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# Canadian Bibliography of 2010-2012 Publications Linked to the Current NPAFC Science Plan

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## Abstract

The current bibliography lists publications in primary scientific journals and other documents published during 2010-2012 by Fisheries and Oceans Canada scientists and their collaborators relevant to the 2011-2015 NPAFC Science Plan. The bibliography lists 79 papers with abstracts, corresponding to the five key research components of the NPAFC Science Plan.

## Introduction

The Science Sub-Committee of the North Pacific Anadromous Fish Commission (NPAFC) developed a five-year Science Plan (2011-2015) with five research components: 1) Migration and survival mechanisms of juvenile salmon in the ocean ecosystems; 2) Climate impacts on Pacific salmon production in the Bering Sea (BASIS) and adjacent waters; 3) Winter survival of Pacific salmon in the North Pacific Ocean; 4) Biological monitoring of key salmon populations; and 5) Development and application of stock identification methods and models for management of Pacific salmon. Canadian research relevant to this plan was summarized in Irvine et al. 2012[1] .

The current bibliography lists publications in primary scientific journals and other documents published in 2010-2012 by Fisheries and Oceans Canada scientists and their collaborators in order to outline Canadian national research for the current NPAFC Science Plan. The bibliography lists 79 papers with abstracts, corresponding to the five listed research components of the Science Plan. Although each publication is listed under one research component, some are relevant to more than one research component. The list for 2012 is incomplete as some publications are in review or draft.

[1] Irvine, J.R., M. Trudel, A. Tompkins, T. Beacham, and M. Saunders. 2012. Canadian Research in 2012 relevant to the NPAFC Salmon Science Plan for 2011-2015. NPAFC Doc. 1379.

## Component 1: Migration and Survival Mechanisms of Juvenile Salmon in the Ocean Ecosystems

Beamish, R. J., R.M. Sweeting, T.D. Beacham, K.L. Lange, and C.M. Neville. 2010. A late ocean entry life history strategy improves the marine survival of Chinook salmon in the Strait of Georgia. North Pacific Anadromous Fish Commission Document 1282.

The productivity of juvenile chinook salmon that enter the Strait of Georgia has generally declined over the past two decades. One aggregate of 15 populations from the South Thompson drainage of the Fraser River drainage, however, has increased. The increased productivity appears to be related to a life history strategy that results in juveniles entering the ocean in July, much later than most other Chinook salmon populations. Juveniles from the South Thompson drainage are generally not common in the Strait of Georgia early in July, but they are abundant in September. They appear to leave the Strait of Georgia by November, probably through Juan de Fuca Strait. Late ocean entry, sea-type, Harrison River sockeye salmon are also surviving better in recent years than the majority of sockeye salmon that are entering the ocean earlier. Because pink and chum salmon that enter the ocean early are at high levels of abundance, it is possible that very early and very late ocean entry times are life history strategies that match the current state of the Strait of Georgia ecosystem.

Beamish, R. J., K.L. Lange, C.M. Neville, R.M. Sweeting, and T.D. Beacham. 2010. Late ocean entry of sea type sockeye salmon from the Harrison River in the Fraser River drainage results in improved productivity. North Pacific Anadromous Fish Commission Document 1283.

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

Beamish, R.J., R.M. Sweeting, C.M. Neville, and K.L. Lange. 2010. Competitive interactions between pink salmon and other juvenile Pacific salmon in the Strait of Georgia. North Pacific Anadromous Fish Commission Document 1284.

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

Beamish, R., K. Lange, C. Neville, R. Sweeting, and T. Beacham. 2011. Structural patterns in the distribution of ocean- and stream-type juvenile Chinook salmon populations in the Strait of Georgia in 2010 during the critical early marine period. North Pacific Anadromous Fish Commission Document 1354.

There is increasing evidence that brood year strength of chinook salmon is mostly determined in the first few months in the ocean, particularly in a stressful environment. During this period in the Strait of Georgia, some chinook salmon populations have a distinct and persistent behaviour that relates to ocean entry times or concentrates their distributions in areas or at particular depths. Populations with both ocean- and stream-type life histories remain within the Strait of Georgia for three to four months, depending on their ocean entry times. These distinct and persistent behaviours during the critical early marine period indicate that conditions in the Strait of Georgia have a major impact on the productivity of the various populations. Populations of both stream- and ocean-type fish remained in the Strait of Georgia through to mid September, indicating that conditions within the Strait of Georgia would have a major impact on growth and survival. The major structural change in the population composition between July and September and the observation that the late ocean entry populations have a higher productivity than populations with an earlier ocean entry is evidence that recent changes in the environment of the Strait of Georgia are affecting the combined productivity of all

populations. Other studies have shown that the environment within the Strait of Georgia has been changing and the changes appear to be long-term trends. Thus, it is advisable that the management of chinook salmon recognize the differences among populations within the early marine period as these differences may explain the reason for poor or good survival. Populations with good survival have the resilience needed to adapt to future environmental changes in the Strait of Georgia.

Beamish, R.J., and R.M. Sweeting. 2012. Exceptionally poor survival of Chinook salmon entering the Strait of Georgia in 2007 is consistent with the synchronous poor survival of other Pacific salmon and Pacific herring. North Pacific Anadromous Fish Commission Document 1424.

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

Cooke, S.J., S.G. Hinch, A.P. Farrell, D.A. Patterson, K. Miller-Saunders, D.W. Welch, M.R. Donaldson, K.C. Hanson, G.T. Crossin, M.T. Mathes, A.G. Lotto, K.A. Hruska, I.C. Olsson, G.N. Wagner, R. Thomson, R. Hourston, K.K. English, S. Larsson, J.M. Shrimpton, and G. Van der Kraak. 2011. Developing a mechanistic understanding of fish migrations by linking telemetry with physiology, behavior, genomics, and experimental biology: An interdisciplinary case study on adult Fraser River sockeye salmon. Fisheries 3:321-339.

Fish migration represents one of the most complex and intriguing biological phenomena in the animal kingdom. How do fish migrate such vast distances? What are the costs and benefits of migration? Some of these fundamental questions have been addressed through the use of telemetry. However, telemetry alone has not and will not yield a complete understanding of the migration biology of fish a or provide solutions to problems such as identifying physical barriers to migration or understanding potential impacts of climate change. Telemetry can be coupled with other tools and techniques to yield new insights into animal biology. Using Fraser River sockeye salmon (Oncorhynchus nerka) as a model, we summarize the advances that we have made in understanding salmonid migration biology through the integration of disciplines (i.e., interdisciplinary research) including physiology, behavior, functional genomics, and experimental biology. We also discuss opportunities for using large-scale telemetry arrays and taking a more experimental approach to studies of fish migration that use telemetry (i.e., intervention studies involving endocrine implants, simulated migration studies) rather than simply focusing on descriptive or correlational techniques. Only through integrative and interdisciplinary research will it be possible to understand the mechanistic basis of fish migrations and to predict and possibly mitigate the consequences of anthropogenic impacts. Telemetry is a tool that has the potential to integrate research across disciplines and between the lab and the field to advance the science of fish migration biology. The techniques that we have applied to the study of Pacific salmon are equally relevant to other fish taxa in both marine and freshwater systems as well as migratory animals beyond ichthyofauna. The interdisciplinary

approach used here was essential to address a pressing and complex conservation problem association with sockeye salmon migration.

Neville, C.M., R.J. Beamish, and C.M. Chittenden. 2010. The use of acoustic tags to monitor the movement and survival of juvenile Chinook salmon in the Strait of Georgia. North Pacific Anadromous Fish Commission Document 1286.

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

Preikshot, D., R.J. Beamish, R.M. Sweeting, C.M. Neville and T.D. Beacham. 2012. The residence time of juvenile Fraser River sockeye salmon in the Strait of Georgia. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:438-449.

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

Trudel, M., J.H. Moss, S. Tucker, J.R. Candy, and T.D. Beacham. 2011. Stock-Specific Distribution of Juvenile Sockeye Salmon in the Eastern Gulf of Alaska. North Pacific Anadromous Fish Commission Document 1353.

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

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

The ocean feeding grounds of juvenile Pacific salmon *Oncorhynchus* spp. range over several thousand kilometers in which ocean conditions, prey quality and abundance, and predator assemblages vary greatly. Therefore, the fate of individual stocks may depend on where they migrate and how much time they spend in different regions. Juvenile ($n$ = 6,266) and immature ($n$ = 659) Chinook salmon *Oncorhynchus tshawytscha* were collected from coastal Washington to Southeast Alaska in coastal trawl surveys from February to November 1998–2008, which allowed us to reconstruct changes in stock composition for seasons and regions by means of DNA stock identification techniques. Individuals were allocated to 12 regional stocks. The genetic stock assignments were directly validated by showing that 96% of the 339 known-origin, coded-wire-tagged fish were accurately allocated to their region of origin. Overall, the analyses performed in this study support the main findings of previous work based on tagging. However, given that the sample sizes for all stocks were larger and additional stocks were analyzed, we can extend those results; coastal residency of local stocks in their first year at sea with differences between smolt classes for southern stocks. Notably, yearling Chinook salmon moved quickly into waters north of the west coast of Vancouver Island, including Southeast Alaska. Furthermore, subyearling salmon were found over shallower bottom depths than yearling fish. Summer catches in all regions were dominated by Columbia River yearling fish, which suggests a rapid northward migration. In contrast, very few Columbia River subyearling fish were recovered north of Vancouver Island. Columbia River fish were a minor component of the catches in fall and winter, as fish originating from other southern stocks dominated catches off the west coast of Vancouver Island while northern British Columbia and Southeast Alaska stocks dominated northern regions during these time periods. In addition, we found no effect of hatchery origin on the distribution of fish.

Tucker, M. Trudel, D.W. Welch, J.R. Candy, J.F.T. Morris, M.E. Thiess, C. Wallace, and T.D. Beacham. 2012. Annual coastal migration of juvenile Chinook salmon: Static

stock-specific patterns in a dynamic ocean. Marine Ecology Progress Series 449:245-262.

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

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

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

## Component 2: Climate Impacts of Pacific Salmon Production in the Bering Sea (BASIS) and Adjacent Waters

Holt, C.A. 2010. Will depleted populations of Pacific salmon recover under persistent reductions in survival and catastrophic mortality events? ICES Journal of Marine Science 67: 2018-2026.

Under Canada's Wild Salmon Policy, benchmarks between zones of biological status are required to distinguish populations requiring conservation attention (Red and Amber zones) from those that can be managed for production (Green zone). The recovery of depleted populations (i.e. from Red to Green) will depend in part on the choice of the lower benchmark. At a minimum, that benchmark should be set high enough to allow recovery within an acceptable time-frame in the absence of targeted fishing. Currently, benchmarks are evaluated and selected using simulation models that assess the probability of recovery to spawner abundance associated with the maximum sustainable yield within a specified time-frame. Guided by case examples, the evaluation is extended to include two scenarios of future conditions: persistent reductions in survival rates below the replacement level; and increased frequency of catastrophic mortality (die-off) events. Probabilities of recovery appear to be more sensitive to persistent reductions in survival than to increased probability of die-off events. The current lower benchmarks on spawner abundance and fishing mortality might not be sufficiently precautionary to allow recovery under those conditions.

Jeffries, K.M., S.G. Hinch, E.G. Martins, T.D. Clark, A.G. Lotto, D.A. Patterson, S.J. Cooke, A.P. Farrell, and K.M. Miller. 2012. Sex and proximity to reproductive maturity influence the survival, final maturation, and blood physiology of Pacific salmon when exposed to high temperature during a simulated migration. Physiological and Biochemical Zoology 85:62-73.

Some Pacific salmon populations have been experiencing increasingly warmer river temperatures during their once-in-a-lifetime spawning migration, which has been associated with en route and prespawn mortality. The mechanisms underlying such temperature-mediated mortality are poorly understood. Wild adult pink (*Oncorhynchus gorbuscha*) and sockeye (*Oncorhynchus nerka*) salmon were used in this study. The objectives were to investigate the effects of elevated water temperature on mortality, final maturation, and blood properties under controlled conditions that simulated a “cool” (13_C) and “warm” (19_C) freshwater spawning migration. After 10 d at 13_C, observed mortality was 50%–80% in all groups, which suggested that there was likely some mortality associated with handling and confinement. Observed mortality after 10 d at 19_C was higher, reaching ≥98% in male pink salmon and female pink and sockeye salmon. Thus, male sockeye salmon were the most thermally tolerant (54% observed mortality). Model selection supported the temperature- and sex-specific mortality patterns. The pink salmon were closer to reproductive maturation and farther along the senescence trajectory than sockeye salmon, which likely influenced their survival and physiological responses throughout the experiment. Females of both species held at 19_C had reduced plasma sex steroids compared with those held at 13_C, and female pink salmon were less likely to become fully mature at 19_ than at 13_C. Male and female sockeye salmon held at 19_C had higher plasma chloride and osmolality than those held at 13_C, indicative of a thermally related stress response. These findings suggest that sex differences and proximity to reproductive maturity must be considered when predicting thermal tolerance and the magnitude of en route and prespawn mortality for Pacific salmon.

Martins, E.G., S.G. Hinch, D.A. Patterson, M.J. Hague, S.J. Cooke, K.M. Miller, M.F. Lapointe, K.K. English, and A.P. Farrell. 2011. Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River sockeye salmon (*Oncorhynchus nerka*). Global Change Biology 17:99-114.

Mean summer water temperatures in the Fraser River (British Columbia, Canada) have increased by ~1.5 °C since the 1950s. In recent years, record high river temperatures during spawning migrations of Fraser River sockeye salmon (*Oncorhynchus nerka*) have been associated with high mortality events, raising concerns about long-term viability of the numerous natal stocks faced with climate warming. In this study, the effect of freshwater thermal experience on spawning migration survival was estimated by fitting capture–recapture models to telemetry data collected for 1474 adults (captured in either the ocean or river between 2002 and 2007) from four Fraser River sockeye salmon stock-aggregates (Chilko, Quesnel, Stellako-Late Stuart and Adams). Survival of Adams sockeye salmon was the most impacted by warm temperatures encountered in the lower river, followed by that of Stellako-Late Stuart and Quesnel. In contrast, survival of Chilko fish was insensitive to the encountered river temperature. In all stocks, in-river survival of ocean-captured sockeye salmon was higher than that of river-captured fish and, generally, the difference was more pronounced under warm temperatures. The survival–temperature relationships for ocean-captured fish were used to predict historic (1961–1990) and future (2010–2099) survival under simulated lower river thermal experiences for the Quesnel, Stellako-Late Stuart and Adams stocks. A decrease of 9–16% in survival of all these stocks was predicted by the end of the century if the Fraser River continues to warm as expected. However, the decrease in future survival of Adams sockeye salmon would occur only if fish continue to enter the river abnormally early, towards warmer periods of the summer, as they have done since 1995. The survival estimates and predictions presented here are likely optimistic and emphasize the need to consider stock-specific responses to temperature and climate warming into fisheries management and conservation strategies.

