagging. The great advantage over PIT tags or CWTs (which estimate net salmon survival to adult return after 2-3 years at sea) is that because much of the marine mortality occurs within the first months after ocean entry, if differential mortality occurrs we would expect to see this difference soon after ocean entry, and acoustic technology provides us with the ability to quantify it. PIT tags or CWTs cannot do this. If Snake River Chinook smolts have lower SARs than non-Snake River fish because of survival differences later in their life history (that may occur for reasons unrelated to anthropogenic influences experienced during hydrosystem migration), then PIT or CWT estimates cannot be used to discriminate this important difference. Therefore, yes, acoustic tags can provide more accurate and precise estimates of differential mortality of juvenile salmonids.

Furthermore, while PIT tags are a fraction of the cost of VEMCO acoustic tags (the cost of which would also be lower if purchased in large volumes), far fewer acoustic tags are required to measure early marine survival. The precise economic trade-off depends on the capital & operational costs for the PIT tag system (mainly operational only at the dams and in tributaries) and the geographically extensive COAST/POST array.

It is our understanding that almost all hatchery Chinook will be adipose-clipped in 2011. We will be tagging a representative sample of run of the river fish and therefore. our sample will be representative of the run at that time greater than 130mm.

6. Detection Efficiencies. The ISRP has a number of questions about tag detection efficiencies that were not addressed in the proposal. What percentages of fish are detected only once, for example, and not again? Are these deemed mortalities or did fish residualize in areas outside of the detection range of arrays? Along the arrays in the ocean, what about fish that migrate close inshore where there are no receivers? And how often are receivers down or lost? On page 22 - the detection range for V7 tags is less than 300m. The detection probability for V7 tags is about 70%. The accuracy and precision of the estimates is questionable. It seems that COAST has given up a lot by going from the V9 to the V7 tag. The depth of a proposed new array at Cape Elizabeth would extend to 500m, but is this depth is beyond the detection range of the V7 tags? Are tagged fish easily detected if they are at or near the surface and the cable is in 500m deep water? What is the effect of wave action on detection of tagged fish?

Response: A substantial amount of the requested information is detailed in our annual reports to BPA. We will endeavour to address other points during the development of our 2010 Annual Report. As for some of the specifics, a brief, and partial, response is provided in the interim:

What percentages of fish are detected only once, for example, and not again?

Single detections represent a very small proportion of the total detections. Details of our data screening procedure can be found in our annual reports.

Are these deemed mortalities or did fish residualize in areas outside of the detection range of arrays?
It is not currently possible to distinguish between these two possibilities.

Along the arrays in the ocean, what about fish that migrate close inshore where there are no receivers?
Any missed fish reduce the estimated detection efficiency. This is true whether they move close to the beach, beyond the outer offshore limit of the sub-array, or simply pass through the sub-array without being detected.

How often are receivers down or lost?
This is addressed in detail in each annual report. It is both year and site-specific. For example, in 2006, the Willapa Bay sub-array suffered ~25% gear loss due to fishing activity. In 2009, however, gear loss was only 11%. For the Lippy Point sub-array gear loss or failure is typically 0%.

On page 22 - the detection range for V7 tags is less than 300m. The detection probability for V7 tags is about 70%. The accuracy and precision of the estimates is questionable.
The accuracy and precision of the array *design software* is based on exact equations and is not subject to error (except with respect to predicting the detection efficiency of the sub-arrays, as this is site-specific). If the ISRP is referring to the *results* from prior years, then precision is based on the accepted standard of the CJS methodology. In Kintama's view, "*accuracy*" is a biological issue, not a statistical one - if we reduce survival of tagged animals relative to the untagged fish our results are innacurate. (This is why we compare the survival of our tagged fish with NOAA's PIT-tagged animals, as it gives us an objective basis for assessing whether the Kintama survival estimates are accurate by comparing the results with a known baseline). In statistical parlance, our results are accurate (unbiased) if our tagged fish have the same survival as their untagged counterparts.

It seems that COAST has given up a lot by going from the V9 to the V7 tag.
We agree, but felt that we had little choice - many in the biological community were dismissing our results (of equal survival of Snake & Yakima smolts, for example) because we only used smolts >14 cm with the V9 tag, and therefore the argument was made that our findings might not apply to smaller fish. The move to the V7 tag was partly intended to address this issue while we developed the array designs for even smaller V5 & V6 tags.

The depth of a proposed new array at Cape Elizabeth would extend to 500m, but is this depth is beyond the detection range of the V7 tags?
When acoustic nodes are deployed in deeper water the receivers are positioned near the surface. Our preferred placement depth is 150m below the surface or 3~5m

above the seabed for shallower locations; all of our reported detection efficiency results are based on this design strategy.

Are tagged fish easily detected if they are at or near the surface and the cable is in 500m deep water?
Yes, because in deeper water, only the anchor is at the bottom; the receiver is suspended in the water column such that it is near the surface.

