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Bibliography of Sockeye, Pink, and Chum Salmon Marine Growth- and Size-at-Age Publications

by

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Abstract

We provide a list of documents, with abstracts (when available) that use time series of annual growth or size-at-age for marine age classes of Sockeye, Pink and Chum Salmon, focusing on time series that exceeded ten years. Our documents are mainly peer-reviewed journals and NPAFC/INPFC documents, but include a small number of publications from other sources. Section 1 assembles articles that review salmon marine growth- or size-at-age. Section 2 lists articles with length or weight time series of return-at-age or catch-at-age. Section 3 lists methodological papers for quantifying growth increments. Section 4, our focus, assembles articles that provide indices of marine growth for at least one age class; all of these studies were based on size estimates from scale annuli measurements. Readers are encouraged to advise us of relevant documents not included in this bibliography.

Keywords: annual growth, size-at-age, scale-based growth estimates, Pacific salmon

Background

This bibliography is part of a project to locate datasets for use in linking size and growth trends in Pacific salmon to environmental and biological variables, especially with respect to ocean carrying capacity.

The current NPAFC Science Plan (http://www.npafc.org/new/science_plan.html) expresses concern about the influence of climate change upon Asian and North American salmon production and recommends research on the ecological mechanisms causing variations in salmon production in recent decades. A better understanding of those links should allow improved prediction of salmon productivity in response to predicted climate change and other ecological variables such changing salmon densities. It is anticipated that providing this bibliography will assist researchers to achieve this better understanding.

The primary foci of the literature search were publications having time series > 10 years and that used datasets with indices or estimates of annual marine growth for at least one age class. All of these papers in this section (Section 4) used distances between scale annuli to estimate annual growth or length at age. While searching for publications with these parameters (Section 4), we also assembled papers that used lengthy time series that were based on size at age of return or escapement (Section 2). Because the latter were not the primary focus of our search, Section 2 is less comprehensive than Section 4. We also compiled size-at-age review papers (Section 1) and annual growth estimation methods papers (Section 3).

Methods

To locate relevant publications, we:

- Identified review articles in the peer-reviewed literature and followed up on relevant papers.

- Systematically reviewed
    - NPAFC documents, accessible from http://www.npafc.org/new/pub_documents_2014.html.
    - NPAFC Technical Reports from http://www.npafc.org/new/pub_technical.html
    - NPAFC Bulletins from http://www.npafc.org/new/pub_bulletin.html
- Used a variety of search terms with Web of Science, Google Scholar, Google, and in NPAFC country-specific bibliographies that address the NPAFC Science Plan mandates, primarily “size”, “length”, “weight”, “growth”, and “scale,” in combination with “salmon” or “fish” where appropriate.

Results

We located 138 relevant publications, primarily from INPFC/NPAFC reports and the peer reviewed literature (Table 1). The bibliography provides abstracts except where indicated. In some cases, abstracts were not readily available and we generated highlights. In these instances, we included text bracketed "from..." to indicate where in that report the text originates.

Readers are encouraged to advise us of relevant documents not included in this bibliography.

Table 1. Number of publications by section and category.

Bibliography Section	INPFC/ NPAFC	Peer-Reviewed	Other	Total
1. Literature reviews	1	8	0	9
2. Size-at-age data	26	26	7	59
3. Methods	7	4	0	11
4. Marine growth indices	29	24	6	59
Total	63	62	13	138

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Bibliography

1. Size at age literature reviews

Bigler, B.S., D.W. Welch, and J. H. Helle. 1996. A review of size trends among North Pacific salmon (*Oncorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences 53: 455–465. http://www.nrcresearchpress.com/doi/pdf/10.1139/f95-181

The abundance of North Pacific salmon (*Oncorhynchus* spp.) has nearly doubled during the period 1975–1993. As salmon population numbers have increased, there have been corresponding decreases in average adult size at return (maturity). As nearly all of the growth of Pacific salmon occurs in the ocean, the ocean plays an important role in determining salmon abundance. We found that 45 of 47 North Pacific salmon populations, comprising five species from North America and Asia, are decreasing in average body size. Total salmon production correlated well with environmental trends between 1925 and 1989, but the inverse relationship between population abundance and average size during the period 1975–1993 indicates that there is a limitation to the salmon-sustaining resources of the ocean. The increased ocean survivorship and expansion of enhancement programs in the 1980s and early 1990s are probable factors in the ocean-wide reduced size of salmon. If these trends continue, the productivity of salmon populations may decrease as fecundity, egg size, and age at maturity change in response.

Enberg, K. C. Jørgensen, E.S. Dunlop, Ø. Varpe, D.S. Boukal, L. Baulier, S. Eliassen, and M. Heino. 2012. Fishing-induced evolution of growth: concepts, mechanisms and the empirical evidence. Marine Ecology 33: 1–25. DOI: 10.1111/j.1439-0485.2011.00460.x

The interest in fishing-induced life-history evolution has been growing in the last decade, in part because of the increasing number of studies suggesting evolutionary changes in life-history traits, and the potential ecological and economic consequences these changes may have. Among the traits that could evolve in response to fishing, growth has lately received attention. However, critical reading of the literature on growth evolution in fish reveals conceptual confusion about the nature of 'growth' itself as an evolving trait, and about the different ways fishing can affect growth and size-at-age of fish, both on ecological and on evolutionary time-scales. It is important to separate the advantages of being big and the costs of growing to a large size, particularly when studying life-history evolution. In this review, we explore the selection pressures on growth and the resultant evolution of growth from a mechanistic viewpoint. We define important concepts and outline the processes that must be accounted for before observed phenotypic changes can be ascribed to growth evolution. When listing traits that could be traded-off with growth rate, we group the mechanisms into those affecting resource acquisition and those governing resource allocation. We summarize potential effects of fishing on traits related to growth and discuss methods for detecting evolution of growth. We also challenge the prevailing expectation that fishing-induced evolution should always lead to slower growth.

Hard, J.J., M. R. Gross, M. Heino, R. Hilborn, R. G. Kope, R. Law, and J. D. Reynolds. 2008. Evolutionary consequences of fishing and their implications for salmon. Evolutionary Applications 1(2): 388-408. DOI: 10.1111/j.1752-4571.2008.00020.x

We review the evidence for fisheries-induced evolution in anadromous salmonids. Salmon are exposed to a variety of fishing gears and intensities as immature or maturing individuals. We evaluate the evidence that fishing is causing evolutionary changes to traits including body size, migration timing and age of maturation, and we discuss the implications for fisheries and conservation. Few studies have fully evaluated the ingredients of fisheries-induced evolution: selection intensity, genetic variability, correlation among traits under selection, and response to selection. Most studies are limited in their ability to separate genetic responses from phenotypic plasticity, and environmental change complicates interpretation. However, strong evidence for selection intensity and for genetic variability in salmon fitness traits indicates that fishing can cause detectable evolution within ten or fewer generations. Evolutionary issues are therefore meaningful considerations in salmon fishery management. Evolutionary biologists have rarely been involved in the development of salmon fishing policy, yet evolutionary biology is relevant to the long-term success of fisheries. Future management might consider fishing policy to (i) allow experimental testing of evolutionary responses to exploitation and (ii) improve the long-term sustainability of the fishery by mitigating unfavorable evolutionary responses to fishing. We provide suggestions for how this might be done.

Heino, M., and U. Dieckmann. 2008. Detecting fisheries -induced life -history evolution: an overview of the reaction-norm approach. Bulletin of Marine Science 83(1): 69–93.

Life-history theory unequivocally suggests that fishing acts as a powerful driver of life-history evolution in exploited fish populations. Because life-history traits are closely linked to the dynamics and productivity of fish populations, understanding and documenting the extent to which this expectation is borne out in reality is both scientifically and practically important. The primary empirical challenges are twofold: observing phenotypic change does not imply genetic change as life-history traits are phenotypically plastic, and fishing is but one potential driver of contemporary evolution. Here we focus on the first challenge by describing how to work toward disentangling genetic and plastic effects in the absence of genetic data. In particular, we explain how the consideration of maturation reaction norms helps to disentangle genetic and plastic changes in age and size at maturation. We first outline the logic and limitations of the maturation reaction-norm approach. We then review the most important statistical methods available for estimating maturation reaction norms from empirical data. For each of these methods, we discuss its domain of applicability together with its strengths and weaknesses.