Martins, E.G., S.G. Hinch, D.A. Patterson, M.J. Hague, S.J. Cooke, K.M. Miller, D. Robichaud, K.K. English, and A.P. Farrell. 2012. High river temperature reduces survival of sockeye salmon approaching spawning grounds and exacerbates female mortality. Canadian Journal of Fisheries and Aquatic Sciences 69:330-342.

Recent studies have shown that warm temperatures reduce survival of adult migrating sockeye salmon (Oncorhynchus nerka), but knowledge gaps exist on where high-temperature-related mortality occurs along the migration and whether females and males are differentially impacted by river temperature. In this study, we monitored 437 radio-tagged Fraser River sockeye salmon and used capture–mark–recapture modelling approaches to investigate whether river thermal conditions differentially influence (i) spatial patterns of survival along a 413-km stretch of migration and (ii) survival of the sexes. Regardless of water temperature, survival decreased in the river section containing the most hydraulically difficult passages of the migration. However, when water temperature was warm (19 °C), survival decreased even further in the final 186 km of the migration prior to reaching the spawning grounds, particularly in females. Female and male survival differed but only when they experienced warm river temperatures. Under such conditions, the overall freshwater migration survival of males was 1.6 times higher (0.79 ± 0.09 standard error, SE) than that of females (0.50 ± 0.11 SE). As maturing female sockeye salmon maintain higher levels of plasma cortisol compared with males, we suspect that females could be immunocompromised and thus less resistant to pathogens whose rates of development are accelerated by warm temperatures.

Thomson, R., R.J. Beamish, T.D. Beacham, M. Trudel, P.H. Whitfield, and R.A.S. Hourston. 2012. Anomalous ocean conditions may explain the recent extreme variability in Fraser River sockeye salmon production. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:415-437.

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

## Component 3: Winter Survival of Pacific Salmon in the North Pacific Ocean Ecosystem

Farley, E.V., Jr., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C. Guthrie, L. Eisner, J. Guyon. 2011. Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. ICES Journal of Marine Sciences 68:1138-1146.

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

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

Winter is generally considered a critical period for juvenile salmon due to low temperatures and food availability. However, mortality rates have not been quantified for juvenile salmon during the winter months. Here, we use changes in the catch-per-unit effort (CPUE) for five brood years (2004-2008) of juvenile Marble River Chinook salmon between fall and winter to estimate stock-specific overwinter mortality rates in juvenile salmon. This stock is ideal for estimating overwinter mortality, as they appear to remain in Quatsino Sound, British Columbia, for a year before migrating to the open ocean. CPUE of juvenile Marble River Chinook salmon in Quatsino Sound dropped by a factor of 7-169 between fall and winter. CPUE varied significantly among brood years and seasons, but the interaction term was not significant. Overall, 80% of these fish died over winter, and mortality rates averaged 0.014-0.017 $d^{-1}$. The variance in fish size did not decrease during winter. Taken together, these results indicates that overwinter mortality can be substantial and variable in juvenile salmon, but that it is size-independent, at least, for this population.

## Component 4: Biological Monitoring of Key Salmon Populations

Beacham, T.D. 2010. Revisiting trends in evolution of egg size in hatchery-enhanced populations of Chinook salmon from British Columbia. Transactions of the American Fisheries Society 139:579-585.

Hatchery enhancement has been reported to result in an increase in egg size in coho salmon *Oncorhynchus kisutch* and a decline in egg size in Chinook salmon *O. tshawytscha*. Egg size may be directly influenced by selection, a larger egg size evolving as a consequence of hatchery incubation. Alternatively, a smaller egg size could evolve as a correlated response to fecundity selection, and a unidirectional change in egg size over time may reflect selection and an underlying genetic change in the population. To address this question, temporal trends in egg size were investigated for two hatchery-enhanced populations of Chinook salmon from Vancouver Island, British Columbia. After the effect of female length variation was removed by standardizing egg sizes to a female of common length (the overall mean for each population), there was no temporal trend in egg size from the 1970s to 2008 for any of the hatchery-enhanced populations evaluated. These results do not support a previous report of genetically based declines in egg size in hatchery-enhanced Chinook salmon populations from this region.

Beacham, T.D., and R.E. Withler. 2010. Comment on “Gene flow increases temporal stability of Chinook salmon (*Oncorhynchus tshawytscha*) populations in the Upper Fraser River, British Columbia, Canada”. Canadian Journal of Fisheries and Aquatic Sciences 67: 202-205.

Temporally stable genetic structure among salmonid populations has been reported in many studies, although the time span evaluated in most studies is limited to 10 years or less. This result has important implications in conservation and management of Pacific

salmon (*Oncorhynchus* spp.) and ramifications for the construction and application of genetic databases for stock identification of fish sampled from mixed-stock fisheries. Walter et al. (2009. Can. J. Fish. Aquat. Sci. 66:167-176) failed to consider recent studies providing evidence that their conclusion ‘‘the overall magnitude of temporal within-population variation exceeding that of among-population variation’’ for the populations under study may be invalid for Fraser River Chinook salmon (*Oncorhynchus tshawytscha*) populations. Their estimation of rates and patterns of migration among Chinook salmon populations also provided results that are difficult to reconcile with published information. Evaluation of the experimental designed employed by Walter et al. (2009) indicates that their sample sizes were too small to estimate reliably genetic variation among or within populations. Extrapolation of their conclusions relating temporal instability of population structure to other Chinook salmon populations or indeed other salmonid species is unwarranted.

Beacham, T.D., M. Wetklo, L. Deng, and C. MacConnachie. 2011. Coho salmon population structure in North America determined from microsatellites. Transactions of the American Fisheries Society 140:253-270.

Population structure of coho salmon *Oncorhynchus kisutch* from Russia to California was examined with a survey of microsatellite variation to describe the distribution of genetic variation. Variation at 17 microsatellite loci was surveyed for approximately 50,000 coho salmon sampled from 318 localities. The genetic differentiation index (*F*ST) over all populations and loci was 0.058, with individual locus *F*ST values ranging from 0.027 to 0.143. The least genetically diverse coho salmon were observed from Russia, the Porcupine River in the Yukon River drainage, and the middle Fraser and Thompson rivers in southern British Columbia. Coho salmon from Vancouver Island, British Columbia; Puget Sound, Hood Canal, and Juan de Fuca Strait, northern Washington; and Oregon displayed the greatest number of alleles compared with coho salmon in other regions. Differentiation in coho salmon allele frequencies among regions and among populations within regions was approximately seven times greater than that of annual variation within populations. A regional structuring of populations was the general pattern observed; coho salmon spawning in different tributaries within a major river drainage or spawning in smaller rivers in a geographic area were generally more similar to each other than to populations in different major river drainages or geographic areas. The distribution of microsatellite variation in coho salmon likely reflects the origins of salmon radiating from refuges after the last glaciation period.

Beacham, T. D., B. McIntosh, C. MacConnachie, B. Spilsted, and B.A. White. 2012. Population structure of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia and Washington, determined with microsatellites. Fishery Bulletin 110:242-256.

Population structure of pink salmon (*Oncorhynchus gorbuscha*) from British Columbia and Washington was examined with a survey of microsatellite variation to describe the distribution of genetic variation. Variation at 16 microsatellite loci was surveyed for approximately 46,500 pink salmon sampled from 146 locations in the odd-year broodline and from 116 locations in the even-year broodline. An index of genetic differentiation, *FST*, over all populations and loci in the odd-year broodline was 0.005, with individual locus values ranging from 0.002 to 0.025. Population differentiation was less in the even-year broodline, with a *FST* value of 0.002 over all loci, and with individual locus values

ranging from 0.001 to 0.005. Greater genetic diversity was observed in the odd-year broodline. Differentiation in pink salmon allele frequencies between broodlines was approximately 5.5 times greater than regional differentiation within broodlines. A regional structuring of populations was the general pattern observed, and a greater regional structure in the odd-year broodline than in the even-year broodline. The geographic distribution of microsatellite variation in populations of pink salmon likely ref lects a distribution of broodlines from separate refuges after the last glaciation period.

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

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

Beamish, R.J. 2012. A proposal to establish an International Year of the Salmon. North Pacific Anadromous Fish Commission Document 1425.

The Long-term Research and Monitoring Plan developed by the North Pacific Anadromous Fish Commission concluded that a proposal should be developed for an International Year of the Salmon. An International Year of the Salmon will allow experts from all Pacific salmon producing countries to focus on identifying the mechanisms that regulate Pacific salmon abundance and to use this understanding to maximize economic opportunities in the future while ensuring responsible stewardship. This proposal identifies some of the major climate and ocean influences on Pacific salmon production to show that there will be major changes in abundance trends in the future. It is of benefit to everyone that these changes are anticipated and not come as surprises. I suggest that the NPAFC form a group that will look at the feasibility of funding an International Year of the Salmon.

Beamish, R.J., R.M. Sweeting, K.L. Lange, D.J. Noakes, D. Preikshot, and C.M. Neville. 2010. Early marine survival of coho salmon in the Strait of Georgia declines to very low levels. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2:424-439.

The marine survival of juvenile coho salmon *Oncorhynchus kisutch* from the time they enter the Strait of Georgia in mid-May to the time of our trawl survey in mid-September declined from an average of about 15% in 1998 to approximately 1% in 2007. Early marine survival rates for juvenile coho salmon have been consistently low (<5%) since 2002, and the rate of decline in early marine survival was greater for hatchery fish than for wild fish. This suggests that hatchery coho salmon are perhaps less able to survive than wild fish in the current marine ecosystem. The steady decline in total marine survival for coho salmon over the past four decades coincided with a warming of the Strait of Georgia, where both sea surface and sea bottom temperatures have increased by approximately 18C since 1970. Another factor that appears to have contributed to the decline in early marine survival since the late 1990s is an increase in the number of days with an average sustained wind strength greater than 25 km/h. The linkage between wind strength and marine survival requires further study, but wind strength is known to affect the timing and level of primary productivity. The processes that caused the declining marine survival remain to be identified and may include factors associated with disease originating in both freshwater and salt water, metabolic stress, competition, and predation. The data suggest that coho salmon brood year strength is now mostly determined during the first 4 months spent in the Strait of Georgia. If the current low levels of marine survival continue, management initiatives to protect wild coho salmon will be urgently required, and it will be timely to critically evaluate the hatchery programs and policies.

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

The population dynamics of chinook salmon (Oncorhynchus tshawytscha) from the Cowichan River on Vancouver Island, British Columbia, Canada are used by the Pacific Salmon Commission as an index of the general state of chinook salmon coast wide. In recent years the production declined to very low levels despite the use of a hatchery that was intended to increase production by improving the number of smolts entering the ocean. In 2008, we carried out an extensive study of the early marine survival of the hatchery and wild juvenile chinook salmon. We found that both rearing types mostly remained within the Gulf Islands study area during the period when most of the marine mortality occurred for the hatchery fish. By mid September, approximately 1.3% of all hatchery fish survived, compared to 7.8%–31.5% for wild fish. This six to 24 times difference in survival could negate an estimated increased egg-to-smolt survival of about 13% that is theorized to result through the use of a hatchery. Estimates of the early marine survival are approximate, but sufficient to show a dramatic difference in the response of the two rearing types to the marine nursery area. If the declining trend in production continues for both rearing types, modifications to the hatchery program are needed to improve survival or an emphasis on improving the abundances of wild stocks is necessary, or both. The discovery that the juvenile Cowichan River chinook salmon remain within a relatively confined area of the Gulf Islands within the Strait of Georgia offers an excellent opportunity to research the mechanisms that cause the early marine mortalities and hopefully contribute to a management that improves the production.

Beamish, R.J., C. Neville, R. Sweeting, and K. Lange. 2012. The synchronous failure of juvenile Pacific salmon and herring production in the Strait of Georgia in 2007

and the poor return of sockeye salmon to the Fraser River in 2009. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4 403-414.

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

Beamish, R., C. Neville, and R. Sweeting. 2012. An early marine life history strategy for Fraser River sockeye salmon. North Pacific Anadromous Fish Commission Document 1423.

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

Borstad, G., W. Crawford, J.M. Hipfner, R. Thomson, and K. Hyatt. 2011. Environmental control of breeding success of rhinoceros auklets at Triangle Island, British Columbia. Marine Ecology Progress Series 424:285-302.

There are few studies of the mechanistic links between physical environmental processes and biotic responses in marine ecosystems that have strong predictive power. At Triangle Island, the largest seabird colony along Canada's Pacific coast, annual breeding success of rhinoceros auklets (*Cerorhinca monocerata)* varies dramatically. Previous studies have correlated this variability with ocean temperature, but this relationship occasionally fails, suggesting that it is not causal. We used historical satellite data time series of sea surface temperature, chlorophyll, and winds to study the oceanography of this remote colony. We found that rhinoceros auklets bred more successfully when the spring transition in regional winds and the resulting spring phytoplankton bloom occurred early in April. These factors appear to control the annual recruitment of Pacific sandlance (*Ammodytes hexapterus*), as measured by the percent by biomass of young-of-the-year sandlance in the nestling diet. These linkages imply bottom-up control in this system. Suggesting broader implications of our work, we also found that marine survival of economically and culturally important sockeye salmon (*Oncorhynchus nerka)* from nearby Smith Inlet was strongly correlated with the fledgling mass of the rhinoceros auklets, sandlance in the chicks' diets, and regional chlorophyll in April. The timing of the spring wind transition and phytoplankton bloom appear to be important for other predators in this system. We think that these relationships with wind and chlorophyll derived from satellite data are potentially valuable explanatory tools that will be widely applicable to studies of early marine survival of many marine species.

Bradford, M.J., J.M.B. Hume, R.E. Withler, D. Lofthouse, S. Barnetson, S. Grant, M. Folkes, N. Schubert, and A.-M. Huang. 2011. Status of Cultus Lake sockeye salmon. DFO Canadian Science Advisory Secretariat Research Document. 2010/123.

The sockeye salmon *(Oncorhynchus nerka*) population from Cultus Lake, British Columbia, was assessed as endangered in 2003 as a result of a long term decline in abundance that began in the 1970s. Recovery measures that include a conservation breeding program, harvest management and a predator control program in Cultus Lake have been implemented. This report reviews the current status of the population and the efficacy of the recovery measures. We found that that status of the population has not improved since 2003 largely because of poor smolt-recruit survival, and the average number of spawners remains at about 1000 fish. Harvest rates have been reduced since the 1990s and the predator control program appears to have increased the survival of juveniles in the lake. Supplementation releases of juveniles from the captive breeding program to the lake have resulted in increasing numbers of returning hatchery adults, but their success as spawners in the wild remains unknown. Modeling suggests that under the current low smolt-recruit survival rates, recovery is only possible with the successful implementation of all recovery measures. We conclude that the recovery of the Cultus Lake sockeye salmon population is highly uncertain and that continued monitoring is needed to determine if the recovery actions are indeed reducing risks to the population.

Crawford, W.R., and J.R. Irvine. 2010. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009. DFO Canadian Science Advisory Secretariat Research Document 2010/053.

Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by a number of government departments, to

understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. This eleventh report of an annual series updates the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems.

One of the biggest stories for 2009 was the return of far fewer sockeye salmon than expected. Accurately forecasting salmon returns is difficult as there are few observations of salmon between the time adults spawn in fresh water, and the time the next generation returns to British Columbia waters. Scientists base predictions of numbers of returning adult Sockeye salmon primarily on the empirical relationship between stock size (spawners, returns, or smolts depending on the stock) and consequent recruitment. For 2009, the forecast indicated there was a 90% probability the total run would be between 3.5 and 37.6 million Sockeye, yet the actual number was less than 2 million. Efforts to incorporate ocean indices to improve forecast performance were examined, and show promise for certain stocks; however, not Fraser River sockeye salmon at this time.

Ocean temperatures off the west coast on Canada were cooler than normal at the beginning of 2009 but warmed through the summer and autumn. By early 2010 most regions along the American and Canadian west coast were above normal in temperature. The shift from cool to warm is likely in response to a change from La Niña to El Niño conditions in the tropical Pacific and a shift in ocean temperature patterns all across the North Pacific Ocean, called the Pacific Decadal Oscillation. The North Pacific Current has declined in strength from its peak flow in 2008. This eastward current splits into a northward flowing Alaska Current and southward flowing California Current, when it approaches the west coast of North America. The Alaska Current flow, in 2009, was the strongest in the eight years of continuous observations provided by the International Argo Program.

Zooplankton are small animals drifting in the ocean’s currents. The type of zooplankton available is thought to determine the growth and survival rates of juveniles of many endemic marine species. Species off the coast of Oregon and British Columbia, in the spring of 2009, were dominated by cool water groups that might be a better food source for endemic (native) marine life. These cool-water zooplankton dominated for the past three years of cooler ocean temperatures, although the dominant groups shifted to warm-water species in late summer 2009, along the outer continental shelf of southern Vancouver Island. Perhaps in response to the dominance of cool-water zooplankton in spring and early summer, many endemic species of seabirds on Triangle Island and in Pacific Rim Nature Preserve successfully raised chicks. Pink (smooth) shrimp numbers off the west coast of Vancouver Island increased in the May surveys of 2008 and 2009, from very low levels during 2004-2007. Such increases appear related to colder water when the shrimp were young, and to low abundances of Pacific hake. Many juvenile salmon from the Columbia River and west coast of Vancouver Island were larger in size or more numerous, or both, through spring and early summer of 2009, but their growth rates through summer and early autumn were low. Biomass of adult herring off Vancouver Island were low, attributed to several factors, including warmer ocean temperatures prior to 2007, when these adults were young and most sensitive to ocean temperatures and to the predators and prey associated with these conditions. Catches of Albacore tuna in Canadian waters, in 2009, were lower than average, attributed to these cooler ocean temperatures. As noted above, several species along the west coast of Vancouver Island appear sensitive to interannual changes in ocean temperature; elsewhere this link is not as clear, and the timing of spring conditions or presence of

predators might be more relevant. For example, herring in the Strait of Georgia are relatively high in number and year-to-year changes in their biomass does not follow changes in temperature.

Humboldt squid appeared off the west coast in record high numbers in 2009. They were most abundant at several hundred metres depth, just seaward of the continental shelf among schools of Pacific hake, and were likely feeding on hake. Many of these squid were also observed closer to shore, and scores were found dead on west coast beaches. The biomass of Pacific hake off the Canadian coast seemed low, but assessment was difficult due to the many squid also observed among them.

Several highlights are specific to the waters of central and northern British Columbia, which form the Pacific North Coast Integrated Management Area (PNCIMA). This region warmed later in the year than the Oregon, Washington and southern British Columbia coasts. Zooplankton species here also continued the dominance of cool-water groups. There are three stocks of herring in PNCIMA, and the biomass of adults of all three stocks is relatively low. Their biomass might increase if hake numbers remain low. The abundance of central and north coast Chinook salmon seems to be rebounding, from a low in 2008.

Surface temperatures were generally above normal at most lighthouse stations in 2009 in the Strait of Georgia and Juan de Fuca Strait, but below the surface the waters remained relatively cool. Very high concentrations of phytoplankton were observed during the ship-based survey in April in the Strait of Georgia and in summer in Juan de Fuca Strait. Both were dominated by diatoms, as is normal for these regions. Satellite observations provide estimates of the concentration of phytoplankton at the ocean surface, when ship-based sampling is unavailable. These satellite observations reveal that when a plankton bloom appears very early in the Strait of Georgia, it is often associated with a bloom that is found in Malaspina Strait and also in Jervis Inlet. When viewed from space this bloom sometimes takes on the shape of a dragon, and it has acquired the name “Malaspina Dragon.” These satellite measurements became available in 2001, and the Dragon appeared in 2005, 2008, and 2009.

Finally, measurements of contaminants in cores from the bottom of the Strait of Georgia reveal past changes in the relative concentrations of contaminants in this region. Most contaminants that have been banned for many years, such as lead in gasoline and PCBs, are declining in concentration. In contrast, the concentration of flame retardant polybrominated diphenyl ethers (PBDEs) is increasing rapidly in sediment, despite its recent ban in Canada.

Crawford, W.R. and J.R. Irvine. 2011. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2010. DFO Canadian Science Advisory Secretariat Research Document 2011/054.

The near-record high number of returning Sockeye Salmon to the Fraser River was the good news story for 2010. Approximately 30 million adults returned, and of these about 17 million were headed for Shuswap Lake. These returns contrast with 2009 when fewer than 2 million sockeye migrated back to the Fraser. With such wide changes between years it is difficult to predict returns for 2011 with high certainty. The DFO prediction for 2011 is between 1.0 and 12 million (10% and 90% probabilities) if the low recent productivity persists. If on the other hand salmon have the long-term average

productivity seen last year and in previous decades, between 1.7 and 15 million sockeye are predicted to return.

The story was reversed for Humboldt squid. Squid were found in record-high numbers in summer 2009 along the west coast, but in 2010 not even one was observed in British Columbia waters. Several causes have been proposed, but none proven. The year 2010 started with extreme El Niño weather along the west coast, with strong southerly winds bringing warm, fresh ocean waters to the Oregon and British Columbia coast. These winds weakened in April and by summer the winds blew much more strongly than normal from the north, upwelling cool salty water along the outer coast. Waters of the Strait of Georgia shifted from cool to normal or even warm in 2010. La Niña conditions of late 2010 and early 2011 were linked to stronger westerly winds in the Pacific Ocean and cooler ocean waters along the coast. Overall the cool conditions prevailed in 2010, and this year was the third consecutive year with cooler than normal ocean temperatures along the Pacific Canadian coast.

Over the past decade and a half both the Pacific Decadal Oscillation and ENSO (El Niño – La Niña) have shifted phase together and reinforced the impact of each one on west coast ocean temperature. Whereas in the 1990s scientists would attribute changes in ocean temperatures and species compositions to changes in PDO or ENSO, they have recently been able to use these indices almost interchangeably in local waters to link physical changes in the ocean to shifts in abundance of one or several marine species.

Scientists monitor abundance and species of plankton in local waters to determine the quantity and quality of prey for larger species. Phytoplankton can be tracked by measuring chlorophyll in the ocean. Summer 2010 chlorophyll concentrations were often low in the southern Strait of Georgia and Juan de Fuca Strait, while fall chlorophyll concentrations were higher in Juan de Fuca Strait and slightly lower in the Strait of Georgia compared with previous years. The timing of the spring bloom in the Strait of Georgia is considered important for juvenile herring and salmon survival. Numerical models suggest that this bloom occurred in mid-April in 2010, compared to March to early April for most years. Bloom timing depends on local winds and cloud cover. A study of Rivers Inlet of Central BC discovered the spring bloom could be blown completely out of this short inlet by outflow winds. Its late development in 2009 could have been due to these winds. Studies of impacts of this outflow on local sockeye juveniles are ongoing.

Zooplankton species tend to shift from cold-water to warm-water types with corresponding shifts in local ocean temperature. Monthly surveys found the 2010 composition of cold-water copepods (a type of zooplankton) off Oregon was 4th highest in 15 years of observations. However, the species richness, which usually correlates with ocean temperature, was also high in 2010. These contrasting observations might be attributed to a warm ocean waters in winter and cool summer of 2010. Similar surveys in British Columbia observed more cold-water copepods species.

Recent surveys found the that biomass of *Pandalus jordani* shrimp off central west coast Vancouver Island had increased in 2008, 2009, and 2010 from very low levels during 2004-2007. Such increases appear related to colder waters in 2006, 2007, and 2008 during the larval stages of the shrimp (this species has a 2-yr time lag from hatch to recruitment at age 2) and to low abundances of Pacific hake (a potential shrimp predator) in May surveys in 2008, 2009, and 2010. This survey in May also provides insight into populations of resident flatfish, such as sole, Pacific cod, halibut, and

arrowtooth flounder. Biomass trends of key flatfish indicator species all increased in 2010, as did the biomass of the "cold water indicator" species walleye pollock.

Offshore Pacific hake (*Merluccius productus*) is a trans-boundary stock that exhibits seasonal migratory behavior, ranging from offshore and generally southern waters during the winter spawning season to coastal areas between northern California and northern British Columbia from spring to fall. In 2011, spawning biomass is estimated to have rebounded rapidly from a low in 2007 based on the strength of recent year classes (2005, 2006 and particularly 2008). However, estimates of spawning biomass are highly uncertain. The most recent coast-wide survey in 2009, using ship-based sonar sampling, was difficult to interpret due to large numbers of Humboldt squid among the hake.

Coast wide, herring adult biomass is generally low in all areas except the Strait of Georgia, where the stock remains somewhat high due to its near-record high biomass several years ago and indications of strong returns in 2011. Sardine numbers went from zero to many thousands of tonnes in the 1990s, but have declined since 2006. Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. Indices of eulachon abundance in central and southern British Columbia rivers remain at low levels. COSEWIC recently assessed eulachon, and designated stock from some BC rivers as Threatened and in others as Endangered. The abundance of albacore tuna in BC coastal waters in 2010 was the second highest since 1990, and those caught were in cooler water than in previous years.

Counts of seabirds in Pacific Rim Marine Reserve on the west coast of Vancouver Island revealed many species increased in number over the past five years. However, on Triangle Island where seabird breeding depends critically on ocean conditions in April, the mean growth rate for chicks of Cassin's auklet was extremely low in 2010 – in fact, the lowest in the 15-year time series by quite a wide margin. This poor growth is linked to late arrival of spring weather.

A Pacific North Coast Integrated Management Area (PNCIMA) Groundfish overview revealed several general trends. Gadoid (Pacific Cod, Walleye Pollock, Pacific Hake) stocks are stable or increasing. Most rockfish species are at low abundance with some being listed as Special Concern or Threatened by COSEWIC. Flatfish stocks appear to be stable. Sablefish stocks appear to be stable at low abundance. Lingcod and Elasmobranch (e.g. Spiny Dogfish) stocks appear stable.

Sockeye ocean survival was high for stocks in Barkley Sound on the west coast of Vancouver Island, attributed to cool ocean waters when they entered the ocean two years earlier. An assessment of ~60 years of escapement and catch data of five salmon species to the central and north coast suggests that Pink Salmon, with significant increases in escapements, are doing relatively well. Coho and Chinook salmon are doing relatively poorly - declines over the time series were significant for Coho Salmon catches, escapements, and returns; and for Chinook Salmon catches and returns. A different picture can emerge from shorter-term studies. For example, the Chinook Abundance Index for stocks between SE Alaska and Oregon has increased and declined over 10 to 15 year cycles since 1979, and this index is presently increasing from a low in 2008.

Donaldson, M.R., S.G. Hinch, D.A. Patterson, A.P. Farrell, J.M. Shrimpton, K.M. Miller-Saunders, D. Robichaud, J. Hills, K.A. Hruska, K.C. Hanson, K.K. English, G.

Van Der Kraak, and S.J. Cooke. 2010. Physiological condition differentially affects the behaviour and survival of two populations of sockeye salmon during their freshwater spawning migration. Physiological and Biochemical Zoology 83:446-458.

Recently, a segment of the Adams-Shuswap sockeye salmon (*Oncorhynchus nerka*) population initiated freshwater migration several weeks earlier than historically recorded, resulting in high mortality rates. The comigrating Chilko population maintained their historic river entry timing and did not experience elevated mortality. To test the hypothesis that population-specific differences in physiological condition would differentially influence behavior and survival when exposed to fisheries capture stress, we physiologically sampled individuals from both populations at the onset of the freshwater phase of their reproductive migration and tracked the remainder of their migrations using radio telemetry. Adams-Shuswap individuals had slower migration rates and were less likely to reach natal subwatersheds relative to Chilko individuals. Metabolic and osmoregulatory impairment was related to mortality for Adams-Shuswap individuals but not for Chilko individuals. Similarly, physiological condition correlated with migration rate for Adams-Shuswap but not Chilko fish. Survival to natal subwatersheds was 1.9 times higher for Chilko relative to Adams-Shuswap, a result that did not emerge until individuals approached natal subwatersheds several days after the stressor was applied. We conclude that physiological condition differentially affects the behavior and survival of these two populations, which may be a consequence of the early-entry phenomenon by a segment of the Adams-Shuswap population.

Evans, T.G., E.D.D. Hammill, K. Kaukinen, A.D. Schulze, D.A. Patterson, K.K. English, J.M.R. Curtis, and K.M. Miller. 2011. Transcriptomics of environmental acclimatization and survival in wild adult Pacific sockeye salmon (*Oncorhynchus nerka*) during spawning migration. Molecular Ecology 20(21):4472-4489.

Environmental shifts accompanying salmon spawning migrations from ocean feeding grounds to natal freshwater streams can be severe, with the underlying stress often cited as a cause of increased mortality. Here, a salmonid microarray was used to characterize changes in gene expression occurring between ocean and river habitats in gill and liver tissues of wild migrating sockeye salmon (*Oncorhynchus nerka* Walbaum) returning to spawn in the Fraser River, British Columbia, Canada. Expression profiles indicate that the transcriptome of migrating salmon is strongly affected by shifting abiotic and biotic conditions encountered along migration routes. Conspicuous shifts in gene expression associated with changing salinity, temperature, pathogen exposure and dissolved oxygen indicate that these environmental variables most strongly impact physiology during spawning migrations. Notably, transcriptional changes related to osmoregulation were largely preparatory and occurred well before salmon encountered freshwater. In the river environment, differential expression of genes linked with elevated temperatures indicated that thermal regimes within the Fraser River are approaching tolerance limits for adult salmon. To empirically correlate gene expression with survival, biopsy sampling of gill tissue and transcriptomic profiling were combined with telemetry. Many genes correlated with environmental variables were differentially expressed between premature mortalities and successful migrants. Parametric survival analyses demonstrated a broad-scale transcriptional regulator, cofactor required for Sp1 transcriptional activation (CRSP), to be significantly predictive of survival. As the environmental characteristics of salmon habitats continue to change, establishing how current environmental conditions

influence salmon physiology under natural conditions is critical to conserving this ecologically and economically important fish species.