What is the effect of wave action on detection of tagged fish?
Generally, it increases ambient noise levels, and thus decreases detection efficiency. "Weather" related effects are included in the reported detection efficiency results.

7. Genetic stock identification (GSI). How many genetic stocks of juvenile spring Chinook salmon can be identified by the proposed GSI? Procedures for GSI need to be described. Proponents need to demonstrate that current techniques are capable of identifying origins of individual fish that are tagged and released. Ocean studies should advance toward designs that can also evaluate differences/similarities in survival of hatchery vs. wild fish of the same genetic stock. Is there a way to standardize genetic stock identification methods so that results of the three BPA-funded ocean projects are directly comparable (different labs are using different methods)?

Response: Dr. Narum of CRTFC, to whom we are subcontracting this work, recommends that we use his panel of SNP markers to allow initially identifying each fish to an ESU, and then deal with more complex stock assignments within the Columbia Basin. We are advised by Dr. Narum that the inclusion of microsatellite markers is unnecessary and will make the project considerably more expensive if we were to genotype both SNPs and microsatellites. Narum's panel of SNP markers includes 75 loci that have been standardized among genetics labs, along with additional markers that will allow us to address specific issues in the Columbia Basin.

While there are many benefits of standardizing markers for baselines (which the genetics community has done), GSI applications vary widely and a standardized approach for determining stock proportions in mixtures cannot suit all needs. For example, field studies on ocean-caught smolts may be satisfied with assignment to ESU level, while others (including Kintama's proposal) require finer scale assessment of stocks. Further, fine scale applications in the Columbia Basin have issues of complexity that differ greatly from other areas such as Puget Sound and BC (each regional area has specific problems regarding stock separation). We note that the Pacific Salmon Commission has already held some in-depth workshops regarding GSI with broad participation and the workgroups have developed recommendations available at: http://www. psc.org/info_genetic_stock_id.htm# REPORTS.

8. Definition of the plume. Why is the plume defined as Sand Island to Willapa Bay? The proponents' definition of the plume (Sand Island to Willapa Bay) is very different than accepted terminology, and the proposal would be improved by an explanation as why they chose this definition. The plume is usually described as outside the Columbia River bar, and the plume disperses both to the north along the Washington coastline and to the south along the Oregon coastline.

Response: Our definition is operational, and is defined by regions where we believe we can effectively deploy telemetry sub-arrays. The plume is a major feature within the Astoria/Sand Island to Willapa Bay region. In the future we will define the plume using the accepted terminology, and state that the migration segment from Astoria/Sand Island to Willpa Bay (and any lines to the south) encompasses the plume.

9. Alternatives to Fixed Arrays. Are there other more innovative techniques than fixed acoustic arrays that could be employed in the future to track open coast and ocean distribution, migration patterns, and survival of Columbia River spring Chinook? For example, what about the use of robotic vehicles to measure ocean conditions and track tagged salmon to extend coverage beyond the detection range of fixed listening lines on the continental shelf/slope?

Response: Dr. John Payne of POST began experimenting with gliders in a collaboration with UW/APL researchers this year (See http://mediaglide.com/view/1479/ or the "*November 2010 POST e-Blast*" email). The trial picked up one of our tagged smolts over the Washington shelf north of the Columbia (near La Push). However, while we are interested in and support the concept of POST's glider research, we are sceptical that it will become a cost-effective alternative to fixed arrays for detailed survivval and tracking studies in the forseeable future. We assessed the use of gliders back in the 2001~02 period. At present, the approach still remains more expensive, more labor-intensive, and more difficult to both interpret (the position of the glider must be estimated for each fish detection) and analyze (with gliders continuously moving about, the concept of detection efficiency does not really apply). Nevertheless, receiver-borne gliders have some utility in truly deep offshore waters, but we feel that our current array deployment technology is probably effective in waters of up to at least 1,000m.

10. Scientific workshop. The ISRP recommends a scientific workshop in 2011 focused on estimation of estuarine and ocean survival, forecasting of adult returns, and adaptive estuary, plume, and ocean environmental assessment for Columbia River Basin salmon and steelhead. Perhaps the proposal should include this workshop. A workshop would help to improve coordination and collaboration, standardization of methods (e.g., genetic stock identification), development of simulation and predictive models, and integration of results among Columbia River Basin estuary/ocean projects. One aspect of all projects that needs work is how to include more detail on sub-stock structure, including hatchery

versus wild fish, hatchery release time, area comparisons, in-river migration and associated ocean migration, and more in the models.

Response: We will develop a joint coordination meeting between NOAA, DFO, and Kintama that will discuss some of these topics at an additional day added on to the annual Ocean Ecology of Salmon workshop (end of March 2011) at which the participants will be attending.

11. Adaptive management. Is it possible that tagging experiments could be designed in concert with hatchery, hydrosystem, and harvest managers to test specific hypotheses related to estuarine and early ocean survival? Are the proponents overselling their ability to use this approach to improve real-time management of spill and transport? How can adaptive management with respect to estimates of ocean survival be implemented in the Columbia River system?