Hilborn, R., and C.V. Minte-Vera. 2008. Fisheries-induced changes in growth rates in marine fisheries: are they significant? Bulletin of Marine Science 83(1): 95–105.

Fishing provides selective pressure on many fisheries life-history traits, and interest in the impact of size-selective fishing on the evolution of growth rates is long standing. Recent studies, both laboratory and empirical, suggest that such size-selective fishing is significant. Using a meta-analysis of 73 commercially fished stocks, we found that declines in mass at age are slightly more common than increases, but no relationship was apparent between the intensity of fishing and the change in growth rate. We reviewed a number of size-selectivity patterns in major commercial fisheries and found that the intensity of selection and the size selectivity were both considerably less than are used in laboratory experiments. We simulated the evolutionary impact of fishing on growth and found that, given the actual selectivity patterns found in most commercial fisheries, little evolutionary impact on growth rates is expected. The model showed that the best way to reduce evolutionary impacts is to lower exploitation rates. We suggest that, for fisheries where size-specific selection is very intense, managers should use a model such as ours to evaluate potential evolutionary impacts.

Law, R. 2000. Fishing, selection, and phenotypic evolution. ICES Journal of Marine Science 57: 659–669. DOI: 10.1006/jmsc.2000.0731

Large changes are taking place in yield-determining traits of commercially exploited fish, including traits such as size-at-age and age-at-maturation. The cause of these phenotypic changes is often not understood, and genetic change arising from the selective effects of fishing may be a contributory factor. Selection generated by fishing gear is strong in heavily exploited fish stocks, and the spatial location of fishing can also cause strong selection. The success of selective breeding in aquaculture indicates that significant amounts of genetic variation for production-related traits exist in fish populations. Fisheries managers should be alert to the evolutionary change caused by fishing, because such changes are likely to be hard to reverse and, if properly controlled, could bring about an evolutionary gain in yield.

Martins, E. G., S.G. Hinch, S.J. Cooke, and D. A. Patterson. 2012. Climate effects on growth, phenology, and survival of sockeye salmon (*Oncorhynchus nerka*): a synthesis of the current state of knowledge and future research directions. Reviews in Fish Biology and Fisheries 22(4): 887-914. DOI: 10.1007/s11160-012-9271-9

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

Myers, K.W., N.V. Klovach, O.F. Gritsenko, S. Urawa, and T.C. Royer. 2007. Stock-specific distributions of Asian and North American salmon in the open ocean, interannual changes, and oceanographic conditions. North Pacific Anadromous Fish Commission Bulletin No. 4: 159–177.

Knowledge of migration routes, migration timing, and resident areas for populations of Pacific salmon in the open ocean is vital to understanding their status and role in North Pacific marine ecosystems. In this paper we review information from the literature, as well as some previously unpublished data, on stock-specific distribution and migration patterns of salmon in the open ocean, interannual variation in these patterns, and associated ocean conditions, and we consider what this information can tell us about ocean conditions on small- to mid-size scales. We conclude that climate-driven changes in open-ocean feeding areas and along the migratory routes of Asian and North American salmon can result in predictable interannual changes in stock-specific distribution, migration patterns, and other biological characteristics. Global climate change is currently causing more frequent and unpredictable environmental changes in the open ocean habitats through which salmon migrate. Data on changes in the distribution and migration of indicator stocks of adult salmon returning from the open ocean might provide an “advance warning” of interannual changes in North Pacific marine ecosystems.

Shin, Y-J., Rochet, M-J., Jennings, S., Field, J. G., and Gislason, H. 2005. Using size-based indicators to evaluate the ecosystem effects of fishing. ICES Journal of Marine Science 62: 384-396.

The usefulness and relevance of size-based indicators (SBIs) to an ecosystem approach to fisheries (EAF) are assessed through a review of empirical and modelling studies. SBIs are tabulated along with their definitions, data requirements, potential biases, availability of time-series, and expected directions of change in response to fishing pressure. They include mean length in a population, mean length in a community, mean maximum length in a community, and the slope and intercept of size spectra. Most SBIs can be derived from fairly standard survey data on length frequencies, without the need for elaborate models. Possible fishing- and environment-induced effects are analysed to distinguish between the two causes, and hypothetical cases of reference directions of change are tabulated. We conclude that no single SBI can serve as an effective overall indicator of heavy fishing pressure. Rather, suites of SBI should be selected, and reference directions may be more useful than reference points. Further modelling and worldwide comparative studies are needed to provide better understanding of SBIs and the factors affecting them. The slow response to fishing pressure reflects the complexity of community interactions and ecosystem responses, and prohibits their application in the context of short-term (annual) tactical fisheries management. However, movement towards longer-term (5-10 years) strategic management in EAF should facilitate their use.

2. Size-at-age

Azumaya, T., and Y. Ishida. 2000. Density interactions between pink salmon *(Oncorhynchus gorbuscha)* and chum salmon (*0. keta)* and their possible effects on distribution and growth in North Pacific Ocean and Bering Sea. North Pacific Anadromous Fish Commission Bulletin No. 2: 165-174.

The long-term mean spatial and temporal distributions of pink salmon *(Oncorhynchus gorbuscha)* and chum salmon (*0. keta)* in the North Pacific Ocean were investigated using data collected on board Japanese salmon research vessels from 1972 to 1998. The distribution patterns of chum salmon differed between odd- and even-number years, and were more concentrated to the west in even-number years of low pink salmon abundance. In the Bering Sea, the density of pink salmon was higher in odd-number years than in even-number years, and density of chum salmon showed an opposite trend (higher in even than in odd-number years). Also chum salmon distribution shifted southeastward in odd-number years. These results suggest that there is a possible interaction between pink and chum salmon. The mean fork length of maturing pink salmon decreased from 1972 to 1998. Decreasing trends in fork length of age 3-5 chum salmon were also found during the same period. Significant negative relationships between density and mean growth of age 2-4 chum salmon were observed in the Bering Sea, although there was no relationship between density of pink salmon and mean growth of chum salmon directly. These results suggest that the growth of age 2-4 chum salmon is affected by intra-species in the Bering Sea and the abundance of pink salmon influenced the growth of chum salmon indirectly.

Beamish, R.J. 1995. Climate change and northern fish populations. Canadian Special Publications of Fisheries and Aquatic Sciences 121. 739 p.

These proceedings summarize some of the recent studies of the relationships among climate, the aquatic environment, and the dynamics of fish populations. The studies are mostly from the North Pacific Ocean, but there are reports of investigations from the North Atlantic Ocean and from fresh water. The various papers include numerous examples of the relationships between fish abundance trends and the environment.

Beamish, R.J., I.A. Pearsall, and M.C. Healey. 2003. A history of the research on the early marine life of Pacific salmon off Canada's Pacific coast. North Pacific Anadromous Fish Commission Bulletin No. 3: 1–40.

We review studies of the early ocean period of salmon life history conducted in the coastal areas off Canada's West Coast. The role of the ocean in the dynamics of salmon populations has received considerably less study than their life cycle in fresh water, even though Pacific salmon in general spend more time in the ocean than in fresh water and the survivals in the ocean are extremely low and variable. Feeding, growth and distribution studies from the late 1950s until the present have contributed to an improved appreciation of biology of salmon during the marine phase of their life history. However, conclusions about the processes that cause the high and variable mortality in the ocean remain speculative. How fishing impacts interact with natural processes also remain to be clarified. Recent studies have demonstrated that ocean and climate conditions are important contributors to the total marine mortality of a number of species, and to the stock and recruitment relationship. We suggest that it is time to conduct the definitive studies that will identify the processes that regulate the survival of Pacific salmon throughout their entire life cycle. We propose that an international effort to study the early marine period is the way to change the current beliefs and speculations into explanations.

Bigler, B.S., and J.H. Helle. 1994. Decreasing size of North Pacific salmon *(Oncorhynchus* sp.): possible causes and consequences. North Pacific Anadromous Fish Commission. Document 61.