Fryer, J.K., H. Wright, S. Folks, K. Hyatt, and M. Stockwell. 2012. Limiting factors of the abundance of Okanagan and Wenatchee sockeye salmon in 2011. Columbia River Inter-Tribal Fish Commission Technical Report 12-08, Portland, Oregon.

A total of 763 sockeye salmon, Oncorhynchus nerka, were PIT tagged at the Bonneville Dam Adult Fish Facility in 2011. These fish, in addition to three previously PIT tagged sockeye salmon we sampled at Bonneville Dam, were tracked upstream using data from detection arrays within fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Granite, and Tumwater dams as well as in-river arrays in the Wenatchee and Okanagan basins. The estimated stock composition of sockeye salmon passing Bonneville Dam was 76.8% Okanagan 21.9% Wenatchee, and 1.3% Snake.

Godbout, L., C.C. Wood, R.E. Withler, S. Latham, J. Nelson, L. Wetzel, R. Barnett-Johnson, M. J. Grove, A.K. Schmitt and K.D. McKeegan. 2011. Sockeye salmon (*Oncorhynchus nerka*) return after an absence of nearly 90 years: a case of reversion to anadromy. Canadian Journal of Fisheries and Aquatic Sciences 68:1590-1602.

We document the recent reappearance of anadromous sockeye salmon (Oncorhynchus nerka) that were thought to have been extirpated by the construction of hydroelectric dams on the Coquitlam and Alouette rivers in British Columbia, Canada, in 1914 and 1927, respectively. Unexpected downstream migrations of juveniles during experimental water releases into both rivers in 2005 and 2006 preceded upstream return migrations of adults in 2007 and 2008. Genetic (microsatellite and mitochondrial DNA) markers and stable isotope (d34S and 87Sr/86Sr) patterns in otoliths confirm that both the juvenile downstream migrants and adult upstream migrants were progeny of nonanadromous sockeye salmon (kokanee) that inhabit Coquitlam and Alouette reservoirs. Low genetic diversity and evidence of genetic bottlenecks suggest that the kokanee populations in both reservoirs originated from relatively few anadromous individuals that residualized after downstream migration was largely prevented by the construction of dams. Once given an opportunity for upstream and downstream migration, both populations appear capable of reverting to a successful anadromous form, even after 25 generations.

Grant, S.C.H., B.L. MacDonald, T.E. Cone, C.A. Holt, A. Cass, E.J. Porszt, J.M.B. Hume, and L.B. Pon. 2011. Evaluation of Uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy Status using Abundance and Trends in Abundance Metrics. DFO Canadian Science Advisory Secretariat Research Document 2011/087.

The Department of Fisheries and Oceans (DFO) Wild Salmon Policy (WSP) goal is “to restore and maintain healthy salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity” (Fisheries and Oceans Canada 2005). In order to achieve this goal, the WSP outlines a number of strategies, including ‘Strategy 1: standardized monitoring of wild salmon statuses’, which is the subject of this paper. In the current paper, Fraser Sockeye (*Oncorhynchus nerka*) conservation units

(CUs) from ‘WSP Action Step 1.1: the identification of conservation units’ are used to update ‘Action Step 1.2: the development of criteria to assess CUs and identify benchmarks to represent biological statuses’, and to address ‘Action Step 1.3: CU status assessment’, for the 22 current CUs and two de novo ‘CUs’. Using a previously developed toolkit for CU status assessment (Holt et al. 2009; Holt 2009), abundance benchmarks (unique to each CU) were estimated for each CU with stock-recruitment data, and trends in abundance upper and lower benchmarks (common across all CUs) were modified to apply to Fraser Sockeye. These benchmarks were used to delineate the three WSP biological status zones (Red, Amber, and Green). Abundance benchmarks were estimated across a range of stock-recruitment models, including the standard Ricker model that assumes constant productivity and other Ricker model forms that assume time varying productivity. Consideration of time varying productivity in the estimation of abundance benchmarks was important since most Fraser Sockeye CUs have exhibited systematic declines in productivity over recent decades (Grant et al. 2011) and extirpation risk can increase when a CUs productivity is linearly decreasing or low (Holt 2009; Holt and Bradford 2011). Abundance benchmarks were also estimated across a range of probability levels to reflect uncertainty in the estimation process. Estimates of a CU’s spawner abundances at maximum juvenile production (Smax) were also updated and used as carrying capacity priors in Ricker models, where available and appropriate. In the evaluation of status using the abundance metric, both the geometric and arithmetic means of the recent CU abundance were compared against benchmarks. Since multiple metrics (one abundance and three trends in abundance metrics, depending on the CU) and uncertainty in abundance benchmarks are presented in the current paper, statuses for a single CU can comprise all three WSP status zones. Status integration will be explored in future processes and publications.

Hammill, E., J.M.R. Curtis, D.A. Patterson, A.P. Farrell, T. Sierocinski, P. Pavlidis, S.G. Hinch, and K. Miller. 2012. Comparison of techniques for correlating survival and gene expression data from wild salmon. Ecology of Freshwater Fish 21:189-199.

In laboratory and field studies of survival, one of two alternative analytical techniques is often used to estimate survival rates and identify covariates, namely parametric survival analysis or Cormack–Jolly–Seber models. These techniques differ in algorithms and assumptions of the data. They also tend to be used under different circumstances depending on whether the intention is to demonstrate group-specific differences or to predict survival variables. Here, we apply and compare both analytical techniques in a study that couples functional genomics with biotelemetry to ascertain the role of physiological condition on survival of adult sockeye salmon (*Oncorhynchus nerka*) migrating in the Fraser River, British Columbia, which builds on the growing concern over the decline in numbers of spawning fish. Herein, we show a high level of quantitative and qualitative agreement between the two analytical methods, with both showing a strong relationship exists between the genomic signature that accounts for the largest source of variance in gene expression among individuals and survival in one of the three populations assessed. This high level of agreement suggests the data and the approaches are generating reliable results. The novel approach used in our study to identify physiological processes associated with reduced fitness in wild populations should be of broad interest to conservation biologists and resource managers as it may help reduce the uncertainty associated with predicting population sizes.

Hinch, S.G., S.J. Cooke, A.P. Farrell, K.M. Miller, M. Lapointe, and D.A. Patterson. 2012. Dead fish swimming: a review of research on the early migration and high premature mortality in adult Fraser River sockeye salmon *Oncorhynchus nerka*. Journal of Fish Biology 81:576-599.

Adult sockeye salmon *Oncorhynchus nerka* destined for the Fraser River, British Columbia are some of the most economically important populations but changes in the timing of their homeward migration have led to management challenges and conservation concerns. After a directed migration from the open ocean to the coast, this group historically would mill just off shore for 3–6 weeks prior to migrating up the Fraser River. This milling behaviour changed abruptly in 1995 and thereafter, decreasing to only a few days in some years (termed early migration), with dramatic consequences that have necessitated risk-averse management strategies. Early migrating fish consistently suffer extremely high mortality (exceeding 90% in some years) during freshwater migration and on spawning grounds prior to spawning. This synthesis examines multidisciplinary, collaborative research aimed at understanding what triggers early migration, why it results in high mortality, and how fisheries managers can utilize these scientific results. Tissue analyses from thousands of *O. nerka* captured along their migration trajectory from ocean to spawning grounds, including hundreds that were tracked with biotelemetry, have revealed that early migrants are more reproductively advanced and ill-prepared for osmoregulatory transition upon their entry into fresh water. Gene array profiles indicate that many early migrants are also immunocompromised and stressed, carrying a genomic profile consistent with a viral infection. The causes of these physiological changes are still under investigation. Early migration brings *O. nerka* into the river when it is 3–6° C warmer than historical norms, which for some late-run populations approaches or exceeds their critical maxima leading to the collapse of metabolic and cardiac scope, and mortality. As peak spawning dates have not changed, the surviving early migrants tend to mill in warm lakes near to spawning areas. These results in the accumulation of many more thermal units and longer exposures to freshwater diseases and parasites compared to fish that delay freshwater entry by milling in the cool ocean environment. Experiments have confirmed that thermally driven processes are a primary cause of mortality for early-entry migrants. The Fraser River late-run *O. nerka* early migration phenomenon illustrates the complex links that exist between salmonid physiology, behaviour and environment and the pivotal role that water temperature can have on population-specific migration survival.

Holt, C.A. and M.J. Bradford. 2011. Evaluating benchmarks of population status for Pacific salmon. North American Journal of Fisheries Management 31:363-378.

Canada is developing an indicator approach for assessing the biological status of conservation units of Pacific salmon *Oncorhynchus* spp. under its Wild Salmon Policy that is based, in part, on the abundance of adult fish. Two benchmarks will be used to place populations in one of three abundance categories. The lower benchmark is proposed to be at a level that allows for a substantial buffer between it and the abundance that would result in a population's being assessed as at risk of extirpation based on quantitative criteria used by the Committee on the Status of Endangered Wildlife in Canada. Using Monte Carlo simulation, we evaluated eight candidate lower benchmarks calculated from parameters of the stock–recruit relationship against two criteria, the probability of extirpation over 100 years and the probability of recovery to spawner abundances that result in the maximum sustainable yield in one or three generations. For modeled populations of moderate size (unfished equilibrium

abundances >25,000) and moderate productivity (~four adult recruits produced per spawner at low spawner abundances), all benchmarks protected populations from extirpation when harvest restrictions were imposed at the lower benchmark. For small or unproductive populations, none of the benchmarks was adequate to prevent populations from being at risk of extirpation. However, those benchmarks that covaried with the productivity parameters of the stock-recruitment relationship performed better and are preferred to those that were derived mainly from estimates of habitat capacity.

Hyatt, K.D., D.J. McQueen, D.P. Rankin and E. Demers. 2011. Density-dependent growth in juvenile sockeye salmon (*Oncorhynchus nerka*).The Open Fish Science Journal 49-61.

Data gathered over 77 lake-years from 4 coastal British Columbia sockeye salmon nursery lakes suggest that density-dependent growth reductions are only possible at exceptionally high fry densities. In Great Central Lake (n=33 years) and Sproat Lakes (n=30 years) there was no relationship between smolt weight and mean summer fry densities ranging from 760-3800 fry ha-1. However, in two years when Sproat Lake fry densities were unusually high (1983=5183 ha-1, 1996=4801 ha-1) smolt weights were among the lowest recorded. In Woss and Vernon lakes (n=14 lake-years), there were significant bottom-up relationships between fall-fry weights and zooplankton biomass, but no relationships between December-fry weights and average fry densities (range 331-1361 ha-1), nor were there significant top-down relationships between fry densities and average zooplankton biomass. Comparisons of zooplankton production with bioenergetic-based fry consumption, suggested that the carrying capacity for Vernon Lake which had the highest rate of zooplankton production, was 12,700 fry ha-1, and for Sproat Lake which had the lowest zooplankton production, was 5200 fry ha-1. We conclude that fry densities in the range commonly observed for British Columbia coastal lakes (i.e. 500-4000 ha-1) cannot cause density-dependent reductions in prey biomass or fry growth rates. Further research is necessary.

Irvine, J.R., and W.R. Crawford. 2011. State of the Ocean Report for the Pacific North Coast Integrated Management Area (PNCIMA). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2971.

As part of a national ecosystem review of large ocean management areas, this report examines the marine ecosystem of the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA encompasses approximately 102,000 km2 from the edge of the continental shelf east to the British Columbia mainland. The region extends from the British Columbia-Alaska border south to Bute Inlet on the mainland, across to Campbell River on the east side of Vancouver Island and the Brooks Peninsula on the west side of Vancouver Island. This report updates information from a major 2007 review.

Wet windy winters and drier, relatively calmer summers dominate the seasonal weather, resulting from very different air pressure patterns in the Gulf of Alaska in summer and winter. Frequent winter storms with strong southerly winds (blowing from the south) bring not only high waves, but also warmer waters from the south and deep downwelling and mixing of surface waters. Relatively calmer weather in summer with periods of northerly winds brings calmer seas and allows nutrients from deep waters to reach the surface. Intense rainfall in late autumn and winter along the Coast Mountains provides massive input of fresh water along the eastern side of PNCIMA. Large rivers from the BC interior

snowfields and glaciers dominate the fresh water runoff in other seasons, especially in late spring. Although this summer-winter change in weather dominates PNCIMA, there have been variations in the weather over past decades that have impacted PNCIMA.

Some of these variations in the weather and their impacts are listed below. In addition, we summarize recent ecosystem research not necessarily related to changes in weather and climate.

•Two recent winters illustrate the increasingly frequent shifts between strong El Niño (2010 - stronger southerly winds, relatively warmer ocean waters in PNCIMA) and La Niña (2011 -stronger westerly winds, cooler waters) conditions.

•Downwelling winds (from the south or southeast) in PNCIMA were, on average, much stronger since the mid 1990s than in previous decades back to 1950.

•In general, the last two decades have seen warmer, less saline ocean waters.

•Recent declines in sub-surface oxygen concentrations may lead to negative effects on marine species such as groundfish.

•The timing of spring plankton blooms in Queen Charlotte Sound appears to have a major influence on the survival of certain marine birds as well as young salmon.

•PNCIMA provides important habitat for ancient colonies of corals and sponge reef communities; a recently released conservation strategy was designed to protect these rare and sensitive components of our marine ecosystem.

•While many native invertebrate species are harvested, two are doing poorly: Northern abalone are listed as endangered, and Olympia oyster are listed as a species of special concern by COSEWIC.

•Groundfish catches constitute about half of the total groundfish catches within BC with Pacific hake the single largest species catch both coast-wide and within PNCIMA.

•Gadoid (Pacific cod, walleye pollock, Pacific hake) stocks are generally stable or increasing, flatfish, lingcod, sablefish and elasmobranch stocks are stable, while many rockfish species are at low levels of abundance with some being threatened or special concern.

•The region provides essential spawning and rearing habitat for local salmon populations and is also important as a marine migration corridor for more southerly populations. Marine waters are especially important for juvenile salmon during summer and fall.

•Over the last 50 years, numbers of adult pink salmon have increased, while coho salmon and to a lesser extent Chinook salmon numbers have declined.

•Over the past decade, herring biomass in Haida Gwaii has been depressed whereas the biomass in both Prince Rupert and the central coast has remained relatively stable. Herring stocks in Haida Gwaii and the central coast are below cut off levels established to determine if fishing should be allowed.

•After more than a 50-year absence, sardines returned to the west coast of Vancouver Island, Hecate Strait and Dixon Entrance in 1998. The extent of sardine migration into PNCIMA varies among years and is strongly affected by sea surface temperature.

•Many species of marine mammal occur within PNCIMA for at least part of their life history.

•Whaling resulted in significant declines for many baleen whales; blue, sei and North Pacific right whales are listed as endangered under Species at Risk Act while fin and humpback whales are threatened and eastern Pacific grey whales are listed as special concern.