Response: We believe it is possible to develop these specific tagging experiments and would welcome the opportunity to explore this further with managers. It should be possible to relate both spill levels (=flow rates) and transport effort to salmon conservation, since at times when ocean survival rates are lower than in the hydrosystem, retaining the smolts longer in the river would be beneficial to their conservation. A model to predict periods within years when $S_{FW}<S_{Ocean}$ is necessary and would likely be based on oceanographic variables, and amongst these variables identify triggers of poor salmon survival. The key to our proposed work is that the only technology that is capable of relating these measures <u>directly</u> to early ocean survival of salmonid smolts is acoustic telemetry.

The proposal would be improved by further details on how POST results have influenced on-the-ground management decisions by fishery or hydrosystem agencies. For example, has the Welch et al. (2008) paper ("Survival of migrating salmon smolts in large rivers with and without dams") resulted in any changes in operations of the Columbia River Basin dams? How do COAST indicators tie in with those being developed by CDFO, NOAA, and other projects in this review?

Response: We are in the early stage of relating our along-shelf measurements of survival with NOAA & DFO's measurements; at the date of writing, we now have 4 data points on directly measured ocean survival (2006, 2008, 2009, 2010) that we can compare with NOAA & DFO's ocean surveys. The time series is thus just barely long enough to provide some insight into how well the two approaches can mesh.

In the past several reviews, the ISRP asked, "How would the fully-implemented ocean array and long-term monitoring data on seasonal and interannual variations in survival rates or migration rates among years or stocks actually be used by managers of the Columbia River Basin hydrosystem?" The ISRP agrees with the proponents' past response that estimates of ocean survival for tagged release groups of hatchery fish can be used to inform policy makers, fishery managers, and researchers. However, the proponents have never answered the ISRP's question about how hydrosystem managers would actually use the data. The proponents still do not seem to recognize that ocean variability will make the concept of tracking the geography of ocean mortality and subsequent adjustment of hydropower system very difficult to manage.

Response: Although we do not wish to minimize the complexity of developing models/triggers **that can be used for real-time management, the basic points that are coming out of our research are clear:**

1. **In years when $S_{Ocean} < S_{Hydrosystem}$, transporting the smolts around the hydrosystem would be counterproductive, because barging would result in fewer adults returning than if they were left in-river to migrate of their own volition. (This corresponds to the years when the T:IR SAR ratios are <1, which currently occurs about half the time). Hydrosystem managers could use this result to determine whether to barge or to spill water to accelerate or retard smolt arrival in the ocean.**
2. **Testing the survival versus release date/time of ocean entry/size at release of tagged hatchery smolts could inform hatchery management by identifying best practices for release that improves the number of adults that return, thereby improving hatchery economics. Managers could use these results to direct the improvement of hatchery production processes, quickly identifying strategies that improve the adult returns from hatchry releases.**
3. **Identifying (by daily releases of tagged smolts) ocean survival patterns on a daily basis and relating them to, say, satellite remote sensing data, it may be possible to identify simple measurements (e.g. , ocean color) to indicate when hatchery releases should be timed to occur, or spill ramped up or decreased to accelerate or retard the arrival of the wild smolts in the ocean during windows of favorable survival. Managers could thus use the array to learn what patterns of ocean conditions promote survival in the ocean and what patterns degrade survival in the ocean, and thus manage accordingly.**
4. **If we can demonstrate to most people's satisfaction that delayed (latent) mortality effects of the hydrosystem do _*not*_ influence survival in the ocean, then this divorces hydrosystem operations from blame for subsequent poor ocean survival after the smolts leave the river. If this point is accepted, then monitoring survival to some defined point (say, Astoria) and showing that freshwater survival remained high in a smolt migration year that led to a catastrophic failure of the adults to return would then credibly make the case that the hydrosystem operations were not responsible for the failure of the adult run. This would thus allow a clear demonstration that low SARS were not the result of freshwater influences but were the result of factors operating out in the ocean that were beyond the hydrosystem managers control. This would be of importance to Columbia River managers if a collapse were to occur that was similar to Snake River Spring Chinook SARS in the 1990s or the catastrophic collapses of Sacramento R Chinook or Fraser River sockeye returns in several recent years. Without such data, it would likely not be possible to provide a defensible response that the hydrosystem management had in fact achieved its goals and was still in compliance.**

The project is clearly significant to regional programs, but the proposal could be improved by attention to unrealistic objectives and expectations that implementation of acoustic tagging technology would result in improved real-time management of spill and transport. The proponents state that the latter two options could be decided upon by measurement of marine survival with their methods: "For example, if marine survival is exceptionally low, transportation and/or increased spill may not be beneficial, as smolts would reach the ocean sooner thereby exposing them to unfavorable ocean conditions (e.g., increased predation or decreased food supply), leading to lower survival. " Explain the specific processes that would be used to achieve real-time management. Do managers think this process would work?