As a consequence of wild stock management, artificial enhancement, and favorable ocean conditions, the abundance of North Pacific salmon *(Oncorhynchus* sp.) has nearly doubled during the period 1975-1993. As salmon population numbers have increased there has been growing evidence of regional decreases in average adult size. We found that five species of North Pacific salmon are decreasing in average body size on an oceanwide scale. With the exception of chinook salmon populations in California and British Columbia, all populations and species of Pacific salmon examined were found to be decreasing at rates ranging from only detectable on a statistical level, to rates evident to fishery participants. Total salmon production (harvest) has correlated well with environmental trends between 1925 and 1989, but the inverse relationship between population abundance and average size during the period 1975-1993 indicates there is a limitation to the salmon-sustaining resources of the ocean. The increased ocean survivorship and expansion of enhancement programs in the late 1980s and early 1990s are probable factors in the ocean-wide reduced size of salmon. The reduction in body size may be contributing to the recent decline in abundance of Western Alaska chum salmon populations, where large adult body size is considered essential to survivorship. Among other size-related factors affecting reproductive success, reduced fecundity and egg size, and pressure from a selective gear type may be acting in combination to reduce survivorship of these populations and may represent the model portending the impact of reduced body size on other populations.

Bilton, H.T., E.A.R. Ball, and D.W. Jenkinson. 1967. Age, size and sex composition of British Columbia Sockeye Salmon catches from 1912 to 1963. Fisheries Research Board of Canada Circular (Statistical Series) No. 25.

[from Introduction] The present report is, in the main, an attempt to bring together all the information on age, size and sex composition of sockeye in the catches from the four major sockeye areas in northern British Columbia for the period 1912 to 1963 and for other areas as well for the period 1957 to 1963. Data for 1964 and 1965 are presented in separate reports (Bilton et al., 1965 and 1966). These reports did not include continuous data for the province's most important single sockeye producing area, the Fraser. However, Killick and Clemens (1963) have summarized data for that system for the period from 1915 to 1960.

[http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/search-recherche/display-afficher/29484]

Bugaev, V. F., D.W. Welch, M. M. Selifonov, and L.E. Grachev. 1995. Influence of the marine abundance of pink (*Oncorhynchus gorbuscha*) and sockeye salmon (*0. nerka*) on growth of Ozernaya River sockeye. North Pacific Anadromous Fish Commission Document 158. 19 p.

The length and weight eye *(Oncorhynchus nerka)* was substantially reduced in years when the marine abundance of pink salmon *(0. gorbuscha)* from western and eastern Kamchatkan populations was high, and slightly reduced when the ocean 5 abundance of Kamchatka sockeye populations was high. The strongest statistical relationships were found for fish from separate age-groups; measured relationships using pooled data from all age-classes combined were statistically insignificant. We estimate that in the absence of pink salmon the most strongly affected age groups would be twice the size at maturity that they would be if both the eastern and western Kamchatkan pink salmon populations were simultaneously at 10 peak observed abundances. Trophic competition in the ocean can therefore have a significant influence on the productivity of salmon populations for the most strongly affected age-groups, and the salmonid carrying capacity of the ocean is sufficiently limited that it should be considered in the management of salmon populations.

Bugaev, V.F., D.W. Welch, M. M. Selifonov, L. E. Grachev, and M.J. Sweet. 1996. Influence of the marine abundance of pink (*Oncorhynchus gorbuscha*) and sockeye salmon (*0. nerka*) on growth of Ozernaya River sockeye, 1970-1994. North Pacific Anadromous Fish Commission Document 203. 20 p. + 2 figs.

We used an extended data set on the size of Russian sockeye salmon *(Oncorhynchus nerka)* from 1970-94 to examine the effect of salmon abundance on sockeye growth. The length and weight of mature Ozernaya River sockeye was substantially reduced in years when the marine abundance of pink salmon *(0. gorbuscha)* from western and eastern Kamchatkan populations was high, and 35 slightly reduced when the ocean abundance of Kamchatka sockeye populations was high. The strongest statistical relationships were found for fish from separate age-groups; measured relationships using pooled data from all age-classes combined were statistically insignificant. We estimate that in the absence of pink salmon the most strongly affected age groups would be twice the size at maturity that they would be if both the eastern and western Kamchatkan pink salmon 40 populations were simultaneously at peak observed abundances. Trophic competition in the ocean can therefore have a significant influence on the productivity of salmon populations for the most strongly affected age-groups, and we conclude that the salmonid carrying capacity of the ocean is sufficiently limited that it should be considered in the management of salmon populations.

Bugayev, V.F. 2000. Size of sockeye salmon smolts and freshwater age of adults in Azabachye Lake (Kamchatka River Basin). North Pacific Anadromous Fish Commission Bulletin No. 2: 131-135.

Analysis of age composition of early-run sockeye salmon *(Oncorhynchus nerka)* spawners in Azabachye Lake, in the lower reaches of the Kamchatka River, showed that in 1997 45% had spent only one year in fresh water (1.2, 1.3, 1.4). Previously, 80-99% spent two years in freshwater (2.1, 2.2, 2.3, 2.4, 2.5). The freshwater zone of scales from spawners of age 1.2, 1.3 and 1.4, caught in Azabachye Lake qualitatively resembled those of sockeye from tributaries in the lower and middle reaches of Kamchatka River. I hypothesized that high abundance of sockeye of one-year freshwater life in the basin of Azabachye Lake in 1997 arose from presence of spawners from lower and middle Kamchatka River, and that they had come to the lake as juveniles in 1993 to take advantage of excellent feeding there. In 1994, the largest sockeye smolts ever observed between 1979 and 1996 migrated out of Azabachye Lake. A significant correlation (r_s= 0.66-0.82, p < 0.05-0.01, n = 17) was obtained between the numbers of sockeye spawners with one freshwater year on their scales and length-weight of smolts leaving the Lake three years earlier.

Bugaev, V.F., D.W. Welch, M.M. Selifonov, L.E. Grachev, and J.P. Eveson. 2001. Influence of the marine abundance of pink (*Oncorhynchus gorbuscha*) and sockeye salmon (*O. nerka*) on growth of Ozernaya River sockeye Fisheries Oceanography 10(1): 26-32.

The length and weight of Russian sockeye (*Oncorhynchus nerka*) returning to the Ozernaya River (Kamchatka) was substantially reduced in years when the ocean abundances of Kamchatkan pink *(O. gorbuscha*) and sockeye salmon were high. We found that the density-dependent reduction in sockeye growth on a per-capita basis was greater for sockeye than for pink salmon. However, the overall effect of pink salmon abundance on sockeye growth was greater because of the higher numerical abundance of pink salmon. The strongest statistical relationships were found for sockeye from separate age groups; pooled data combining all age classes were statistically insignificant. We estimate that, if pink salmon were absent, the most strongly affected age group of sockeye salmon (2.1 males) would weigh twice as much at maturity than if pink salmon populations from eastern and western Kamchatka were both simultaneously at peak observed abundances. Trophic competition in the ocean between pink and sockeye salmon can therefore have a significant influence on the productivity of sockeye populations for the most strongly affected age groups. These effects are large enough that they should be explicitly considered in the management of salmon populations.

Cox, S.P., and S.G. Hinch. 1997. Changes in size at maturity of Fraser River sockeye salmon (*Oncorhynchus nerka*) (1952-1993) and associations with temperature. Canadian Journal of Fisheries and Aquatic Sciences 54: 1159-1165.

Unlike other Canadian Pacific salmon (*Oncorhynchus* spp.), long-term declines in the size at maturity of Fraser River sockeye salmon (*O. nerka*) have not been reported in past studies. Using data specific for 10 Fraser River sockeye stocks, we demonstrate that size at maturity has generally declined over the past 42 yr for females in all stocks and for males from eight stocks. Independent of this temporal trend, we found that size at maturity of both sexes in all stocks was smaller in years when sea surface temperatures were relatively warm. Slower growth in warmer years may be caused directly by increased metabolic demand, or indirectly by oceanic changes that influence food acquisition. We speculate that fitness of Fraser River sockeye will be reduced in the future if sea surface temperature increases and salmon abundance remains near present levels.

Davidson, F.A., and Vaughan, E. 1941. Relation of population size to marine growth and time of spawning migration in pink salmon (*Oncorhynchus gorbuscha*) of southeastern Alaska. Journal of Marine Research 4: 231–246.

[from Figure 53. caption] Cyclic changes in the characteristics of the pink salmon populations in the Clarence Strait area of southeastern Alaska from 1895 to 1940. (1) Relative size of pink salmon populations, (2) growth of individual fish as indicated by the yearly number of fish packed per case of salmon and (3) the seasonal time of their spawning migration.

Eggers, D.M. and J.R. Irvine. 2007. Trends in abundance and biological characteristics for north Pacific sockeye salmon. North Pacific Anadromous Fish Commission Bulletin No. 4: 53–75.