•Three distinct eco-types of killer whales occur in PNCIMA: northern and the southern resident killer whales, transient killer whales, and offshore killer whales. The

four populations do not associate with each other although their ranges overlap extensively. Southern residents are listed as endangered under Species At Risk Act while northern residents, transients, and offshore killer whales are listed as threatened.

•PNCIMA is host to a range of introduced shellfish and other invertebrate species, two sponges, and two species of marine fish.

•The reader is referred to the extensive bibliography for more details.

Irvine, J.R. and Crawford, W.R. 2012 State of the physical biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2011. DFO Canadian Scientific Advisory Secretariat Research Document 2012/072.

The average global temperature in 2011 was warmer than average almost everywhere, but not in the eastern Pacific Ocean, where cool waters have been present in almost every year since 2008, part of a Pacific-wide weather pattern associated with La Niña conditions of these years. These La Niña conditions were most active in winter, with a stronger North Pacific High Pressure System and stronger, cool westerly winds over the ocean west of British Columbia. This pattern of cool ocean surface water was interrupted only briefly in the winter of 2010, when El Niño winds brought warmer waters to our region.

The North Pacific Current increased its eastward flow speed in the eastern North Pacific Ocean through the winter of 2011 to 2012, with normal flow otherwise. This current is expected to carry tsunami debris from Japan. Although some objects have already arrived, it is expected that the main part will arrive next winter or through 2013.

Sea surface measurements from shore stations along the coast of British Columbia, and in the Strait of Georgia, confirm that ocean conditions were cooler and also fresher in 2011 than in 2010. Relatively fresh surface waters within the Strait of Georgia in 2011 were at least partly a consequence of a heavy snow pack. Ocean surface waters on the British Columbia continental shelf were fresher than normal in the summer of 2011.

Weather conditions in late winter and early spring determine the timing and intensity of growth of phytoplankton that feed the food chain that provides necessary prey for juvenile fish at a critical time in their life. The spring bloom of phytoplankton in the Strait of Georgia in 2011 was later than normal, due to stronger winds of March, but once it began the growth was unusually strong. Observations of this bloom by satellite and by ship-based surveys reveal that it peaked in June and extended into July, and had unusually high biomass of the harmful algae *Heterosigma akashiwo.* Blooms of this phytoplankton have been observed in previous years in nearshore waters of the Strait of Georgia during May through October and have been postulated as perhaps adversely affecting juvenile sockeye salmon during their seaward migration.

Studies of zooplankton are undertaken along the west coast and in the Gulf of Alaska. These tiny drifting animals feed mainly on phytoplankton, and in turn are prey for many juvenile fish. The species composition of zooplankton and their biomass are useful predictors for fisheries. The copepod community of zooplankton on the Oregon continental shelf was dominated by lipid rich “northern” copepods in 2011, suggesting strong survivals for coho and Chinook salmon returning to the Columbia River in 2012 and 2013.

Further north, off the west coast of Vancouver Island, the zooplankton community was of normal composition, except for a summer shift to warm-water oceanic zooplankton seaward of the southern Vancouver Island shelf. In deep-sea waters, zooplankton indices were consistent with cool ocean conditions. When the zooplankton community composition is combined with other environmental indicators for the west coast of

Vancouver Island and Oregon, 2011 conditions for juvenile salmon migrating to sea were rated as average. This rating affects Columbia River salmon as well as those from Vancouver Island itself.

Within the Strait of Georgia, conditions in 2011 were generally favourable for juvenile sockeye salmon from the Fraser River, whereas poor returns are projected for coho salmon returning in 2012, Chinook salmon returning in 2013 and 2014, and chum salmon returning in 2013.

An estimated 5 million Fraser River sockeye returned to British Columbia coastal waters in 2011, well within the range of the prediction provided the previous year. This number contrasts with the record high of about 30 million in 2010 and record low of 1 million in 2009. Lower returns in 2011 compared to 2010 are attributed mainly to reduced survival of young salmon in freshwater. The primary estimator of numbers of sockeye returns is based on the number of parent spawners four years earlier, because most sockeye return to their natal river at age four, after spending two years at sea and two years in freshwater. On this basis, the prediction for 2012 returns is 0.7 million to 7 million, at the 10% to 90% probability distribution. These numbers are lower than average, due to fewer spawning sockeye in 2008. Fraser River sockeye returns in 2013 might be lower than average as well, due to fewer parent spawners in 2009, combined with generally favourable conditions in the Strait of Georgia in 2011, noted previously.

As part of ongoing research into year-to-year changes in ocean conditions and their impact on salmon survival at sea, scientists have examined survivals of a single stock of sockeye, from Chilko Lake in the Fraser River basin. By comparing returns of the small numbers of those returning at age five with the larger numbers returning at age four, they have revealed a sharp pattern break in 1990, when the trend in marine survival changed from increasing prior to 1990 to decreasing after 1990. In contrast, marine survivals for Fraser pink salmon were without trend, and recent increases in pink salmon returns were determined to be primarily the result of reduced fishing. Another research effort, using ecosystem models that include most marine species and climate variability in the Strait of Georgia, identified a shift to lower growth rate of phytoplankton beginning in 1990 and continuing to present that is attributed to stronger wind speeds in spring and summer since 1990. This lower primary production is manifested in the model as declines, after 1990, of coho and Chinook salmon, herring, dogfish, and killer whales.

Other biological findings in 2011 include decreased pink shrimp biomass west of Vancouver Island from higher values in 2009 and 2010, likely as a result of warmer waters in spring two years previously when the shrimp were young.

Biomass indices for most groundfish species in Hecate Strait and Queen Charlotte Sound are trending upwards after several years of decline.

Eulachon populations coast-wide are at low levels, while Pacific sardine biomass off the west coast of Vancouver Island increased in 2011 compared to 2010. Herring biomass forecasts for Haida Gwaii and Central Coast stocks are below fishery thresholds, while for Strait of Georgia and Prince Rupert stocks, forecasts are above thresholds.

Length-at-age and weight-at-age of post-recruit herring has decreased in all BC populations since the 1970s, including herring populations not fished during the herring roe fishery. Similar changes have occurred in California and some, but not all SE Alaska herring populations. Because size-at-age has decreased in areas not fished, this decrease is not believed to be due to fishing.

Birds can be effective indicators of the state of marine ecosystems because their large breeding aggregations can be relatively easily counted. Breeding success of Triangle

Island Cassin's Auklets is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus*. Breeding success of these auklets in 2011 was better than the long-term average and well above that of 2010.

In Pacific Rim National Park Reserve, 2011 seabird abundance remained high and similar to 2010. Most species displayed stable or improving population trends over the past 4 to 5 years. Intertidal bivalve population abundances in the Barkley Sound part of this reserve were about average relative to previous years. Manila clams continue to decline while there appears to be no spatial displacement of this species by the recently introduced varnish clams. SARA-listed Olympia oyster has displayed a recovering trend for the past 7 years but the numbers are still below those observed in late 1990s.

Persistent, bioaccumulative and toxic contaminants present a health risk to aquatic biota, notably those at the top of food web such as killer whales and seals. Recent analyses of biopsy samples taken from young harbour seals live-captured in the Salish Sea reveal that polychlorinated biphenyls (PCBs) declined by 81% between 1984 and 2009 In contrast, the concentration of polybrominated diphenyl ethers (PBDEs) increased, with indication of a peak in PBDE levels in seals between 2003 and 2009 followed by a decline. This pattern would be consistent with the 2004 phase-out of two of the three PBDE products in Canada and the USA.

Airborne surveys for oil on British Columbia waters have operated with increased efficiency since 2006, when more accurate sensors were added to the surveillance aircraft flights by Transport Canada, as part of the National Aerial Surveillance Program. Observations by this program, together with modelling and analyses of these observations from 2006 to 2010 by the Canadian Wildlife Service, reveal that the highest relative likelihood of detecting oil discharges occurred close to shore and, in particular, in the Strait of Georgia, the inside passage of the central coast, near Prince Rupert, and in Alberni Inlet. Although results are preliminary, results suggest that marina densities and intensity of local vessel activity (as opposed to international shipping) generally determine oil discharge patterns in the Pacific Region. There is some evidence that oil discharges have declined since the program was enhanced in 2006.

Scientists have reported alarmingly low oxygen concentrations in near-shore waters of the Oregon coast in summer, beginning in 2002 and most severely in 2006. High crab mortalities on the ocean bottom took place in these summers. Low oxygen concentrations (less than 1 ml/L) have also been observed on off southwest Vancouver Island since 2002, with concentrations of 0.7 ml/L at 150 metres depth recorded in 2006 and 2009, the lowest in the 50-year record. Concentration was 1.0 and 1.1 ml/L in 2010 and 2011, respectively. Hypoxia on the Canadian shelf is much less severe than off Oregon and Washington, and mortality of bottom life has not been reported.

Deep water in the North Pacific Ocean already has the most acidic water in the global ocean and the British Columbia continental shelf might see negative impacts of this feature sooner than most oceanic waters.

Scientists hope to collaborate in the next year to produce more quantitative ocean indices to rank the health of the ocean and its marine species, as part of an ongoing ecosystem approach to management (EAM). This will require scientists to develop a new suite of tools and products to advise resource managers on the impact and management options for human activities in the marine environment. Subsequent State of Ocean workshops and reports are expected to report on the continued development of ecosystem indicators.

Irvine, J.R. and M. Fukuwaka. 2011. Pacific salmon abundance trends and climate change. ICES Journal of Marine Science 68:1122-1130.

Understanding reasons for historical patterns in salmon abundance could help anticipate future climate-related changes. Recent salmon abundance in the northern North Pacific Ocean, as indexed by commercial catches, has been among the highest on record, with no indication of decline; the 2009 catch was the highest to date. Although the North Pacific Ocean continues to produce large quantities of Pacific salmon, temporal abundance patterns vary among species and areas. Currently, pink and chum salmon are very abundant overall and Chinook and coho salmon are less abundant than they were previously, whereas sockeye salmon abundance varies among areas. Analyses confirm climate-related shifts in abundance, associated with reported ecosystem regime shifts in approximately 1947, 1977, and 1989. We found little evidence to support a major shift after 1989. From 1990, generally favourable climate-related marine conditions in the western North Pacific Ocean, as well as expanding hatchery operations and improving hatchery technologies, are increasing abundances of chum and pink salmon. In the eastern North Pacific Ocean, climate-related changes are apparently playing a role in increasing chum and pink salmon abundances and declining numbers of coho and Chinook salmon.

Irvine, J.R., C. Michielsens, B. White, P. Van Will, and M. O'Brien. 2012. Temporal Patterns for Odd- and Even-Year Pink Salmon Conservation Units in British Columbia and Puget Sound (Washington State). North Pacific Anadromous Fish Commission Technical Report 8:13.

We assembled pink salmon escapement data for Conservation Units (CUs) in British Columbia (1953-2011) and Puget Sound (1959-2009), identified those streams with data for two-thirds or more of the years, and imputed values for missing years of data. We accounted for fish in the remaining streams by multiplying annual reconstructed estimates for each CU by a scaling factor that assumed relative abundance within the CU remained stable across years. In general, these data-limited streams were low production systems containing few pink salmon. We assessed escapement trends for each CU using the entire time series as well as the most recent 20 years. There were significant positive trends for many of the odd-year returning CUs, but only rarely for even-year CUs. Odd-year CUs did better than even-year CUs in five of the eight areas containing both, even-year CUs did best in one area, and there was no difference between even and odd-year CUs in the remaining two areas. The generated time series of fishery exploitation for Fraser River pink salmon and other odd-year southern Canadian populations indicated that increases in spawner abundance were partly due to decreased fishery exploitation. Coinciding with increasing spawner numbers, we observed mean body sizes of returning pink salmon have been declining within the available datasets (Fraser River, 1959-2009; Puget Sound, 1973-2009). Fry abundance indices for the Fraser River and Puget Sound allowed us to estimate temporal patterns of freshwater (i.e., index of fry numbers produced per adult) and post-fry (i.e., primarily marine) productivity (i.e., adults produced per index of fry abundance). In both the Fraser River and Puget Sound, freshwater productivity has been declining as spawner abundance has been increasing (i.e., there is a negative anomaly from the average fry/adult ratio). Density dependence, as assumed in a Ricker model, explains negative anomalies at high spawner numbers and positive anomalies at low spawner numbers. Taking density dependence into account, we saw no further signs for increased freshwater productivity. We conclude pink salmon populations in the southern portion of

their range in the eastern North Pacific are increasing, similar to populations further north and west, but the mechanisms responsible for these increases likely differ among areas. In the southeastern North Pacific, increasing pink salmon abundance is more likely a response to declining fishery exploitation than to enhancement, which is minimal. Increasing escapement apparently causes a density-dependent decline in freshwater productivity that suggests to us that fishing opportunities exist.

Irvine, J.R., A. Tompkins, T. Saito, K. B. Seong, J. K. Kim, N. Klovach, H. Bartlett, and E. Volk. 2012. Pacific Salmon Status and Abundance Trends - 2012 Update. North Pacific Anadromous Fish Commission Document 1422.

This report updates a major review published in 2009 of commercial catch and hatchery release data for Pacific salmon. Pacific salmon abundance in the North Pacific, as indexed by aggregate commercial catches, is at all time high levels, with no indication of decline. The highest catches on record occurred during 2009 and 2011 when more than 1 million tonnes (>600 million fish) were caught. There are more adult salmon caught in odd numbered years than even years because the most frequent species in the catch, pink salmon, are most abundant in odd years. The ranking of species in the aggregate catch varied little since the time series began in 1925. Pink salmon have generally been the most numerous, usually followed by chum, sockeye, coho, Chinook, and masu salmon. Although the northern North Pacific Ocean continues to produce large quantities of Pacific salmon, temporal abundance patterns vary among species. Currently, pink and chum salmon are very abundant, coho and Chinook salmon are less abundant than they were previously, while sockeye salmon abundance varies among areas.

Pink and chum salmon dominate Asian catches; numbers increased following the 1977 but especially the 1989 regime shift, and remain at all time highs. Russia currently catches the largest proportion of the Asian catch although in earlier years, Japan often caught a greater proportion; catches by the Republic of Korea are relatively minor. Asian hatchery production continues to increase, primarily because of increased numbers of salmon released from Russian hatcheries. Improved survivals reported for some groups of hatchery-origin salmon are a consequence of both improved hatchery practices and environmental changes. Favourable marine conditions for pink and chum salmon, expanding hatchery operations, and improved hatchery technologies have all played a role in increasing the abundance of chum and pink salmon in Asia.

North American salmon abundance increased following the 1977 regime shift. The relative abundance of salmon species in North America varies from north to south. Pink and sockeye salmon are the primary species in Alaska while in Canada, pink, sockeye, and chum salmon have historically been the most important, and in Washington, Oregon, and California, Chinook and coho salmon are the most abundant species. Interannual variability in the importance of various species in North America has been more pronounced during the last decade than previously.