Response: As above, the point about "real-time management" depends upon the definition. Satellite remote sensing could provide "real-time" monitoring if the latency in the system is low and the satellites can monitor some process that is tightly coupled with salmon survival. Alternatively, in principle survival data could be up-loaded from the coastal arrays near the Columbia River on a daily basis and fed back into the management system. The technology itself is not unrealistic, the question is whether we can use the COAST array to successfully identify either survival or processes that are tightly linked to survival and turn that data around into an accepted product that managers will use. The two key steps here are to:

1. **successfully make the scientific link between ocean conditions and smolt survival and**
2. **Gain acceptance from managers for the use of the technology.**

The sociological issues surrounding change in the workplace are probably hardest, and making the scientific linkage to reliable indices of survival likely somehwat easier. The technological challenges of producing "real-time" survival results (say, within a day of their occurrence) are relatively straightforward (but could be expensive depending upon the approach adopted).

12. Communicating Results. Can the proponents develop more effective approaches for communicating their results directly to Columbia River Basin hatchery, hydrosystem, and harvest managers? Websites, scientific meetings, and peer-review scientific publication are excellent methods for communicating with scientific peers, other government agencies, educational institutions, and conservation organizations, but are likely not effective tools for communicating directly with hydro, harvest, and hatchery managers.

Response: Since 2006 we have attended the Army Corp of Engineers Anadromous Fish Evaluation Program (AFEP) Annual Review in order to communicate our results more broadly, since this meeting is attended by a wide range of Columbia basin researchers and managers. In the past we have also been invited to present our results to researchers and hatchery managers at the Yakima Basin Aquatic Science and Management Conference. If there are basin-wide joint meetings of

hydro, harvest, and hatchery managers, we would be pleased to present and discuss our results; however we are not always aware of any such gatherings. Can the ISRP advise how better to communicate with such parties?

13. Update Online Proposal Format. The format of this proposal was confusing and difficult to follow. Proponents should reformat their online proposal to better conform to the specific information requested in each section of the online form. The repetition of the same deliverables under several objectives seems unnecessarily repetitive. Objectives providing the same deliverables could be combined into one objective. The important information on study design that was included only as an attachment should be incorporated into the online form. The online form should present the complete proposal as a stand-alone document.

Response: The cut and paste nature of the current web submission interface resulted in severe limitations in proposal design, and we found this frustrating as well. Although the web-based proposal was functional and reasonably bug-free, we found that information requested was also repetitive, it being designed for a range of projects of which perhaps the COAST one is not a best example: thus, while to our eyes we thought we had limited the repetition as best we could given the stated requirements, we accept that we may not have been as succesful as we thought.

In most cases we tried to include all of the details within each section; however, it was necessary to attach an external document containing the power analyses because of the difficulty in pasting mathmatical equations in the online form – after several efforts a decision was made that this was the only reasonable solution given that we wanted to provide ISRP the full analyses. (The submission interface only allows cut and paste of individual mathematical symbols and allows no control over typesetting of groups of symbols into equations).

References

Abdul-Aziz, O.I., Mantua, N.J. and Myers, K.W. (2011) Potential climate change impacts on thermal habitats of Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean and adjacent seas. *Can. J. Fish. Aquat. Sci.,* **68,** 1660-1680.

Armstrong, J.L., Boldt, J.L., Cross, A.D., Moss, J.H., Davis, N.D., Myers, K.W., Walker, R.V., Beauchamp, D.A. and Haldorson, L.J. (2005) Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. *Deep-Sea Res, Part II,* **52,** 247-265.

Armstrong, J.L., Myers, K.W., Beauchamp, D.A., Davis, N.D., Walker, R.V., Boldt, J.L., Piccolo, J.J., Haldorson, L.J. and Moss, J.H. (2008) Interannual and Spatial Feeding Patterns of Hatchery and Wild Juvenile Pink Salmon in the Gulf of Alaska in Years of Low and High Survival. *Trans. Am. Fish. Soc.,* **137,** 1299-1316.

Barnett-Johnson, R., Teel, D.J. and Casillas, E. (2010) Genetic and otolith isotopic markers identify salmon populations in the Columbia River at broad and fine geographic scales. *Environ. Biol. Fishes,* **89,** 533-546.

Batten, S.D. and Freeland, H.J. (2007) Plankton populations at the bifurcation of the North Pacific Current. *Fish. Oceanogr.,* **16,** 536-546.

Beacham, T.D., Candy, J.R., McIntosh, B., MacConnachie, C., Tabata, A., Kaukinen, K., Deng, L.T., Miller, K.M., Withler, R.E. and Varnavskaya, N. (2005) Estimation of stock composition and individual identification of sockeye salmon on a Pacific Rim basis using microsatellite and major histocompatibility complex variation. *Trans. Am. Fish. Soc.,* **134,** 1124-1146.

Beacham, T.D., Candy, J.R., Jonsen, K.L., Supernault, J., Wetklo, M., Deng, L.T., Miller, K.M., Withler, R.E. and Varnavskaya, N. (2006a) Estimation of stock composition and individual identification of Chinook salmon across the Pacific Rim by use of microsatellite variation. *Trans. Am. Fish. Soc.,* **135,** 861-888.