Trends in abundance, productivity, and average size were reviewed for sockeye salmon populations from Washington, British Columbia, southeast Alaska, central Alaska, western Alaska, and Russia. Aggregate catch estimates were reasonable indicators of overall stock status, but in areas toward the southern extent of their range, population-specific return and escapement estimates are also needed by fishery managers. Sockeye abundance in Russia and western and central Alaska declined coincident with a regime shift in 1949. Declines also occurred in the eastern North Pacific although they were less severe. Abundance increases were ubiquitous around the time of the regime shift in 1977. Short-term reductions in abundance in western Alaska and parts of central Alaska followed the 1989 shift but were not evident in Russia or the eastern North Pacific. The status of many North American stocks recently declined, with severest declines in southernmost areas. Trends in survival rate indices were similar to trends in catch and abundance. Average body size was inversely related to aggregate abundance, implying that growth was density-dependent. The coherence in trends in abundance, catch, and average weight among stocks suggests that large-scale environmental processes are major factors controlling sockeye salmon survival and production around the North Pacific Rim, and probably restrict the total production from particular ocean zones. However, local-scale environmental processes can result in regional differences in productivity.

Elenderson, M.A., R.E. Diewert, J.G. Stockner, and D.A. Levy. 1995. Effect of water temperature on emigration timing and size of Fraser River pink salmon *(Oncorhynchus gorbuscha)* fry: implications for marine survival. Pages 655-664 *in* R.J. Beamish, editor. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

The effect of water temperature was evaluated on the date and dispersion of the emigration of Fraser River pink salmon *(Oncorhynchus gorbuscha)* fry and their size at the time of emigration. Increases in the number of degree-days over the first few weeks of embryo development resulted in an earlier date of emigration and smaller size of fry. However, the number of degree days over the entire period of embryo development had no effect on the date of emigration or fry size. Dispersion of the emigration was not affected by the number of degree-days over the early, late, or entire period of embryo development. Marine survival of pink salmon fry increased as the date of emigration occurred earlier in the year. Fry size at the time of emigration had no effect on marine survival. Warming of the waters of the Fraser River as the result of climate change should result in an earlier date of emigration of pink salmon fry, and as a result, possibly higher marine survival.

Fukuwaka, M., T. Azumaya, T. Nagasawa, A.N. Starovoytov, J.H. Helle, T. Saito, and E. Hasegawa. 2007. Trends in abundance and biological characteristics of chum salmon. North Pacific Anadromous Fish Commission Bulletin No. 4: 35–43.

Chum salmon are the second most abundant salmon in the North Pacific Ocean. In the 1930s, chum salmon were abundant along the Russian coast and in British Columbia. The total catch of chum salmon was small from the late 1940s into the 1970s but increased in the 1980s, reaching historically high levels from the 1990s to the present. Ocean distribution of chum salmon is affected by sea surface temperature. Ocean growth and fish size at maturity decreased in the 1970s and 1980s but recovered in the 1990s and 2000s. These trends in abundance and biological characteristics correlated with ocean conditions. An international cooperative salmon survey by the North Pacific Anadromous Fish Commission may elucidate the mechanisms underlying the relationships among these trends. For conservation and sustainable use of chum salmon stocks, we should monitor the abundance and biological characteristics of chum salmon both in the ocean and in rivers.

Fukuwaka, M., N.D. Davis, T. Azumaya, and T. Nagasawa. 2009. Bias-corrected size trends in chum salmon in the central Bering Sea and North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin 5: 173–176.

We estimated bias-corrected mean fork lengths of gillnet-caught chum salmon using a size selectivity estimate of the gillnet to test how the bias correction affects the estimated temporal pattern of chum salmon body size, during 1971–1994 and 1994–2007. Results showed bias-corrected mean fork lengths were smaller than uncorrected means. Therefore, when examining ontogenetic changes in fish size (e.g. the growth trajectory) using data collected by research gillnets, the uncorrected mean fork length can overestimate the true value. Comparison of temporal trends in bias-corrected mean fish lengths to uncorrected means showed similar results because both illustrated a decrease in chum salmon fork length in 1971–1994, and a stable fish size after 1994. Uncorrected mean values of chum salmon fork length for fish caught using research gillnets can be used as a proxy for fish size to examine temporal trends. We conclude that interpreting temporal trends using either uncorrected or bias-corrected data will support the same general conclusions regarding long-term changes in chum salmon body size.

Godfrey, H. 1959*a*. Variations in annual average weights of British Columbia pink salmon 1944–1958. Journal of the Fisheries Research Board of Canada 16: 329–337.

Average weight data of British Columbia pink salmon, *Oncorhynchus gorbuscha*, since 1944 were made available by the Fisheries Association of British Columbia, and were used to compare annual changes in size among stocks throughout the Province. Adult pinks of the odd-year cycle were almost invariably larger than those of the even-year cycle. In British Columbia this cycle has also been consistently the more abundant, and in southeast Alaska these fish have been either about equally as numerous as the even-year pinks, or, upon occasion, much more numerous. The pink salmon of each of the major fishing areas in the Province show similar annual changes in average weight. From an extremely small average size in 1946t here was a trend of steady increase among all stocks and involving both cycles, over the next 8 years; this was followed by a decline in 1955 and 1956, then a further increase in 1957 and 1958. A comparison between southeastern Alaska pinks and pinks of northern British Columbia showed that they had experienced similar year-to-year weight changes during the earlier period of 1930-1939.

Godfrey, H. 1959*b*. Variation in the annual average weight of chum salmon caught in British Columbia waters, 1946–1958. Journal of the Fisheries Research Board of Canada 16: 553–554.

[No abstract; same methods for chum as for pinks in Godfrey 1959*a*]

Healey, M.C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries. Pages 39-52 *in* D. J. Meerburg, editor. Salmonid age at maturity. Canadian Special Publication of Fisheries and Aquatic Sciences 89.

The five species of Pacific salmon *(Oncorhynchus* spp.) endemic to North America are all anadromous and semelparous. Within this general life-history strategy the five species show considerable interspecific and intraspecific variation in life history parameters, such as age and size at maturity. Sockeye, for example, display 22 mature age categories when the various combinations of freshwater and marine residence are taken into account. Average size of sockeye varies up to 40 cm among mature age classes. At the other extreme, pink salmon display only one mature age category and vary only about 9.5 cm in size among populations. Two life-history models based on demographic parameters give good qualitative prediction and, in some instances, good quantitative prediction of age and size at maturity. In general, however, these models underestimate age at maturity, presumably because they fail to account for multiple mature age classes in some populations. Historic information on size and age of Pacific salmon demonstrates that, for many populations, size declined between 1951 and 1975, but then increased somewhat between 1975 and 1981. The fisheries for salmon are selective for larger fish, and changes in size could be a consequence of genetic selection for slower growth. Recent increases in size in some populations and the failure of other populations to demonstrate expected changes in size are contrary to this hypothesis. The changes in size could also be a consequence of long-term variation in the ocean environment, and the observed changes in size are coincident with changes in some oceanic parameters.

Helle, J.H. 1989. Relation between size-at-maturity and survival of progeny in chum salmon, *Oncorhynchus keta* (Walbaum). Journal of Fish Biology 35 (Supplement A): 99-107.

Data on age- and size-at-maturity, growth, and abundance of chum salmon were collected from 1959 to 1977 at Olsen Creek in Prince William Sound, Alaska. Age composition of spawners (3 to 6-year-olds) varied from year to year: 4-year-old fish were the dominant age group in most (16 out of 19) years and 6-year-old fish usually represented less than 1% of the returns. Mean size of older spawners was significantly larger than that of younger spawners. Size-at-maturity was similar among fish from different broods maturing at different ages in the same year. Size-at-maturity and survival of progeny were significantly related. The larger the mean size of spawners, the higher the survival rate to adulthood of their progeny. Possible reasons for this relationship are discussed.