Jeffries, K.M., S.G. Hinch, M.R. Donaldson, M.K. Gale, J.M. Burt, L.A. Thompson, A.P. Farrell, D.A. Patterson, and K.M. Miller. 2011. Temporal changes in blood variables during final maturation and senescence in male sockeye salmon *Oncorhynchus nerka*: reduced osmoregulatory ability can predict mortality. Journal of Fish Biology 79:449-465.

This study is the first to characterize temporal changes in blood chemistry of individuals from one population of male sockeye salmon *Oncorhynchus nerka* during the final 6 weeks of sexual maturation and senescence in the freshwater stage of their spawning migration. Fish that died before the start of their historic mean spawning period (*c.* 5 November) were characterized by a 20–40% decrease in plasma osmolality, chloride and sodium, probably representing a complete loss of osmoregulatory ability. As fish became moribund, they were further characterized by elevated levels of plasma cortisol, lactate and potassium. Regressions between time to death and plasma chloride (8 October: $P < 0{\cdot}001$; 15 October: $P < 0{\cdot}001$) indicate that plasma chloride was a strong predictor of longevity in *O. nerka*. That major plasma ion levels started to decline 2–10 days (mean of 6 days) before fish became moribund, and before other stress, metabolic or reproductive hormone variables started to change, suggests that a dysfunctional osmoregulatory system may initiate rapid senescence and influence other physiological changes (*i.e.* elevated stress and collapsed reproductive hormones) which occur as *O. nerka* die on spawning grounds.

Jeffries, K.M., S.G. Hinch, E.G. Martins, T.D. Clark, A.G. Lotto, D.A. Patterson, S.J. Cooke, A.P. Farrell, and K.M. Miller. 2012. Sex and proximity to reproductive maturity influence the survival, final maturation, and blood physiology of Pacific salmon when exposed to high temperature during a simulated migration. Physiological and Biochemical Zoology 85: 62-73.

Some Pacific salmon populations have been experiencing increasingly warmer river temperatures during their once-in-a-lifetime spawning migration, which has been associated with en route and prespawn mortality. The mechanisms underlying such temperature-mediated mortality are poorly understood. Wild adult pink (*Oncorhynchus gorbuscha*) and sockeye (*Oncorhynchus nerka*) salmon were used in this study. The objectives were to investigate the effects of elevated water temperature on mortality, final maturation, and blood properties under controlled conditions that simulated a “cool” (13°C) and “warm” (19°C) freshwater spawning migration. After 10 d at 13°C, observed mortality was 50%–80% in all groups, which suggested that there was likely some mortality associated with handling and confinement. Observed mortality after 10 d at 19°C was higher, reaching ≥98% in male pink salmon and female pink and sockeye salmon. Thus, male sockeye salmon were the most thermally tolerant (54% observed mortality). Model selection supported the temperature- and sex-specific mortality patterns. The pink salmon were closer to reproductive maturation and farther along the senescence trajectory than sockeye salmon, which likely influenced their survival and physiological responses throughout the experiment. Females of both species held at 19°C had reduced plasma sex steroids compared with those held at 13°C, and female pink salmon were less likely to become fully mature at 19° than at 13°C. Male and female sockeye salmon held at 19_C had higher plasma chloride and osmolality than those held at 13°C, indicative of a thermally related stress response. These findings suggest that sex differences and proximity to reproductive maturity must be considered when predicting thermal tolerance and the magnitude of en route and prespawn mortality for Pacific salmon.

McClelland, E.K., T.J. Ming, A. Tabata, and K.M. Miller. 2011. Sequence analysis of MHC class I α2 from sockeye salmon (*Oncorhynchus nerka*). Fish and Shellfish Immunology 31:507-510.

Most studies assessing adaptive MHC diversity in salmon populations have focused on the classical class II DAB or DAA loci, as these have been most amenable to single PCR amplifications due to their relatively low level of sequence divergence. Herein, we report the characterization of the classical class I UBA a2 locus based on collections taken throughout the species range of sockeye salmon (Oncorhynchus nerka). Through use of multiple lineage-specific primer sets, denaturing gradient gel electrophoresis and sequencing, we identified thirty-four alleles from three highly divergent lineages. Sequence identity between lineages ranged from 30.0% to 56.8% but was relatively high within lineages. Allelic identity within the antigen recognition site (ARS) was greater than for the longer sequence. Global positive selection on UBA was seen at the sequence level (dN:dS ¼ 1.012) with four codons under positive selection and 12 codons under negative selection.

Miller, K.M., S. Li, K.H. Kaukinen, N. Ginther, E. Hammill, J.M.R. Curtis, D.A. Patterson, T. Sierocinski, L. Donnison, P. Pavlidis, S.G. Hinch, K.A. Hruska, S.J. Cooke, K.K. English, and A.P. Farrell. 2011. Genomic signatures predict migration and spawning failure in wild Canadian salmon. Science 331:214-217.

Long-term population viability of Fraser River sockeye salmon (*Oncorhynchus nerka*) is threatened by unusually high levels of mortality as they swim to their spawning areas before they spawn. Functional genomic studies on biopsied gill tissue from tagged wild adults that were tracked through ocean and river environments revealed physiological profiles predictive of successful migration and spawning. We identified a common genomic profile that was correlated with survival in each study. In ocean-tagged fish, a mortality-related genomic signature was associated with a 13.5-fold greater chance of dying en route. In river-tagged fish, the same genomic signature was associated with a 50% increase in mortality before reaching the spawning grounds in one of three stocks tested. At the spawning grounds, the same signature was associated with 3.7-fold greater odds of dying without spawning. Functional analysis raises the possibility that the mortality-related signature reflects a viral infection.

Oka, G., C. Holt, J.R. Irvine, and M. Trudel. 2012. Density-dependent growth of salmon in the North Pacific Ocean: Implications of a limited, climatically varying carrying capacity for fisheries management and international governance. North Pacific Anadromous Fish Commission Technical Report 8:112.

Recent evidence has revealed that hatchery-origin salmon compete with wild salmon for a common pool of prey resources in the North Pacific Ocean. Density-dependent effects on growth of chum salmon are of special concern because of large increases in hatchery production of this species (and pink salmon) in Asia and evidence for both intra- and inter-specific competition for limited prey. Age-specific body size-at-return of chum salmon has declined over the last 3-4 decades in Japan, Korea, Alaska, Washington, and BC, and these declines have been explained by competition with abundant hatchery-produced chum salmon from Asia, although spatial overlap of distribution remains uncertain. This has led to international interest on potential effects of hatchery production on wild stocks in Asia and North America. In order to investigate the relative contribution of density-dependent growth arising from a limited carrying capacity and climatically varying oceanographic drivers, in this pilot project we investigated the marine growth of one population of chum salmon from BC (Big Qualicum, Vancouver Island, 1968-2005). Salmon marine growth was determined by analyzing scales from fish

captured on the spawning grounds at ages three (31) and four (41). Preliminary results indicated that return year had a significant effect on the growth rate of most chum salmon in both age groups. Specifically, scale growth (and presumably fish length) was greatest in the first marine year and declined incrementally in subsequent years. The growth rate of 31 chum salmon in all years was higher than 41 chum salmon. The effect of sex on scale growth was less conclusive, with male growth rates being higher than female growth rates in some years. Correlation analysis revealed a negative correlation between the first and second year of growth for both 31 and 41 chum salmon, suggesting that chum salmon may have an optimal size at the end of their second year. Growth was also correlated by ocean entry year, and as different ages of fish presumably occupy different areas in the ocean, this demonstrates the importance of large-scale climatic factors in determining chum salmon growth. Proposed future work includes comparisons of marine growth among pink, chum, and sockeye salmon from neighbouring and spatially diverse populations across British Columbia.

Oka, G., J.R. Irvine, C. Holt, M. Trudel, S. Tucker, D. Gillespie, and L. Fitzpatrick. 2012. Temporal growth patterns of Big Qualicum River chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean. NPAFC Doc. 1429. 13 pp

Increases in salmon abundance in the Pacific Ocean over the past three to four decades have been attributed to favourable environmental conditions and enhanced hatchery production. However, the effects of inter- and intra- species competition for food resources in the ocean remains inconclusive. Chum salmon (*Oncorhynchus keta)* are of particular interest because of the large numbers of hatchery releases and some evidence of density dependence. Scales from Big Qualicum River chum salmon gathered during 1971-2010 were examined to evaluate marine growth during this period. A consistent temporal trend was observed for all growth years for the dominant age classes of chum salmon; growth was most rapid in the early 1980s and 2000s and slowest in years centred around 1990. Future work to continue statistical analysis of these data and examine temporal patterns in growth of other populations and species is recommended.

Olsen, J.B., T.D. Beacham, M. Wetklo, L.W. Seeb, C.T. Smith, B.G. Flannery, and J.K. Wenburg. 2010. The influence of hydrology and waterway distance on population structure of Chinook salmon (*Oncorhynchus tshawytscha*) in a large river. Journal of Fish Biology 76:1128-1148.

Adult Chinook salmon *Oncorhynchus tshawytscha* navigate in river systems using olfactory cues that may be influenced by hydrologic factors such as flow and the number, size and spatial distribution of tributaries. Thus, river hydrology may influence both homing success and the level of straying (gene flow), which in turn influences population structure. In this study, two methods of multivariate analysis were used to examine the extent to which four indicators of hydrology and waterway distance explained population structure of *O. tshawytscha* in the Yukon River. A partial Mantel test showed that the indicators of hydrology were positively associated with broad-scale (Yukon basin) population structure, when controlling for the influence of waterway distance. Multivariate multiple regression showed that waterway distance, supplemented with the number and flow of major drainage basins, explained more variation in broad-scale population structure than any single indicator. At an intermediate spatial scale, indicators of hydrology did not appear to influence population structure after accounting

for waterway distance. These results suggest that habitat changes in the Yukon River, which alter hydrology, may influence the basin-wide pattern of population structure in *O. tshawytscha*. Further research is warranted on the role of hydrology in concert with waterway distance in influencing population structure in Pacific salmon.

Peacock, S.J., and C.A. Holt. 2010. A review of metrics of distribution with application to Conservation Units under Canada's Wild Salmon Policy. Canadian Technical Report of Fisheries and Aquatic Sciences 2888.

Metrics describing the distribution of individuals among groups and across the landscape can provide information on the resilience of a population that may not be apparent from abundance information alone. The distribution of spawners has therefore been recommended as an indicator of the biological status of Conservation Units (CUs) under Canada's Wild Pacific Salmon. The objectives of this report were to review metrics of distribution from the scientific and management and compare those to metrics previously proposed for assessing status of CUs. Only a subset of metrics were relevant for assessing status of CUs, but others may be useful for other biological and management settings.

Peacock, S.J., and C.A. Holt. 2012. Metrics and sampling designs for detecting trends in the distribution of spawning Pacific salmon (*Oncorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences 69:681-694.

The distribution of individuals among populations and in space may contribute to their resilience under environmental variability. Changes in distribution may indicate the loss of genetically distinct subpopulations, the deterioration of habitat capacity, or both. The distribution of Pacific salmon (*Oncorhynchus* spp.) among spawning locations has recently been recognized as an important component of status assessment by USA and Canadian management agencies, but metrics of spawning distribution have not been rigorously evaluated. We evaluated three metrics of spawning distribution and four sampling designs for their ability to detect simulated contractions in the production of coho salmon (*Oncorhynchus kisutch*). We simulated population dynamics at 100 sites using a spawner–recruit model that incorporated natural variability in recruitment, age-at-maturity, dispersal, and measurement error in observations of abundance. Sensitivity analyses revealed that high observation error and straying of spawners from their natal streams may mask changes in distribution. Furthermore, monitoring only sites with high spawner abundance, as is often practiced, failed to capture the simulated contraction of production, emphasizing the importance of matching monitoring programs with assessment objectives

Porszt, E.J., R.M. Peterman, N.K. Dulvy, A.B. Cooper, and J.R. Irvine. 2012. Reliability of iIndicators of decline in abundance. Conservation Biology. doi: 10.1111/j.1523-1739.2012.01882.x

Although there are many indicators of endangerment (i.e., whether populations or species meet criteria that justify conservation action), their reliability has rarely been tested. Such indicators may fail to identify that a population or species meets criteria for conservation action (false negative) or may incorrectly show that such criteria have been met (false positive). To quantify the rate of both types of error for 20 commonly used

indicators of declining abundance (threat indicators), we used receiver operating characteristic curves derived from historical (1938–2007) data for 18 sockeye salmon (*Oncorhynchus nerka*) populations in the Fraser River, British Columbia, Canada. We retrospectively determined each population's yearly status (reflected by change in abundance over time) on the basis of each indicator. We then compared that population's status in a given year with the status in subsequent years (determined by the magnitude of decline in abundance across those years). For each sockeye population, we calculated how often each indicator of past status matched subsequent status. No single threat indicator provided error-free estimates of status, but indicators that reflected the extent (i.e., magnitude) of past decline in abundance (through comparison of current abundance with some historical baseline abundance) tended to better reflect status in subsequent years than the rate of decline over the previous 3 generations (a widely used indicator). We recommend that when possible, the reliability of various threat indicators be evaluated with empirical analyses before such indicators are used to determine the need for conservation action. These indicators should include estimates from the entire data set to take into account a historical baseline.

Rand, P.S., M. Goslin, M.R. Gross, J.R. Irvine, X. Augerot, P.A. McHugh, and V.F. Bugaev. 2012. Global assessment of extinction risk to populations of sockeye salmon *Oncorhynchus nerka*. PLoS ONE 7(4): e34065. doi:10.1371/journal.pone.0034065

Background: Concern about the decline of wild salmon has attracted the attention of the International Union for the Conservation of Nature (IUCN). The IUCN applies quantitative criteria to assess risk of extinction and publishes its results on the Red List of Threatened Species. However, the focus is on the species level and thus may fail to show the risk to populations. The IUCN has adapted their criteria to apply to populations but there exist few examples of this type of assessment. We assessed the status of sockeye salmon as a model for application of the IUCN population-level assessments and to provide the first global assessment of the status of an anadromous Pacific salmon.

Methods/Principal Findings: We found from demographic data that the sockeye salmon species is not presently at risk of extinction. We identified 98 independent populations with varying levels of risk within the species' range. Of these, 5 (5%) are already extinct. We analyzed the risk for 62 out of 93 extant populations (67%) and found that 17 of these (27%) are at risk of extinction. The greatest number and concentration of extinct and threatened populations is in the southern part of the North American range, primarily due to overfishing, freshwater habitat loss, dams, hatcheries, and changing ocean conditions.

Conclusions/Significance: Although sockeye salmon are not at risk at the species-level, about one-third of the populations that we analyzed are at risk or already extinct. Without an understanding of risk to biodiversity at the level of populations, the biodiversity loss in salmon would be greatly underrepresented on the Red List. We urge government, conservation organizations, scientists and the public to recognize this limitation of the Red List. We also urge recognition that about one third of sockeye salmon global population diversity is at risk of extinction or already extinct.

Sandher, J., R. Cook, and J.R. Irvine. 2010. Canadian enhanced salmonid production during 1978-2009 (1977-2008 brood years). North Pacific Anadromous Fish Commission Document 1258.