Beacham, T.D., Jonsen, K.L., Supernault, J., Wetklo, M., Deng, L.T. and Varnavskaya, N. (2006b) Pacific Rim population structure of Chinook salmon as determined from microsatellite analysis. *Trans. Am. Fish. Soc.,* **135,** 1604-1621.

Beacham, T.D., McIntosh, B., MacConnachie, C., Miller, K.M. and Withler, R.E. (2006c) Pacific rim population structure of Sockeye salmon as determined from microsatellite analysis. *Trans. Am. Fish. Soc.,* **135,** 174-187.

Beacham, T.D., Candy, J.R., Wallace, C., Sato, S., Urawa, S., Varnavskaya, N., Le, K.D. and Wetklo, M. (2008) Microsatellite stock identification of chum salmon on a Pacific Rim basis and a comparison with single nucleotide polymorphisms (SNPs). NPAFC Doc. 1105. (Available at http://www.npafc.org). 77pp.

Beacham, T.D., Candy, J.R., Wallace, C., Urawa, S., Sato, S., Varnavskaya, N.V., Le, K.D. and Wetklo, M. (2009) Microsatellite Stock Identification of Chum Salmon on a Pacific Rim Basis. *N. Am. J. Fish. Manage.,* **29,** 1757-1776.

Beacham, T.D., McIntosh, B. and Wallace, C. (2010) A comparison of stock and individual identification for sockeye salmon (*Oncorhynchus nerka*) in British Columbia provided by microsatellites and single nucleotide polymorphisms. *Can. J. Fish. Aquat. Sci.,* **67,** 1274-1290.

Beacham, T.D., Candy, J.R., Porszt, E., Sato, S. and Urawa, S. (2011) Microsatellite Identification of Canadian Sockeye Salmon Rearing in the Bering Sea. *Trans. Am. Fish. Soc.,* **140,** 296-306.

Beacham, T.D., Candy, J.R., Wallace, C., Wetklo, M., Deng, L.T. and MacConnachie, C. (In press) Microsatellite stock identification of coho salmon in British Columbia. *Mar. Coast. Fish.*

Beacham, T.D., Jonsen, K.L. and Wallace, C. (In review) A comparison of stock and individual identification for Chinook salmon (*Oncorhynchus tshawytscha*) in British Columbia provided by microsatellites (STRs) and single nucleotide polymorphis(SNPs). *Fish. Bull.*

Beamish, R.J. and Mahnken, C. (2001) A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Prog. Oceanogr.,* **49,** 423-437.

Bi, H., Ruppel, R.E. and Peterson, W.T. (2007) Modeling the pelagic habitat of salmon off the Pacific Northwest (USA) coast using logistic regression. *Mar. Ecol. Prog. Ser.,* **336,** 249-265.

Brodeur, R.D., Daly, E.A., Schabetsberger, R.A. and Mier, K.L. (2007) Interannual and interdecadal variability in juvenile coho salmon (*Oncorhynchus kisutch*) diets in relation to environmental changes in the northern California Current. *Fish. Oceanogr.,* **16,** 395-408.

Campbell, L.A. (2010) Life histories of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River estuary as inferred from scale and otolith microchemistries. Fisheries and Wildlife. Corvallis, OR, Oregon State University, M.Sc. Thesis.

DiMaria, R., Miller, J. and Hurst, T. (2010) Temperature and growth effects on otolith elemental chemistry of larval Pacific cod, *Gadus macrocephalus*. *Environ. Biol. Fishes,* **89,** 453-462.

Donohoe, C.J., Adams, P.B. and Royer, C.F. (2008) Influence of water chemistry and migratory distance on ability to distinguish progeny of sympatric resident and anadromous rainbow trout (*Oncorhynchus mykiss*). *Can. J. Fish. Aquat. Sci.,* **65,** 1060-1075.

Ehrenberg, J.E. and Steig, T.W. (2009) A study of the relationship between tag-signal characteristics and achievable performances in acoustic fish-tag studies. *ICES J. Mar. Sci.,* **66,** 1278-1283.

Elsdon, T.S., Wells, B.K., Campana, S.E., Gillanders, B.M., Jones, C.M., Limburg, K.E., Secor, D.H., Thorrold, S.R. and Walther, B.D. (2008) Otolith chemistry to describe movements and life-history parameters of fishes: Hypotheses, assumptions, limitations and inferences. In: *Oceanography and Marine Biology: An Annual Review, Vol 46.* R.N. Gibson, R.J.A. Atkinson and J.D.M. Gordon (eds). p. 297.

Emmett, R.L., Brodeur, R.D. and Orton, P.M. (2004) The vertical distribution of juvenile salmon (Oncorhynchus spp.) and associated fishes in the Columbia River plume. *Fish. Oceanogr.,* **13,** 392-402.

Faulkner, J.R., Smith, S.G., Muir, W.D., Marsh, D.M. and Williams, J.G. (2010) Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2010. Portland, Oregon: Report to the Bonneville Power Administration http://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=P120402, 100 (2010).