Helle, J.H., and M.S. Hoffman. 1995. Size decline and older age at maturity of two chum salmon *(Oncorhynchus keta)* stocks in western North America, 1972-92. Pages 245-260 *in* R.J. Beamish, editor. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

Two populations of chum salmon *(Oncorhynchus keta)* in western North America were monitored for long-term changes in size and age at maturity. One population was from Fish Creek, a tributary of the Salmon River at the head of Portland Canal near Hyder, Alaska, where age and size samples were collected from 1972 to 1992. Chun salmon from this stream are known for their large size. The second population was from the Quilcene National Fish Hatchery on Hood Canal near Quilcene, Wash., where age and size samples were collected from 1973 to 1992. Both populations showed a significant decline in mean length at maturity of all age groups, starting about 1980. The carcass weight difference estimated from mean lengths of age-4 males for both populations between 1976 and 1991 was about 3 kg, a 46% reduction. The mean age at maturity for both populations increased as growth decreased. Decreased size could be caused by changes in oceanographic conditions, increased population density, or both. Regardless of the reason, the smaller size could result in lower survival of chum salmon stocks.

Helle, J.H., and M.S. Hoffman. 1998. Changes in size and age at maturity of two North American stocks of chum salmon *(Oncorhynchus keta*) before and after a major regime shift in the North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin No. 1: 81-89.

Changes in size and age at maturity of chum salmon *(Oncorhynchus keta* were monitored for two locations in North America. Chum salmon spawners returning to Fish Creek, southeastern Alaska, were sampled yearly from 1972 through 1996. Spawners returning to the Quilcene National Fish Hatchery in Hood Canal, Washington, were sampled yearly from 1973 through 1996. Size at maturity of both populations declined significantly from about 1980 to the mid-1990s. Age at maturity increased during this time. These changes were associated with a major ocean climate regime shift in the North Pacific Ocean that occurred in 1976-77. Population abundance of chum salmon increased greatly after the regime shift, especially in Asia. Similar changes in size and age at maturity occurred in Asian chum salmon; because the range of North American and Asian chum salmon overlaps on the high seas, these changes are discussed in relation to possible density-dependent population factors. Since the mid-

1990s, size at maturity and population abundance have increased, possibly indicating another climate change in the North Pacific Ocean.

Helle, J.H., E.C. Martinson, D.M. Eggers, and O. Gritsenko. 2007. Influence of salmon abundance and ocean conditions on body size of Pacific salmon. North Pacific Anadromous Fish Commission Bulletin No. 4: 289–298.

After the North Pacific Ocean climate change in 1976–77, most species of Pacific salmon (*Oncorhynchus* spp.) in North America and Asia increased in abundance and declined in body size up until the early 1990s. Several authors attributed this decline in body size of chum salmon (*O. keta*) to increasing population density of chum salmon in the ocean. In the mid-1990s, the body size of adult chum salmon increased in several streams in North America in spite of high population numbers. To determine if these increases in body size were restricted to local areas or more widespread geographically in North America, we examined data on the abundance and mean body size of salmon from commercial catches in waters from northern Alaska south to the state of Oregon among three time periods (1960–76, 1977–94, 1995–2006). Trends in body size indicate that northern and southern populations of chum, pink, and sockeye, and coho in Washington and Oregon experienced increased body size in the mid-1990s. In correlation analyses, chum, pink (*O. gorbuscha*), and sockeye salmon (*O. nerka*) body size was, in many cases, negatively related to abundance, and more negatively correlated during the 1977–94 period. For the 1960–76 period, the abundance of Pacific salmon was low, and the effect of density-dependence on the fish was the lowest. For the 1977–94 period, salmon were numerous and the effect of density on the body size of salmon was significant in many cases. For the 1995–2006 period, the abundance of salmon remained high, however, the body size of the salmon was not commonly related to population density. The 1995–2006 period appears most favorable for salmon, in that ocean resources supported salmon of large body size and large population numbers. We conclude that the carrying capacity of the North Pacific Ocean for producing Pacific salmon is not a constant value and varies with changing environmental and biological factors.

Hinch, S.G. , M.C. Healey, R.E. Diewert, K.A. Thornson, R. Hourston, M.A. Henderson, and F. Juanes. 1995. Potential effects of climate change on marine growth and survival of Fraser River sockeye salmon. Canadian Journal of Fisheries and Aquatic Sciences 52: 2651-2659.

Simulation results from the Canadian Climate Centre's atmospheric general circulation model (CCC GCM) coupled to a simplified mixed-layer ocean model predict that doubled atmospheric C8, concentrations would increase northeast Pacific Ocean sea surface temperatures and weaken existing north-south air pressure gradients. On the basis of predicted changes to air pressure and an empirical relationship between wind-driven upwelling and zooplankton biomass, we calculate that production of food for sockeye salmon *(Oncorhynchus nerka)* may decrease by 5-9%. We developed empirical relationships between sea surface temperature, zooplankton biomass, adult recruitment, and terminal ocean weight for the early Stuart stock of Fraser River sockeye salmon. Our analyses show that warmer sea surface temperatures, larger adult recruitment, and lower zooplankton biomass are correlated with smaller adult sockeye. Bioenergetics modeling suggests that higher metabolic costs in warmer water coupled with lower food availability could cause the observed reductions in size. Warmer sea surface temperatures during coastal migration by juveniles were correlated with lower recruitment 2 yr later. Warmer sea surface temperatures may be a surrogate for increased levels of predation or decreased food during the juvenile stage. We speculate that Fraser sockeye will be less abundant and smaller if the climate changes as suggested by the Canadian Climate Centre's general circulation model.

International North Pacific Fish Commission (INPFC) Secretariat. 1979. Historical catch statistics for salmon of the North Pacific Ocean. International North Pacific Fish Commission. Kenkyusha Printing Company, Tokyo.

[Tables 89-94 show time series of average weights in USSR, Japanese, State of Alaska, and State of Oregon fisheries.]

Ishida, Y, S. Ito, Y. Ueno, and J. Sakai. 1998. Seasonal growth patterns of Pacific salmon *(Oncorhynchus* spp.) in offshore waters of the North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin No. 1: 66-80.

Seasonal growth patterns of Pacific salmon *(Oncorhynchus* spp.) in the North Pacific Ocean were explored using biological data collections from the Japanese salmon research programs. Seasonal change in fork length and body weight was similar between sockeye and chum salmon, and between pink and coho salmon. Seasonal change in condition factors was very similar among the five species, that is, condition factors increased in spring, peaked in summer, decreased in fall, and were lowest in winter. Average growth rate in weight during maturing stage was significantly higher than that in immature stage for sockeye, pink, and coho salmon. For chum salmon, there was no significant difference in growth rate between immature and maturing fish, but the growth rate of immature fish was higher than those of other species, especially at age 0.2. Growth rates during life stages when density dependent growth may occur are higher than those in other life stages. We can hypothesize that higher growth rates require greater demands for food intake, which may lead to density-dependent growth during these rapid-growth seasons if prey resources are limited.

Ishida, Y., and T. Azumaya. 1999. Changes in abundance and biological character of Pacific salmon in the North Pacific Ocean from 1972 to 1998. North Pacific Anadromous Fish Commission Document 426.

Catch-per-unit-effort(CPUE: number of fish caught by 30 tan gillnets), fork length (FL) and gonad somatic index (GSI) of the Pacific salmon caught by research gillnets in the western North Pacific (WNP), Bering Sea (BS), and eastern North Pacific (ENP) in July from 1972 to 1998 were compared. CPUE of sockeye and chum salmon (less than 100 fish per 30 tans) was higher in BS and ENP than in WNP, especially the CPUE in BS was high in the late 1970s to early 1980s and in 1990s. Pink salmon CPUE (less than 500 fish per 30 tans) increased in BS in odd years after 1989, although it was stable in WNP and ENP. Coho salmon were abundant in WNP and ENP, and chinook salmon were abundant in BS, but their CPUEs were less than 50 fish per 30 tans. FL of sockeye salmon decreased in BS, but increased in WNP and ENP.

For chum salmon, FL of ocean age 1 fish increased, but those of older age groups decreased in WNP and BS. FL of pink salmon decreased both in odd and even year in BS, but not in WNP and ENP. FL of coho salmon decreased in WNP, but increased in ENP. GSI of sockeye salmon was very variable and there was not a specific trend. GSI of chum salmon showed a decreasing trend in recent years in BS. GSI of pink salmon was low in odd years and high in even years in BS. These results indicate that the abundance and biological characters of Pacific salmon changed differently in three waters of the North Pacific Ocean.

Ishida, Y., T. Azumaya, M. Fukuwaka, N. Davis. 2002. Interannual variability in stock abundance and body size of Pacific salmon in the central Bering Sea. Progress in Oceanography 55: 223–234.