The Salmonid Enhancement Program (SEP) in British Columbia, Canada was initiated in 1977 to rebuild stocks and increase catch through the expanded use of enhancement technology. The program comprises over 400 projects that produce chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye salmon (*O. nerka*), as well as small numbers of steelhead salmon (*O. mykiss*) and cutthroat trout (*O. clarki*). Projects include hatcheries, fishways, spawning and rearing channels, habitat improvements, flow control works, lake fertilization, and small classroom incubators, and range in size from spawning channels releasing nearly 100 million juveniles annually, to schools with classroom incubators that release fewer than one thousand. Data from facilities that operate outside the direction of SEP are not included in this report. Steelhead and cutthroat are a provincial government responsibility, but some enhancement takes place at SEP facilities under a cooperative arrangement. Steelhead and cutthroat numbers in this report do not include releases from facilities operated by the Freshwater Fisheries Society of British Columbia.

Sandher, J., C. Lynch, D. Willis, R. Cook and J. R. Irvine. 2012. Canadian enhanced salmonid production during 1977-2011 (1976-2010 brood years). NPAFC Doc. 1420.

The Salmonid Enhancement Program (SEP) in British Columbia, Canada was initiated in 1977 to rebuild stocks and increase catch through the expanded use of enhancement technology. The program currently comprises approximately 150 projects which produce chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon, as well as small numbers of steelhead (*O. mykiss*) and cutthroat trout (*O. clarkii*). Projects include hatcheries, fishways, spawning and rearing channels, and small classroom incubators, and range in size from spawning channels releasing nearly 100 million juveniles annually, to schools with classroom incubators that release fewer than one hundred. Data from facilities that operate outside the direction of SEP are not included in this report. Steelhead and cutthroat are a provincial government responsibility, but some enhancement takes place at SEP facilities under a cooperative arrangement. Steelhead and cutthroat numbers in this report do not include releases from facilities operated by the Freshwater Fisheries Society of British Columbia.

Selbie, D.T., J.N. Sweetman, P. Etherton, K.D. Hyatt, D.P. Rankin, B.P. Finney, and J.P. Smol. 2011. Climate change modulates structural and functional lake ecosystem responses to introduced anadromous salmon. Canadian Journal of Fisheries and Aquatic Sciences 68(4):675-692.

We integrated limnological, paleolimnological, and fisheries analyses in Tuya Lake, British Columbia, Canada, to explore the effects and interactions of climate warming and sockeye salmon introductions on northern lake ecology. We tracked millennially unprecedented, climate-correlated changes in inferred lake production, stratification, and trophic structure since the mid-1800s, most likely resulting from declining ice cover and enhanced stratification. Post-1970s algal (diatom) species turnover, coeval across several remote northern Cordilleran lakes, marked an apparent increase in warming and

the induction of inferred nitrogen deficiencies in Tuya Lake. Lower post-stocking phosphorus (P) and nitrogen (N) concentrations and a strong P-modeled salmon biomass correlation (r2 = 0.87) indicated salmon production reduced epilimnetic nutrient availability. Post-stocking chlorophyll reductions, late-summer algal dominance by heterocystous cyanobacteria and low-N-tolerant diatoms, and a strong chlorophyll-modeled salmon biomass correlation (r2 = 0.87) indicated that salmon influenced lake productivity, most likely by enhancing climate-induced N-deficiencies. Predicted smolt-biomass nutrient exports were minimal, with post-introduction nutrient reductions likely related to planktivory and enhanced sedimentation losses. Our study highlights how climate warming changes northern lake ecosystem structure and functioning, influencing responses to subsequent stresses.

Sharma, R., L. Vélez-Espino, A, Wertheimer, N. Mantua, and R. Francis. 2012. Relating spatial and temporal scales of climate and ocean variability to survival of Pacific Northwest Chinook. Fisheries Oceanography (in press).

Pacific Northwest Chinook, *Oncorhynchus tshawytscha*, have exhibited a high degree of variability in smolt-to-adult survival over the past three decades. This variability is summarized for twenty two Pacific Northwest stocks and analyzed using Generalized Linear Modeling techniques. Results indicate that survival can be grouped into eight distinct regional clusters: (1) Alaska, Northern BC and North Georgia Strait; (2) Georgia Strait; (3) Lower Fraser River and West Coast Vancouver Island; (4) Puget Sound and Hood Canal; (5) Lower Columbia Tules; (6) Columbia Upriver Brights, Willamette and Cowlitz; (7) Oregon and Washington Coastal; and (8) Klamath River and Columbia River Summers. Further analysis for stocks within each of the eight regions indicates that local ocean conditions following the outmigration of smolts from freshwater to marine areas had a significant effect on survival for the majority of the stock groups analyzed. Our analyses of the data indicate that Pacific Northwest Chinook survival covaries on a spatial scale of 350-450 km. Lagged time series models are presented that link large-scale tropical Pacific conditions, intermediate-basin scale northeastern Pacific conditions, and local sea surface temperatures to survival of Pacific Northwest stocks.

Tompkins A., G. Brown, and M. Thiess. 2011. Temporal patterns in productivity of North American sockeye and Chinook salmon. North Pacific Anadromous Fish Commission Document 1356.

Although recent catches of salmon in the North Pacific are at record levels, relative catches of some species have declined. We used a Kalman filter estimation procedure to estimate time series of productivity values for North American Sockeye and Chinook salmon. Generally, Sockeye stocks in Alaska are experiencing above average productivity while stocks in British Columbia have experienced below average productivity since the early 1990s. Coast wide Chinook salmon stocks experienced poor productivity in the early 1990s but Alaskan and Upper Columbia River stocks have shown improved productivity for the last decade. Common temporal patterns in productivity across distant stocks and species may be useful in identifying shared environmental factors to explain observed variations in productivity.

Tompkins, A., N. Komick and M. Thiess. 2012. Salmon Assessment in British Columbia and Yukon. NPAFC Doc. 1431. 13 pp.

The purpose of salmon stock assessment is to provide the information on stock status, trends and productivity needed to inform and guide management of salmon fisheries. Understanding the status of salmon stocks and the factors (e.g. climate) influencing Pacific salmon production requires long-term monitoring of biological data. Stock assessment data are required to address issues related to conservation, fisheries management, biodiversity, fish habitat, and the effects of climate change. Stock assessment research conducted by Canadian Department of Fisheries and Oceans Pacific Region includes freshwater sampling activities to determine abundance of returning adults and juvenile production and marine sampling activities to determine stock composition of catch.

Vélez-Espino, L.A., R.E. McNicol, G. Brown, and C.K. Parken. 2010. Correction factors for numbers of released Chinook salmon reported in commercial troll logbooks: expanding the applications of the observer program. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2898.

The need for accurate information on the number of Chinook salmon (*Oncorhynchus tshawytscha*) caught and released during fishing periods has become increasingly important with the Pacific Salmon Treaty now requiring both Canada and the United States of America to provide a measure of total mortality (fishing mortality plus incidental mortality) from salmon fisheries. The number of Chinook released is essential to estimate incidental mortality, which is the product of assumed post-release mortality and estimated number of Chinook released. Statistical analyses of data reported by observer and logbook programs in West Coast Vancouver Island (WCVI) troll fishery for the period 1998-2008 demonstrated that there is a consistent underreporting of released Chinook in retention periods in logbooks when trollers are allowed to keep only legal size fish. The consistency of this bias across the study period translated into average correction factors of 1.33-1.67. The stability of the underreporting bias was demonstrated with two different approaches characterized by two different spatial-temporal stratifications (management area-license year and management area-statistical week) of observer and logbook datasets and two different statistical metrics (proportion of the encounters released and the number released per fishing effort). A third metric was explored (the ratio between the number released and the number kept) and considered suboptimum to explain the variability in observer data. The ability to correct underreporting of the number of released fish is important to more effectively assess incidental mortality rates in Chinook salmon troll fisheries, and is vital within a total mortality management regime in which fishers are accountable for legal and sublegal mortality.

Vélez-Espino, L.A., G. Mullins, J. Willis, A. Krimmer, A. W. Levesque. 2010. Mark-recapture experiment for the 2009 Chinook salmon spawning escapement in the Atnarko River. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2930.

Two-sample, closed population estimates of spawning escapement in Pacific salmon populations have constituted a common practice. This pooled-Petersen mark-recapture approach seems appropriate for cases where closed-population assumptions are met, but could ignore major bias sources if violations to these assumptions are overlooked. In addition, the richness of information commonly generated by many Pacific salmon mark-

recapture studies is not being utilized when following a pooled- Petersen protocol, therefore missing important opportunities to enrich our knowledge of salmon ecology. The main goals of this paper are: (i) to provide an estimate of the 2009 Chinook salmon (Oncorhynchus tshawytscha) spawning escapement in the Atnarko River applying the standard pooled-Petersen mark-recapture experiment; (ii) to apply an alternative and robust approach to spawning escapement estimation within a model selection framework encompassing suites of open-population and closed-population maximum likelihood estimators based on individual encounter histories and formal testing of primary closed-population assumptions; and, (iii) to demonstrate the use of information provided by individual encounter histories from mark-recapture experiments allowing the reconstruction of migration phenologies and the estimation of stream residence times.

Spawning escapements of 3,593 (95% CI: 3,077-4,108) females, 5,636 (95% CI: 4,640-6,632) males, and 1,532 (95% CI: 1,028-2,035) jacks were estimated with the Petersen model for a total spawning escapement of 10,761 (95% CI: 8,745-12,775; CV = 5.7%) fish. These numbers exclude the fish removed from the system for hatchery purposes (969).

Using the maximum likelihood model selection approach, closure assumptions were violated and best open-population escapement estimates for females, males, and jacks were 8,232 (SE: 615.2), 7,877 (SE: 513.2), and 4,159 (SE: 796.5), respectively, for a total escapement estimate of 20,268 (95% CI: 16,985-24,601; CV = 9.5%). These numbers represent the fish escaping the terminal fisheries and entering the study area and include the fish removed from the system for hatchery purposes (969) and their removal's effect on capture probabilities. Accounting for the survival rates of Chinook salmon within the study period (0.95 for females, 0.94 for males, and 0.95 for jacks) left an average of 19,157 total effective natural spawners.

The analysis of scales from a sample of salmon carcasses indicated that about 80% of the spawners consisted of age-3 and age-4 individuals with 100% of the age-3 fish and 91.4% of the age-4 fish exhibiting ocean-type life history. Only 37.9% of the age-5 fish and 28.6% of the age-6 fish exhibited this life history type. The analysis of coded-wire-tag data from a sample of adipose-fin-clipped carcasses indicated that 37.0% of the females, 50.6% of the males, and 61.4% of the jacks in the spawning escapement were of hatchery origin, which translated into an overall hatchery contribution of 49%.

Important sources of uncertainty in the mark-recapture experiment of the 2009 Atnarko Chinook spawning escapement were associated to a high tag-loss rate, inconsistencies in the record of recaptures and losses-on-capture, and the return to the system of fish previously removed for hatchery purposes. Although these factors influence escapement estimates of mark-recapture experiments in general, they are particularly crucial in analyses dependent on individual encounter histories. The identification of these issues is expected to improve the reliability of spawning escapement estimates derived from robust analytical approaches in future years. It is herein argued that the intensive and extensive sampling effort currently at work in the Atnarko should be capitalized on by following an experimental approach characterized by the evaluation of closure assumptions, mark-recapture model selection, and the optimization of the use of information.

Vélez-Espino, L.A., J. Willis, C.K. Parken, and G. Brown. 2011. Cohort analyses and new developments for coded wire tag data of Atnarko River Chinook salmon. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2958.

The Coded Wire Tag (CWT) workgroup of the Pacific Salmon Commission (PSC) recently identified that major Chinook salmon (Oncorhynchus tshawytscha) production regions and life histories are poorly represented by CWT indicator stocks currently used for assessments by the PSC Chinook Technical Committee (CTC). One of these major production areas without a CWT indicator stock is the central coast of British Columbia, where the abundance of Chinook salmon spawners is dominated by returns to the Atnarko River in the Bella Coola River watershed. Although the Bella Coola River watershed has had the most intensive assessment in central British Columbia, including the most thorough escapement assessment in the region, and in spite of Atnarko Chinook being CWTed since 1976, significant issues have prevented the inclusion of this population as a CWT indicator stock in PSC assessments: (i) a need for validation of the quality of estimates of total escapement; (ii) the need for adequate sampling allowing estimation of freshwater CWT recoveries; (iii) data coordination reporting problems; and, (iv) limitations of funds to conduct robust and effective sampling and analysis. The main objectives of this investigation were to compile, evaluate, and improve the Atnarko Chinook CWT recovery data from freshwater fisheries and escapement, and then use these data for cohort analyses. Cohort analysis is the reconstruction of the exploitation and spawning history of a stock using CWT release and recovery data to estimate key population statistics, such as survival, maturation, and exploitation rates. The successful completion of cohort analyses for this stock contributes to the goal of incorporating Atnarko Chinook into future CTC assessments to better represent life histories and exploitation patterns of central British Columbia Chinook salmon populations.

Wilkinson, J., C. Lynch, and J.R. Irvine. 2011. Canadian enhanced salmonid production during 1978-2010 (1977-2009 brood years). North Pacific Anadromous Fish Commission Document 1339.

The Salmonid Enhancement Program (SEP) in British Columbia, Canada was initiated in 1977 to rebuild stocks and increase catch through the expanded use of enhancement technology. The program currently comprises approximately 150 projects which produce chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon, as well as small numbers of steelhead (*O. mykiss*) and cutthroat trout (*O. clarkii*). Projects include hatcheries, fishways, spawning and rearing channels, and small classroom incubators, and range in size from spawning channels releasing nearly 100 million juveniles annually, to schools with classroom incubators that release fewer than one hundred. Data from facilities that operate outside the direction of SEP are not included in this report. Steelhead and cutthroat are a provincial government responsibility, but some enhancement takes place at SEP facilities under a cooperative arrangement. Steelhead and cutthroat numbers in this report do not include releases from facilities operated by the Freshwater Fisheries Society of British Columbia.

Withler, R.E., R.H. Devlin, S. Latham, C.C. Wood and K. J. Supernault. 2011. Analysis of gene origin in the first adult returns to the Cultus sockeye salmon captive breeding program. Conservation Genetics 12:1469-1483.

Rigorous evaluation of the utility of captive breeding for the restoration of depleted wild salmonid fish populations has not been undertaken. In particular, little is known about the reproductive success of captively-bred individuals that are released back into an extant population and their capacity to assist in long-term population persistence. For the endangered Cultus Lake sockeye salmon population, we examined the potential genetic contribution of the first juvenile fish released from a captive breeding program upon their maturity in the natural Cultus Lake environment. Genetic analysis of 792 Cultus sockeye salmon that were spawned in captivity in 2004 and their adult progeny of 2007 and 2008 revealed a genetic bottleneck originating from 20 wild sockeye salmon hatchery spawned at Cultus Lake in the previous generation. Pedigree analysis revealed that six of the 20 sockeye salmon spawned in 2001 (grandparents) gave rise to a majority of the hatchery spawners in 2004 (parents) and provided more than 30% of the genes in the progeny that survived to maturity in the wild. Allele frequencies and genetic diversity of the age three progeny that returned to Cultus Lake from their marine migration in 2007 reflected the bottleneck, but its genetic signature was faint among the more genetically diverse age four fish that returned in 2008. Two-generation analysis of gene origin among fish resulting from 2004 hatchery production indicated that they contained the genetic diversity expected from 36 effective ancestors.