Fisk, A.T., Hobson, K.A. and Norstrom, R.J. (2001) Influence of chemical and biological factors on trophic transfer of persistent organic pollutants in the northwater polynya marine food web. *Environ. Sci. Technol.,* **35,** 732-738.

Giorgi, A., Skalski, J.R., Peven, C., Langeslay, M., Smith, S., Counihan, T., Perry, R. and Bickford, S. (2010) Guidelines for conducting smolt survival studies in the Columbia River. In: *Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities. Pacific Northwest Aquatic Monitoring Partnership (PNAMP) Special Publication 2010-002.* K.S. Wolf and J.S. O'Neal (eds). Chapter 3, (http://www.pnamp.org/node/2867). pp. 47-48.

Grimes, C.B., Brodeur, R.D., Haldorson, L.J. and McKinnell, S.M. (2007) *The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons.* American Fisheries Society, Symposium 57, Bethesda, MD.

Habicht, C., Seeb, L.W. and Seeb, J.E. (2007) Genetic and ecological divergence defines population structure of sockeye salmon populations returning to Bristol Bay, Alaska, and provides a tool for admixture analysis. *Trans. Am. Fish. Soc.,* **136,** 82-94.

Hanson, M.B., Baird, R.W., Ford, J.K.B., Hempelmann-Halos, J., Van Doornik, D.M., Candy, J.R., Emmons, C.K., Schorr, G.S., Gisborne, B., Ayres, K.L., Wasser, S.K., Balcomb, K.C., Balcomb-Bartok, K., Sneva, J.G. and Ford, M.J. (2010) Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. *Endanger. Spec. Res.,* **11,** 69-82.

Hoffman, J.C. and Sutton, T.T. (2010) Lipid correction for carbon stable isotope analysis of deep-sea fishes. *Deep-Sea Res, Part I,,* **57,** 956-964.

Iwamoto, E.M., Myers, J.M. and Gustafson, R.G. (In press) Resurrecting an extinct salmon evolutionarily significant unit: archived scales, historical DNA, and implications for restoration. *Mol. Ecol.*

Jacobson, K.C., Teel, D., Van Doornik, D.M. and Casillas, E. (2008) Parasite-associated mortality of juvenile Pacific salmon caused by the trematode *Nanophyetus salmincola* during early marine residence. *Mar. Ecol. Prog. Ser.,* **354,** 235-244.

Kennedy, B.P., Klaue, A., Blum, J.D., Folt, C.L. and Nislow, K.H. (2002) Reconstructing the lives of fish using Sr isotopes in otoliths. *Can. J. Fish. Aquat. Sci.,* **59,** 925-929.

Kraus, R.T. and Secor, D.H. (2004) Incorporation of strontium into otoliths of an estuarine fish. *J. Exp. Mar. Biol. Ecol.,* **302,** 85-106.

Limburg, K.E. (1995) Otolith strontium traces environmental history of subyearling American shad Alosa sapidissima. *Mar. Ecol. Prog. Ser.,* **119,** 25-35.

Litz, M.N.C., Phillips, A.J., Brodeur, R.D. and Emmett, R.L. (2011) Seasonal occurrences of Humboldt squid (*Dosidicus gigas*) in the northern California Current System. *CALCOFI Rep,* **52,** 97-108.

McConnaughey, T. and McRoy, C.P. (1979) Food web structure and the fractionation of carbon stable isotopes in the Bering Sea. *Mar. Biol.,* **53,** 257-262.

McMichael, G.A., Eppard, M.B., Carlson, T.J., Carter, J.A., Ebberts, B.D., Brown, R.S., Weiland, M., Ploskey, G.R., Harnish, R.A. and Deng, Z.D. (2010) The Juvenile Salmon Acoustic Telemetry System: A New Tool. *Fisheries,* **35,** 9-22.

Melnychuk, M.C. (2009) Estimation of survival and detection probabilities for multiple tagged salmon stocks with nested migration routes, using a large-scale telemetry array. *Marine and Freshwater Research,* **60,** 1231-1243.

Melnychuk, M.C. and Walters, C.J. (2010) Estimating detection probabilities of tagged fish migrating past fixed receiver stations using only local information. *Can. J. Fish. Aquat. Sci.,* **67,** 641-658.

Miller, J.A. (2009) The effects of temperature and water concentration on the otolith incorporation of barium and manganese in black rockfish Sebastes melanops. *J. Fish Biol.,* **75,** 39-60.

Miller, J.A. and Kent, A.J.R. (2009) The determination of maternal run time in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) based on Sr/Ca and (87)Sr/(86)Sr within otolith cores. *Fish. Res.,* **95,** 373-378.

Miller, J.A., Bellinger, M.R., Golden, J.T., Fujishin, L. and Banks, M.A. (2010a) Integration of natural and artificial markers in a mixed stock analysis of Chinook salmon (*Oncorhynchus tshawytscha*). *Fish. Res.,* **102,** 152-159.