Variability in catch-per-unit-effort (CPUE) and mean body size was examined for pink, chum and sockeye salmon collected with research gillnets in the central Bering Sea in July from 1972 to 2000. The CPUEs for all three species showed significant increasing trends, but with large interannual variability. The CPUE of pink salmon was higher in odd years than in even years, and abruptly increased in the odd years post-1989. Chum salmon also showed odd/even year fluctuations, which were out-of-phase with those of pink salmon. Sockeye salmon showed no biennial such fluctuations. The CPUEs of chum and sockeye salmon were higher during 1979–1984 and 1992–1998, but lower during 1985–1991, especially for younger age group such as ocean age 2 and 3. Data for sea surface temperature (SST) and abundances of chum and sockeye salmon during four periods (1972–1976, 1977–1984, 1985–1990, and 1991–2000) indicated a portion of chum and sockeye salmon were distributed in the northern Gulf of Alaska in 1985–1990, when SST in the Gulf of Alaska was low. However, the fish were more abundant in the Bering Sea in 1977–1984 and 1991-2000 when SST was relatively high in the Gulf of Alaska. Body size of pink salmon showed a significant decreasing trend. Chum and sockeye salmon also showed significant decreasing trends in body size at ocean age 3 and older ages, but not at ocean age 2. Significant negative relationships between CPUE and body size were found within species. No significant correlations were found between an Aleutian low pressure index (ALPI) with CPUE and body size, but the increases in CPUE around the late 1970s and early 1990s may be partly be the result of shifts in the distributions of chum and sockeye salmon caused by SST changes related to the regime shift in 1977 and 1989 identified by the ALPI.

Kaev, A.M., A.A. Antonov, V.M. Chupakhin, and V.A. Rudnev. 2007. Possible causes and effects of shifts in trends of abundance in pink salmon of southern Sakhalin and Iturup Islands. North Pacific Anadromous Fish Commission Bulletin No. 4: 23–33.

Data on the abundance of spawning pink salmon (*Oncorhynchus gorbuscha*) are presented for rivers of southern Sakhalin Island and Iturup Island. Fluctuations in abundance are more dependent on marine survival than on the abundance of fry migrating downstream. This is explained by the favorable spawning conditions in small rivers with dense aggregations on the spawning grounds. We found stable long-term trends in changes in abundance, fish length and the seasonal dynamics of spawning migrations. These trends suggest an important role for climatic-oceanological cyclical processes in pink salmon stock dynamics.

Karpenko, V.I., and M.V. Koval. 2012. Feeding strategies and trends of pink and chum salmon growth in the marine waters of Kamchatka. North Pacific Anadromous Fish Commission Technical Report No. 8: 82-86.

[from text] In total, 24,112 pink and chum salmon stomachs (13,322 juveniles and 10,790 adult fish) were analyzed for this study. Laboratory analysis of salmon feeding habits since 1952 has employed one standardized method at KamchatNIRO, which is the same method that has been standardized across Russian laboratories (Anonymous 1974). Thus, we hope that we have managed to avoid the problem of data comparability for different periods of observation. For analysis of changes in growth of salmon populations, we used annual commercial catch statistics and the average weight of salmon in West and East Kamchatka from 1971 to 2010.

Kendall, N.W., J.J. Hard, and T.P. Quinn. 2009. Quantifying six decades of fishery selection for size and age at maturity in sockeye salmon. Evolutionary Applications 2(4): 523–536. DOI: 10.1111/j.1752-4571.2009.00086.x

Life history traits of wild animals can be strongly influenced, both phenotypically and evolutionarily, by hunting and fishing. However, few studies have quantified fishery selection over long time periods. We used 57 years of catch and escapement data to document the magnitude of and trends in gillnet selection on age and size at maturity of a commercially and biologically important sockeye salmon stock. Overall, the fishery has caught larger fish than have escaped to spawn, but selection has varied over time, becoming weaker and less consistent recently. Selection patterns were strongly affected by fish age and sex, in addition to extrinsic factors including fish abundance, mesh size regulations, and fish length variability. These results revealed a more complex and changing pattern of selective harvest than the 'larger is more vulnerable' model, emphasizing the need for quantified, multi-year studies before conclusions can be drawn about potential evolutionary and ecological effects of fishery selection. Furthermore, the results indicate that biologically robust escapement goals and prevention of harvest of the largest individuals may help prevent negative effects of size-selective harvest.

Kendall, N.W., and T.P. Quinn. 2009. Effects of population-specific variation in age and length on fishery selection and exploitation rates of sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 66: 896–908. DOI: 10.1139/F09-047

Conspecific salmonid populations often differ in age and body size at maturity, and these differences can cause fishery exploitation rates and patterns of directional selection on size to vary among populations. Based on age and length data on five representative spawning populations of sockeye salmon (*Oncorhynchus nerka*) in the Wood River system, Bristol Bay, Alaska, USA, we estimated exploitation rates and population-specific patterns of selection from a gillnet fishery between 1963 and 2007. Exploitation rates have differed among age groups and have varied greatly over time, likely due to changes in fishery selectivity. Populations with older, larger fish were more heavily exploited than populations with small, young fish. Differential fishery selection was detected among the populations, linked to persistent differences in size and age of fish among the populations. Specifically, we found evidence of stronger size selectivity on populations with smaller-bodied fish and less directional selection on populations dominated by larger-bodied fish. These results reveal the complex variation in the intensity and selectivity of fishing that can result from exploitation of populations that differ in age and size at maturity and shape. Evolutionary responses to this selection may be taking place, but natural processes provide countervailing selection.

Kendall, N.W., and T.P. Quinn. 2012. Quantifying and comparing size selectivity among Alaskan sockeye salmon fisheries. Ecological Applications, 22(3): pp. 804–816. http://dx.doi.org/10.1890/11-1189.1

Quantifying long-term size-selective harvest patterns is necessary for understanding the potential evolutionary effects on exploited species. The comparison of fishery selection patterns on the same species subject to different gear types, in different areas, and over multi-decadal periods can reveal the factors influencing selection. In this study we quantified and compared size-selective harvest by nine Alaskan sockeye salmon (*Oncorhynchus nerka*) fisheries to understand overall patterns. We calculated length-specific linear selection differentials (the difference in average length of fish before vs. after fishing), which are produced by different combinations of exploitation rates and length-selectivity values, and nonlinear standardized differentials, describing disruptive selection, across all years for each fishery. Selection differentials varied among years, but larger fish were caught in 73% of years for males and 84% of years for females, leaving smaller fish to spawn. Disruptive selection was observed on female and male fish in 84% and 92% of years, respectively. Linear selection was stronger on females than males in 77% of years examined, and disruptive selection was stronger on males in 71% of years. Selection pressure was influenced by a combination of factors under and beyond management control; analyses using mixed-effects models indicated that fisheries were less size selective in years when fish were larger than average and had lower exploitation rates. The observed harvest of larger than average sockeye salmon is consistent with the hypothesis that size-selective fishing contributes to decreasing age and length at maturation trends over time, but temporal variability in selection and strong disruptive selection suggests that the overall directional pressure is weaker than is often assumed in evolutionary models.

Kendall, N.W., U. Dieckmann, M. Heino, A. E. Punt, and T.P. Quinn. 2014. Evolution of age and length at maturation of Alaskan salmon under size-selective harvest. Evolutionary Applications 7(2): 313-322. DOI: 10.1111/eva.12123

Spatial and temporal trends and variation in life-history traits, including age and length at maturation, can be influenced by environmental and anthropogenic processes, including size-selective exploitation. Spawning adults in many wild Alaskan sockeye salmon populations have become shorter at a given age over the past half-century, but their age composition has not changed. These fish have been exploited by a gillnet fishery since the late 1800s that has tended to remove the larger fish. Using a rare, long-term dataset, we estimated probabilistic maturation reaction norms (PMRNs) for males and females in nine populations in two basins and correlated these changes with fishery size selection and intensity to determine whether such selection contributed to microevolutionary changes in maturation length.

PMRN midpoints decreased in six of nine populations for both sexes, consistent with the harvest. These results support the hypothesis that environmental changes in the ocean (likely from competition) combined with adaptive microevolution (decreased PMRNs) have produced the observed life history patterns. PMRNs did not decrease in all populations, and we documented differences in magnitude and consistency of size selection and exploitation rates among populations. Incorporating evolutionary considerations and tracking further changes in life-history traits can support continued sustainable exploitation and productivity in these and other exploited natural resources.