## Component 5: Development and Applications of Stock Identification Methods and Models for Management of Pacific Salmon

Beacham, T.D., B. McIntosh, and C. Wallace. 2010. A comparison of stock and individual identification for sockeye salmon (*Oncorhynchus nerka*) in British Columbia provided by microsatellites and single nucleotide polymorphisms. Canadian Journal of Fisheries and Aquatic Sciences 67: 274-1290.

Variation at 14 microsatellite loci, one major histocompatibility complex (MHC) locus, and 49 single nucleotide polymorphism (SNPs) loci was surveyed in 44 populations of sockeye salmon (*Oncorhynchus nerka*) over 16 regions from southern and central British Columbia, Canada. Sequential addition of the five highest rated SNPs to the suite of 14 microsatellites provided the equivalent average accuracy when compared with the current suite of microsatellites and MHC. Six microsatellites provided the equivalent average stock identification resolution and individual assignment accuracy compared with 46 SNPs. For regional stock compositions, 53–104 SNPs were projected to be required to provide accuracy and precision equivalent to the microsatellites. For population-specific stock compositions, 75–79 SNPs were projected to be required to provide accuracy and precision equivalent to the microsatellites. Equivalency in individual assignment accuracy to region was estimated to require 100 SNPs of the quality evaluated in the study, whereas equivalent accuracy in assignment to specific populations was estimated to require 124 SNPs. Applications that incorporate the existing power of a combined microsatellite–SNP approach are the best current technique available for sockeye salmon stock identification applications in southern British Columbia.

Beacham, T.D., B. McIntosh, and C. Wallace. 2011. A comparison of polymorphism of genetic markers and population sample sizes required for mixed-stock analysis of sockeye salmon (*Oncorhynchus nerka*) in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 68:550-562.

We evaluated two questions: (*i*) do microsatellites require larger population baseline sample sizes than single nucleotide polymorphisms (SNPs) to allow the accuracy provided by the microsatellites in genetic stock identification (GSI) applications to be expressed, and (*ii*) do less genetically distinct populations require larger population baseline sample sizes than more distinct populations to improve population-specific accuracy in GSI applications? Forty-six SNP loci were surveyed in 40 populations of sockeye salmon (*Oncorhynchus nerka*) over 16 regions from southern and central British Columbia and were split into two groups: the top 23 SNPs evaluated for stock identification for British Columbia sockeye salmon and the poorest 23 nuclear SNPs. Fourteen microsatellites were surveyed and split into two groups, with loci from the top 7 loci for stock identification accuracy assembled in one group, and the remaining 7 microsatellites assigned to a second group. SNPs and microsatellites with lower stock identification power required larger population sample sizes to allow expression of stock identification potential. To achieve the same level of population-specific accuracy, SNPs required fewer individuals to be sampled in a population than did microsatellites. Less genetically distinct populations required larger population sample sizes to achieve a given level of accuracy in estimated stock compositions.

Beacham, T.D., J.R. Candy, E. Porszt, S. Sato, and S. Urawa. 2011. Microsatellite identification of Canadian sockeye salmon rearing in the Bering Sea. Transactions of the American Fisheries Society 140:296-306.

The stock composition of sockeye salmon *Oncorhynchus nerka* caught in the central Bering Sea in the summer of 2009 was estimated to evaluate migration patterns of salmon of Canadian origin, which have not been demonstrated previously to rear in the Bering Sea. The variation at 14 microsatellites was analyzed for 450 immature sockeye salmon, and a baseline of 387 populations from Japan, Russia, Alaska, Canada, and Washington State was used to determine the stock composition of the fish sampled. Sockeye salmon originating from Alaska were the most abundant in the catch, comprising 86.0% of all sockeye salmon caught, the catch being dominated by sockeye salmon of Bristol Bay origin. Russian-origin sockeye salmon accounted for 10.2% of the catch, while Canadian origin sockeye salmon accounted for 3.8% of the catch. Salmon from Canada were estimated to originate from the Fraser River, Rivers Inlet (Owikeno Lake), the Skeena River (Babine Lake), the Stikine River, and the Alsek River, British Columbia. These results indicate that the central Bering Sea provides a summer rearing area for some Canadian sockeye salmon.

Beacham, T.D., K. Jonsen, and C. Wallace. 2012. A comparison of stock and individual identification for Chinook salmon in British Columbia provided by microsatellites and single nucleotide polymorphisms (SNPs). Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:1-22.

The following questions were addressed in this study: (1) If a suite of 12–15 microsatellites were used in the genetic stock identification (GSI) of Chinook salmon *Oncorhynchus tshawytscha*, which microsatellites should be in the suite? (2) How many

microsatellites are required to provide stock identification resolution equivalent to that of 72 single-nucleotide polymorphisms (SNPs)? (3) How many SNPs are required to replace the current microsatellite baselines used in GSI applications? (4) If additional GSI power is required for microsatellite baselines, what is the incremental increase provided by SNPs and microsatellites? The variation at 29 microsatellite loci and 73 SNP loci was surveyed in 60 populations of Chinook salmon in 16 regions in British Columbia. Microsatellites with more observed alleles provided more accurate estimates of stock composition than those with fewer alleles. The options available for improving the accuracy and precision of stock composition estimates for a 12-locus Fisheries and Oceans Canada (DFO) microsatellite suite range include adding either 4 microsatellites or 25 SNPs to the existing suite to achieve an overall population-specific accuracy of 86% across 60 populations. For the 13-locus Genetic Analysis of Pacific Salmon (GAPS) microsatellites, either 2 microsatellites or 20–25 SNPs can be added to the existing suite to achieve approximately 86% population-specific accuracy in estimated stock composition. The enhanced DFO (16 loci) and GAPS (15 loci) microsatellite baselines were projected to require 179 and 166 SNPs, respectively, for equivalent precision of the population-specific estimates. The level of regional accuracy of individual assignment available from the enhanced DFO and GAPS suites of microsatellites was projected to require 90 and 82 SNPs, respectively. The level of individual assignment to specific populations available from the enhanced DFO and GAPS suites of microsatellites was projected to require 137 and 121 SNPs, respectively.

Beacham. T.D., J.R. Candy, C. Wallace, M. Wetklo, L. Deng, and C. MacConnachie. 2012. Microsatellite mixed-stock identification of coho salmon (*Oncorhynchus kisutch*) in British Columbia. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:85-100.

Variation at 17 microsatellite loci was analyzed for about 50,000 coho salmon *Oncorhynchus kisutch* sampled from 274 locations ranging from Russia to California (but largely from British Columbia), and the variation was applied to estimate stock composition in mixed-stock fishery samples. High resolution of mixed-stock samples was possible; accurate estimates of stock composition were available for coho salmon originating from 39 regions (Russia, 1 region; Yukon River, 1; southeast Alaska, 1; British Columbia, 28; Washington, 5; Columbia River, 1; Oregon, 1; California, 1). The power of a locus in providing accurate estimates of stock composition of simulated single-population mixtures was related to the number of alleles observed at the locus. Approximately 800 alleles were observed across the 17 microsatellites. Analysis of known-origin samples indicated that accurate regional estimates of stock composition were obtained; estimates from 37 of 39 regions had accuracy greater than 90%. Estimated stock compositions of five mixed-fishery samples collected in British Columbia and the San Juan Islands (Washington) reflected the presence and timing of migration of the local populations. Microsatellites provided accurate estimates of stock composition from many locations in the British Columbia distribution of coho salmon.

Beacham, T.D., C.G. Wallace, K.D. Le, and M. Beere. 2012. Population structure and run timing of steelhead trout in the Skeena River, British Columbia. North American Journal of Fisheries Management 32:262-275.

Identification of population-specific run timing is an important component of salmonid fisheries management and was a major focus of our study. Population structure of

steelhead *Oncorhynchus mykiss* was examined in the Skeena River of northern British Columbia. Variation at 14 microsatellites was surveyed in 3,062 steelhead sampled from 17 populations in the drainage. During 1998–2010, 6,691 individuals were sampled in a lower river test fishery to obtain information on relative abundance and time of arrival of specific populations near the river mouth. The genetic differentiation index *F*ST calculated over all populations and loci was 0.021; individual locus values ranged from 0.017 to 0.045. Differentiation in steelhead allele frequencies among populations was approximately 14 times the differentiation observed among years within populations. A regional structuring of populations was the general pattern observed, with steelhead populations from the upper portion of the drainage clustering together in 87% of dendrograms evaluated and those in the lower portion of the drainage clustering together in 100% of dendrograms. The 17 populations sampled were arranged in nine reporting groups for genetic stock identification applications. The estimated stock composition of a simulated known-origin mixture was within 2% of the correct estimate for seven of the nine reporting groups present in the mixture. The stock composition of an actual known-origin sample was estimated within 2% of the correct estimate for eight of the nine reporting groups present. Application to actual samples from the test fishery indicated that upper drainage populations generally migrated through the lower river earlier than other populations, whereas lower river populations typically migrated later. Genetic mixed-stock analysis can assist managers in regulating fisheries to maintain productivity of Skeena River steelhead.

Beacham, T.D., J.R. Candy, S. Sato and S. Urawa. 2012. Microsatellite identification of sockeye salmon rearing in the Bering Sea 2011. North Pacific Anadromous Fish Commission Document 1389.

Stock composition of sockeye salmon (*Oncorhynchus nerka*) caught in the southern central Bering Sea during a Japanese research cruise in the summer of 2011 was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for 177 immature sockeye salmon, and a 387-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the stock composition of the fish sampled. Alaskan-origin sockeye salmon were the most abundant in the catch, comprising 86.1% of all sockeye salmon caught (United States total 86.7%), with the catch dominated by sockeye salmon of Bristol Bay origin. Russian-origin salmon accounted for 12.1% of the catch, while Canadian-origin sockeye salmon accounted for 1.2% of the catch.

Flannery, B.G., T.D. Beacham, J.R. Candy, R.R. Holder, G.F. Maschmann, E.J. Kretschmer, and J.K. Wenburg. 2010. Mixed-stock analysis of Yukon River chum salmon: Application and validation in a complex fishery. North American Journal of Fisheries Management 30:1324-1338.

Yukon River chum salmon Oncorhynchus keta are managed under the Pacific Salmon Treaty (PST), which requires conservation and equitable sharing of this fishery resource by the USA and Canada. Fall chum salmon are of special concern because they spawn in both the United States and Canada, and the focus of the PST is on Canadian-origin salmon. Yukon River chum salmon were assayed for genetic variation at 22 microsatellite loci to establish a baseline for mixed-stock analysis (MSA) applications to assist in addressing conservation and allocation issues. The baseline has been applied yearly to estimate the stock composition of Yukon River fall chum salmon from samples collected in the Pilot Station test fishery. Accuracies in MSA simulations for 12 of 14

management regions exceeded 90%, with a range of 80–98%, for the 12 most informative loci. Stock composition estimates were within 10% of the actual proportions in a known-origin mixture analysis. Stock-specific abundance estimates, which were derived from combining the estimates of genetic stock composition of Pilot Station test fishery harvests with sonar abundance estimates, were concordant with upriver escapement data. The combination of genetic MSA using the baseline developed in this study and sonar abundance provides a viable tool for assessing stock strength and assisting managers in regulating fisheries to maintain the productivity and evolutionary potential of Yukon River chum salmon.

Flannery, B.G., P.A. Crane, J.H. Eiler, T.D. Beacham, W.D. Templin, O.L. Schlei, and J.K. Wenburg. 2012. Comparison of radio telemetry and genetic methods for determining the origin of Yukon River Chinook salmon. North American Journal of Fisheries Management 32:720-730.

Chinook salmon *Oncorhynchus tshawytscha* support important subsistence and commercial fisheries throughout the Yukon River. Low returns and diverse user groups have made management of these fisheries contentious and have necessitated information on the origin of the spawning migration and harvest. Here we compare estimates of individual assignment and stock composition derived from genetic and radiotelemetry data collected from the same Chinook salmon. Radiotelemetry and genetic individual assignments were highly concordant. Agreement between methods for individual assignment was 79% to region and 93% to country when using the most probable genetic criterion, improving to 94% for region and 98% for country when using the ≥95% probability genetic criterion; however, under the more stringent criterion, fewer individuals could be assigned. Further analysis showed that estimates of stock composition based on radiotelemetry and genetic methods were within 6% of each other and were not significantly different. The concordance between estimates of individual assignment and stock composition from the radiotelemetry and genetic methods indicates that both methods are credible tools for fishery assessment of Yukon River Chinook salmon.

Godbout, L., M. Trudel, J.R. Irvine, C.C. Wood, M.J. Grove, A.K. Schmitt, and K.D. McKeegan. 2010. Sulfur isotopes in otoliths allow discrimination of anadromous and non-anadromous ecotypes of sockeye salmon (*Oncorhynchus nerka*). Environmental Biology of Fishes 89:521-532.

*Oncorhynchus nerka* occur both as anadromous sockeye salmon that spend most of their life in the ocean, and as non-anadromous kokanee salmon that remain in fresh water their entire lives. We assessed whether stable isotopes of sulfur ($\delta^{34}S$) in otoliths could be used to distinguish sockeye salmon and kokanee ecotypes that are otherwise difficult to identify when they share a common freshwater rearing environment. We also investigated the chemical link between salmon and their diet by measuring δ34S in various fish tissues (eggs, muscle, scales) and zooplankton. $\delta^{34}S$ (mean ± SE) in sockeye salmon eggs (18.7±0.4‰) and marine zooplankton (20.5±0.1‰) were enriched by 10–14‰ compared with kokanee eggs and freshwater zooplankton. $\delta^{34}S$ in the otolith cores of sockeye salmon (19.2±0.7‰) and kokanee salmon (5.3±1.1‰) were similar to δ34S in marine and freshwater zooplankton, respectively, indicating that the core is derived from maternal yolk tissue and reflects the maternal diet. $\delta^{34}S$ in the freshwater growth zone of otoliths did not differ significantly between sockeye (5.9±1.1‰) and

kokanee salmon (4.4±1.2‰), and was similar to freshwater zooplankton. The mean difference between $\delta^{34}S$ in the otolith core and first year of growth was 13.3±1.4‰ for sockeye and 0.65±1.3‰ for kokanee salmon. A quadratic discriminant function developed from measurements of $\delta^{34}S$ in otoliths of known maternal origin provided perfect classification rates in cross-validation tests. Thus, sulfur isotope ratios in otoliths are effective in discriminating between anadromous and non-anadromous ecotypes of *O. nerka*.