Miller, J.A., Gray, A. and Merz, J. (2010b) Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon *Oncorhynchus tshawytscha*. *Mar. Ecol. Prog. Ser.,* **408,** 227-240.

Mintenbeck, K., Brey, T., Jacob, U., Knust, R. and Struck, U. (2008) How to account for the lipid effect on carbon stable-isotope ratio (delta C-13): sample treatment effects and model bias. *J. Fish Biol.,* **72,** 815-830.

Morris, J.F.T., Trudel, M., Welch, D.W., Thiess, M.E. and Zubkowski, T. (2004) Canadian Highseas Salmon surveys: CWT recoveries from juvenile Chinook and coho salmon on the continental shelf of British Columbia and southeast Alaska from 1998 to 2003. *N. Pac. Anadrom. Fish. Comm., Doc.,* **823**.

Narum, S.R., Banks, M., Beacham, T.D., Bellinger, M.R., Campbell, M.R., Dekoning, J., Elz, A., Guthrie, C.M., Kozfkay, C., Miller, K.M., Moran, P., Phillips, R., Seeb, L.W., Smith, C.T., Warheit, K., Young, S.F. and Garza, J.C. (2008) Differentiating salmon populations at broad and fine geographical scales with microsatellites and single nucleotide polymorphisms. *Mol. Ecol.,* **17,** 3464-3477.

Narum, S.R., Hess, J.E. and Matala, A.P. (2010) Examining Genetic Lineages of Chinook Salmon in the Columbia River Basin. *Trans. Am. Fish. Soc.,* **139,** 1465-1477.

Pearcy, W.G. (1992) *Ocean ecology of North Pacific salmonids.* Washington Sea Grant Program, University of Washinton Press, Seattle, WA, 179pp.

Peterson, W.T. and Schwing, F.B. (2003) A new climate regime in northeast pacific ecosystems. *Geophys. Res. Lett.,* **30**.

Peterson, W.T. (2009) Copepod species richness as an indicator of long term changes in the coastal ecosystem of the northern California Current. *CALCOFI Rep,* **50,** 73-81.

Peterson, W.T., Morgan, C.A., Fisher, J.P. and Casillas, E. (2010) Ocean distribution and habitat associations of yearling coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*) salmon in the northern California Current. *Fish. Oceanogr.,* **19,** 508-525.

Porter, A.D., Welch, D.W., Rechisky, E.L., Challenger, W.O., Scott, M.C.J., Lydersen, H., Winchell, P.M., Neaga, L., Robb, J.D. and Muirhead, Y.K. (2011) Marine and freshwater measurement of delayed and differential-delayed mortality of Columbia & Snake River yearling Chinook smolts using a continental-scale acoustic-telemetry array, 2010. Portland, Oregon: Report to the Bonneville Power Administration by Kintama Research Services Ltd., Contract No. 46389, Project No. 2003-114-00. p. 492 pp.

Post, D.M., Layman, C.A., Arrington, D.A., Takimoto, G., Quattrochi, J. and Montana, C.G. (2007) Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. *Oecologia,* **152,** 179-189.

Prairie, Y.T. (1996) Evaluating the predictive power of regression models. *Can. J. Fish. Aquat. Sci.,* **53,** 490-492.

Rasmussen, J.B., Rowan, D.J., Lean, D.R.S. and Carey, J.H. (1990) Food chain structure in Ontario lakes determines PCB levels in lake trout (*Salvelinus namaycush*) and other pelagic fish. *Can. J. Fish. Aquat. Sci.,* **47,** 2030-2038.

Rechisky, E.L., Welch, D.W., Porter, A.D., Jacobs, M.C. and Ladouceur, A. (2009) Experimental measurement of hydrosystem-induced delayed mortality in juvenile Snake River spring Chinook salmon (*Oncorhynchus tshawytscha*) using a large-scale acoustic array. *Can. J. Fish. Aquat. Sci.,* **66,** 1019-1024.

Rechisky, E.L. and Welch, D.W. (2010) Surgical implantation of acoustic tags: Influence of tag loss and tag-induced mortality on free-ranging and hatchery-held spring Chinook (*O. tschawytscha*) smolts. In: *PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations. A Compendium of New and Recent Science for Use in Informing Technique and Decision Modalities. The Pacific Northwest Aquatic Monitoring Partnership.* K.S. Wolf and J.S. O'Neal (eds). Special Publication 2010-002, Duvall, WA. pp. 71-96.

Secor, D.H., Hendersonarzapalo, A. and Piccoli, P.M. (1995) Can otolith microchemistry chart patterns of migration and habitat utilization in anadromous fishes? *J. Exp. Mar. Biol. Ecol.,* **192,** 15-33.