Killick, S.R., and W.A. Clemens. 1963. The age, sex ratio and size of Fraser River sockeye salmon 1915 to 1960. Bulletin (International Pacific Salmon Fisheries Commission) 14. International Pacific Salmon Fisheries Commission, New Westminster, BC.

A total of 88,368 samples have been taken from the commercial catches to provide a continuous record of the annual age composition, sex ratio and size (weight and length) of Fraser River sockeye. Variations in annual sizes were attributed to basic differences in the genetic size characteristics of different races and to changes in growth conditions in the marine environment.

[http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/search-recherche/display-afficher/254988]

Mathisen, O.A., L. Fair, R. J. Beamish, and V. Bugaev. 2007. Density-dependent growth of sockeye salmon in the north Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin No. 4: 299-310.

Length measurements were obtained for sockeye salmon from several major rivers around the perimeter of the North Pacific Ocean. The salmon from the Kvichak River in Bristol Bay, Alaska exhibit strong cyclic changes in abundance, usually with a period of 5 years. The lengths of salmon show the same cyclic changes but are inversely related to the magnitude of salmon abundance. The same relationship was found for all streams in Bristol Bay. The strength of this association was measured by the correlation coefficients between the same age-classes in other districts. High values were interpreted as occupation of overlapping feeding areas by each age-class during the last year in the ocean before salmon reach full maturity. There was some overlap in feeding areas of salmon from neighboring districts such as the Copper River and the Karluk/Chignik watersheds in Alaska. No association was found between Bristol Bay sockeye salmon and their counterparts in either Russia or the Fraser River, British Columbia, Canada.

Mayama, H., and Y. Ishida. 2003. Japanese studies on the early ocean life of juvenile salmon. North Pacific Anadromous Fish Commission Bulletin No. 3: 41–67.

Almost all the salmon resources in Japan have been supported by artificial enhancement, and because of the success of this program the population size of chum salmon (*Oncorhynchus keta*) has increased dramatically since the early 1970s. About 90% of Japan's salmon catch is chum; 5–10% is pink salmon (*O. gorbuscha*) and 0.5% masu (*O. masou*). Therefore, biological research has focused on the early ocean life of juvenile chum salmon to establish the proper timing and size for release of juveniles from hatcheries, and, since the late 1960s, to study the distribution and movement of juvenile salmon in nearshore waters. Survey results indicated that juvenile chum salmon remained in coastal water masses with good food conditions and physiologically optimum surface temperature and salinity until they reached about 70–80 mm FL, when they were able to migrate offshore, avoiding high SST (over 12–13ºC) and high salinity (over 34 pus). Japan-Russia cooperative juvenile salmon surveys were conducted in the Okhotsk Sea and the western North Pacific Ocean, from early summer to winter in 1988–1996. Results suggest that the Okhotsk Sea is an important nursery area for juvenile salmon originating from Russia and Japan.

McKinnell, S. 1995. Stock interactions in sockeye salmon in the eastern North Pacific Ocean. North Pacific Anadromous Fish Commission Document 156. 20 p.

For most of the 20th century (1912-late 1960's), age 1.3 sockeye salmon from the Nass and Skeena Rivers, and Rivers Inlet in central and northern British Columbia have returned to spawn at a smaller size when Western Alaska (Bristol Bay) sockeye catches (numbers) have been high. In all these river systems, the size of age 1.2 sockeye has not been affected by the abundance of Western Alaska sockeye. The mean weights of sockeye in these systems follow a similar pattern. The slopes of mean body weight versus Western Alaska sockeye catch is negative, however, fewer of the age 1.3 strata are significant. As with mean length, none of the mean weights age 1.2 strata were significantly affected by the abundance of Western Alaska sockeye. For their condition factor (weight/length^3) only one stratum was significantly correlated with Western Alaska sockeye abundance. Mean lengths, weights, and condition factors are significantly correlated within and between stocks. The pattern of covariation is examined using principal components ordination and provides some insight into the relative importance of genetic and environmental factors in determining characteristics of sockeye growth.

McKinnell, S.M., E. Curchitser, C. Groot, M. Kaeriyama, K.W. Myers. 2012. PICES advisory report on the decline of the Fraser River Sockeye salmon *Oncorhychus nerka* (Steller, 1743) in relation to marine ecology. PICES Science Report No. 41. 149 p.

[See pp.48-51 and Fig. 35 (p. 50).]

[Figure 35 caption:] Mean fork length anomalies (cm) for 16 populations with longer time series measurements for age-1.1 (top), 1.2 (middle) and 1.3 (bottom) panels. Each anomaly was computed by subtracting the long-term average, for each age and population, computed over the entire time series. The male and female fork lengths were averaged.

Morita, K., and M. Fukuwaka. 2007. Why age and size at maturity have changed in Pacific salmon. Marine Ecology Progress Series 335: 289–294.

Over the last few decades, the size at which Pacific salmon *Oncorhynchus* spp. attains maturity has decreased in many populations, whereas the age at maturity has increased. Both fisheries- induced evolution and environmentally-induced phenotypic plasticity could contribute to the changing age and size at maturity of Pacific salmon. We evaluated the potential for genetic changes in the maturation schedule of Japanese chum salmon using the probabilistic maturation reaction norm (PMRN) method. We found that the recent decrease in size at maturity, and increase in age at maturity, of Japanese chum salmon can be largely attributed to a phenotypic response to a reduced growth rate, but that fisheries-induced evolution should not be ruled out. Recent claims concerning fisheries-induced evolution of the maturation schedule are based on the decline in the age-specific body size at which the probability of maturing is 50%, a feature of PMRNs. However, the PMRN could change with changing environmental conditions. Therefore, a genetic change cannot be diagnosed only by the PMRN method.

Nagasawa, K. 2000. Long-term changes in the climate and ocean environment in the Okhotsk Sea and western North Pacific and abundance and body weight of East Sakhalin pink salmon *(Oncorhynchus gorbuscha).* North Pacific Anadromous Fish Commission Bulletin No. 2: 203-211.

Trends in catch of East Sakhalin pink salmon *(Oncorhynchus gorbuscha)* were closely related to the climate and ocean environment in the Okhotsk Sea and western North Pacific. During the period when the intensity of the Aleutian Low strengthened from 1977 to 1988, the area of sea ice expanded in the Okhotsk Sea, but both sea surface temperature (SST) and zooplankton biomass decreased in the western North Pacific, and pink salmon catch declined. Conversely, after the Aleutian Low weakened in 1989, the area of sea ice sharply decreased in the Okhotsk Sea, and pink salmon catch dramatically increased. It is thus suggested that during the period of the intensified Aleutian Low, juveniles have a higher mortality due to decreased SST in the Okhotsk Sea, and overwintering immature fish have a higher mortality due to decreased SST and zooplankton biomass in the western North Pacific. The reverse occurs with a weakened Aleutian Low. With an increase in catch after 1989, the body weight of adult pink salmon increased, suggesting that the carrying capacity of the western North Pacific Ocean for this stock has since increased.

Peterman, R. M. 1984. Density-dependent growth in early ocean life of sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 41: 1825-1829.

Significant decreases in adult body size and marine growth rate occur in seven British Columbia and Bristol Bay, Alaska, sockeye salmon *(Oncorhynchus nerka)* stocks when large numbers of sockeye are present in the Gulf of Alaska. These density-dependent effects arise mainly during early ocean life and are probably due to competition for food. The total sockeye abundance in the Gulf of Alaska is at least as important as within-stock abundance in determining final adult body size. British Columbia sockeye show a 10-22% decrease En adult body weight at high abundance of conspecifics. Thus, future evaluations of management strategies cannot simply focus on individual stocks, but must take a broader perspective which includes other sockeye populations.

Pyper, B.J. and R.M. Peterman. 1999. Relationship among adult body length, abundance, and ocean temperature for British Columbia and Alaska sockeye salmon (*Oncorhynchus nerka*), 1967–1997. Canadian Journal of Fisheries and Aquatic Sciences 56: 1716–1720.