Seeb, L.W., Antonovich, A., Banks, A.A., Beacham, T.D., Bellinger, A.R., Blankenship, S.M., Campbell, A.R., Decovich, N.A., Garza, J.C., Guthrie, C.M., III, Lundrigan, T.A., Moran, P., Narum, S.R., Stephenson, J.J., Supernault, K.J., Teel, D.J., Templin, W.D., Wenburg, J.K., Young, S.E. and Smith, C.T. (2007) Development of a standardized DNA database for Chinook salmon. *Fisheries,* **32,** 540-552.

Sokal, R.R. and Rohlf, F.J. (1995) *Biometry. 3rd edition.* W. H. Freeman and Company, New York.

Tarroux, A., Ehrich, D., Lecomte, N., Jardine, T.D., Bety, J. and Berteaux, D. (2010) Sensitivity of stable isotope mixing models to variation in isotopic ratios: evaluating consequences of lipid extraction. *Methods Ecol. Evol.,* **1,** 231-241.

Teel, D.J., Van Doornik, D.M., Kuligowski, D.R. and Grant, W.S. (2003) Genetic analysis of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington reveals few Columbia River wild fish. *Fish. Bull.,* **101,** 640-652.

Trudel, M., Tucker, S., Zamon, J.E., Morris, J., Higgs, D.A. and D.W. Welch, D. (2002) Bioenergetic response of coho salmon to climate change. N. Pac. Anadrom. Fish Comm, Tech. Rep. 59-61pp.

Trudel, M., Fisher, J.P., Orsi, J.A., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Fergusson, A. and Welch, D.W. (2009) Distribution and migration of juvenile Chinook salmon derived from coded wire tag recoveries along the continental shelf of western North America. *Trans. Am. Fish. Soc.,* **138,** 1369-1391.

Trudel, M., Thiess, M.E., Morris, J.F.T., Zubkowski, T. and Mackas, D.L. (2011) Canada-USA Salmon Shelf Survival Study. Annual Report submitted to the Bonneville Power Administration. 117pp.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C., Teel, D.J., Crawford, W., Farley, E.V. and Beacham, T.D. (2009) Seasonal Stock-Specific Migrations of Juvenile Sockeye Salmon along the West Coast of North America: Implications for Growth. *Trans. Am. Fish. Soc.,* **138,** 1458-1480.

Tucker, S., Trudel, M., Welch, D.W., Morris, J.F.T., Candy, J.R., Wallace, C. and Beacham, T.D. (2011) Life-history and seasonal stock-specific ocean migration of juvenile Chinook salmon. *Trans. Am. Fish. Soc.,* **140,** 1101-1119.

Van Doornik, D.M., Teel, D.J., Kuligowski, D.R., Morgan, C.A. and Casillas, E. (2007) Genetic analyses provide Insight into the early ocean stock distribution and survival of juvenile coho salmon off the coasts of Washington and Oregon. *N. Am. J. Fish. Manage.,* **27,** 220–237.

Volk, E.C., Bottom, D.L., Jones, K.K. and Simenstad, C.A. (2010) Reconstructing Juvenile Chinook Salmon Life History in the Salmon River Estuary, Oregon, Using Otolith Microchemistry and Microstructure. *Trans. Am. Fish. Soc.,* **139,** 535-549.

Weber, P.K. (2002) Geochemical markers in the otoliths of Chinook salmon in the Sacramento-San Joaquin River system, California. Geography. Berkeley, CA, University of California, Ph.D. Thesis.

Weitkamp, L.A. and Emmett, R.L. (2006) Juvenile pink and chum salmon in the northern California Current. In: *Proceedings: The 22nd Northeast Pacific Pink and Chum Workshop.* J. Geiger (ed.) Cape Fox Hotel, Ketchikan, Alaska, February 23-25, 2005. pp. 129-136.

Weitkamp, L.A. and Bentley, P. (2009) Ocean ecology of juvenile pink and chum salmon in the Northern California Current. Proceedings of the pink & chum workshop. Bellingham, WA, February 2008.

Welch, D.W., Ward, B.R. and Batten, S.D. (2004) Early ocean survival and marine movements of hatchery and wild steelhead trout (*O. mykiss*) determined by an acoustic array: Queen Charlotte Strait, British Columbia. *Deep-Sea Research,* **51,** 897-909.

Welch, D.W., Rechisky, E.L., Melnychuk, M.C., Porter, A.D., Walters, C.J., Clements, S., Clemens, B.J., McKinley, R.S. and Schreck, C. (2008) Survival of Migrating Salmon Smolts in Large Rivers With and Without Dams (vol 6, pg 265, 2008). *PLoS Biol.,* **6,** 2940-2940.

Welch, D.W., Melnychuk, M.C., Rechisky, E.R., Porter, A.D., Jacobs, M.C., Ladouceur, A., McKinley, R.S. and Jackson, G.D. (2009) Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (Oncorhynchus nerka) smolts using POST, a large-scale acoustic telemetry array. *Can. J. Fish. Aquat. Sci.,* **66,** 736-750.

Zimmerman, C.E. (2005) Relationship of otolith strontium-to-calcium ratios and salinity: experimental validation for juvenile salmonids. *Can. J. Fish. Aquat. Sci.,* **62,** 88-97.