Body length of adult Pacific sockeye salmon (*Oncorhynchus nerka*) has decreased significantly in recent years. We used 69 time series of age-specific body-length data (1967–1997) for 30 sockeye salmon stocks from southern British Columbia to western Alaska to test hypotheses about the effects of oceanographic conditions and competition on growth rate of sockeye salmon. Using principal components analysis (PCA), we constructed a single time series (PC1) that represented the dominant pattern of variability in length-at-age shared among these stocks. Taking into account time trends and autocorrelation in residuals, we found that increases in total Gulf of Alaska sockeye abundance and increases in sea-surface temperature (SST) across the Gulf of Alaska were significantly associated with reduced adult body length. Abundance and SST together accounted for 71% of the variability in PC1. Although researchers have documented increases in both abundance of sockeye salmon and their food in the northeastern Pacific Ocean over the last few decades, it is possible that increased food was more than offset by increased sockeye abundance, leading to greater competition and reduced body size.

Pyper, B.J., R.M. Peterman, M. F. Lapointe, and C.J. Walters. 1999. Patterns of covariation in length and age at maturity of British Columbia and Alaska sockeye salmon (*Oncorhynchus nerka*) stocks. Canadian Journal of Fisheries and Aquatic Sciences 56: 1046-1057.

We examined patterns of covariation in age-specific adult body length and in mean age at maturity among 31 sockeye salmon (*Oncorhynchus nerka*) stocks from western Alaska to southern British Columbia. Positive covariation in body length was prevalent across stocks of all regions (e.g., correlations (r) from 0.2 to 0.6), suggesting either that growth periods critical to final body length of sockeye salmon occur while ocean distributions of these stocks overlap or that large-scale environmental processes influence these stocks similarly while they do not overlap. We also found stronger covariation among body length of stocks within regions (r from 0.4 to 0.7), indicating that unique regional-scale processes were also important. Mean age at maturity also showed positive covariation both among and within regions, but correlations were weaker than those for length. We also examined patterns of covariation between length and mean age at maturity and between these variables and survival rate. Although length and mean age at maturity were negatively correlated, there was little evidence of covariation between these variables and survival rate, suggesting that environmental processes that influence marine survival rates of sockeye salmon are largely different from those affecting size and age at maturity.

Radchenko, V.I., O.S. Temnykh, and V.V. Lapko. 2007. Trends in abundance and biological characteristics of pink salmon (*Oncorhynchus gorbuscha*) in the North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin No. 4: 7-21.

Pink salmon are the most widely distributed species of the genus *Oncorhynchus*. Biennial cycles in the timing of the spawning migration and catch values are characteristic of pink salmon stock dynamics. Over the long term, two periods of high levels of abundance have been observed on both the Asian and North American coasts of the Pacific Ocean. Large-scale trends in abundance vary less than regional abundances. Coincidences in trends in catch dynamics among odd-year and even-year broodlines were found for several fishery regions. The observed relationships suggest a response of both broodlines to global factors that influence pink salmon reproduction and survival. Trends in abundance are influenced by global factors that are not necessarily cyclical. The dynamics of solar activity and an increase in ocean heat content play a significant role in their cumulative effect. Current pink salmon stock abundance may be close to a historic maximum. There is reason to expect that this level will continue in the near future under the influence of increasing ocean heat content. Pink salmon biological characteristics are related to levels of stock abundance. Average size in specific regions can also be related to the structure of regional salmon stocks which consist of a variety of seasonal races and ecological groupings.

Ricker, W. E. 1976. Review of the rate of growth and mortality of Pacific salmon in salt water, and noncatch mortality caused by fishing. Journal of the Fisheries Research Board of Canada 33(7): 1483-1524.

Mortality (other than landed catch) caused by pelagic gillnetting is estimated to be equal to the catch, for salmon in their penultimate year of life, and equal to about a quarter of the catch for salmon in their final year of life. Mortality caused by trolling for coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) averages about one fish killed (mostly below legal size) for every two that are boated. The natural mortality rate for sockeye salmon (*O. nerka*) in their final year of life averages about0 .015 per mo and is somewhat more in earlier years of pelagic life; the greater part of natural mortality after the smolt stage occurs during the downstream migration and early months of "coastal" life. For coho and chinook the best natural mortality estimate for the last year of life is 0.013 per mo, and that or pink (*O. gorbuscha*) and chum (*O. keta*) is of the same order. Growth rates during the final growing season vary from 0.26 per mo for pink and coho salmon to 0.06 per mo for chinook in their 5th ocean yr. Gains from ceasing to take immature salmon on the high seas range up to 300% of the catch now being taken in that category, while for fish taken in their final year they range up to about 70%,depending on the time of year at which the fishing is done. Gains from transferring existing pelagic net fisheries to the coastal region would be 76% (North American sockeye) and 86% (Asian sockeye) of the weight of fish now caught pelagically. Gains in total yield of existing salmon fisheries (pelagic and coastal) are estimated as 78%of or Asian pink salmon and 72% for Asian sockeye. The increase in weight of the total catch from discontinuing ocean trolling for Columbia River chinook salmon and increasing river fishing correspondingly is estimated tentatively as between 63 and 98%.

Ricker, W.E., H.T. Bilton, and K.V. Aro. 1978. Causes of the decrease in size of pink salmon. Fisheries and Marine Service Technical Report 820.

Pink salmon tend to be larger in odd-numbered years than in even-numbered and the difference increases from Alaska southward to the Strait of Georgia. Pinks caught by gillnets are usually larger than those taken by seines, with those caught by trolling intermediate in recent years, though formerly they were the largest. Odd-year pinks increase in size from north to south from western Alaska to southern British Columbia. So do the even-year pinks in Alaska, but in British Columbia, they have little or no regular geographical variation in size—if anything, a decrease from north to south. Both odd-year and even-year pinks have decreased in size since 1951, the even-year fish about twice as fast as the odd. In a few large runs there are suggestions of an inverse relation between the size of the run and the size of the fish, but no relationships could be detected between size and total salmon landings in British Columbia or in the whole northeastern Pacific. Size of British Columbia pinks was positively correlated with surface temperatures at two northern coastal stations (Langara and Cape St. James), and the trend in temperature has been downward since 1940. However, the rate of decrease in pink size since 1951, computed from this relationship, is only 1/4 to 1/11 of the actual, averaging 0.16. Correlations with salinity at Ocean Station P were barely "significant" in the case of Fraser fish, but any real relationship is doubtful because it was one of several possibilities tried. Selective removal of larger fish by the troll and gillnet fisheries can explain all of the observed downward trend in size of pink salmon. Selection also explains two features that could scarcely have an environmental origin: the fact that the small even-year pinks have decreased in size more rapidly than the large odd-year pinks, and the fact that the decrease is greater among seined than among gillnetted fish. There is also a positive relation between rate of decrease and the percentage of the catch taken by selective gears in different Areas. The downward trend began about 1950, and two or three causes have contributed: the increase in trolling, a change in marketing that emphasizes weight rather than numbers caught, and the introduction of artificial fibres in gillnets. To date different runs have lost 0.5-1.5 lb in average weight. If all the observed decrease is due to selection, mean heritability (h^2) of weight in wild British Columbia pink salmon is estimated to be 0.26 if mean rate of exploitation is 80%, and 0.33 if it is 75%, calculated from the average difference in size between seined and selectively-caught individuals as compared with the observed rate of decrease in size. If decrease in ocean temperature has played some role, the mean heritability estimates are reduced to 0.22 and 0.28. Continuation of the decrease in size of pink salmon is almost certain under present fishing regimes, and it is very likely to reduce progressively the overall productivity of the fishery. Remedial measures pose difficult problems.

Ricker, W.E. 1980. Changes in the age and size of chum salmon (*Oncorhynchus keta*). Canadian Technical Report of Fisheries and Aquatic Sciences No. 930. vii + 99 p.

The mean weights of chum salmon caught during the 1960s and 1970s ranged from 7 lb in western Alaska to almost twice that figure in central British Columbia, then decreased to 11 lb in southern British Columbia, but the progression was not completely regular. The decrease southward in British Columbia resulted from a decrease in average age; within the Province, size at a given age changed very little with latitude.

Between 1951 and 1975 the chum salmon caught in most British Columbia statistical areas have decreased in size, but by only about 1 lb on the average. Between 1957 and 1972 their average age increased by about 0.3 yr, because fish of age 0.2 became scarcer while age 0.4 became more plentiful. In the Northern District the increase in mean age may be mainly or wholly a result of selection by the gillnet fishery, whose catch averaged 1.12 lb smaller than that of the seine fishery. Paradoxically, the decrease in average size might result from the same selection, for the age 0.2 fish grow much faster than older ones, and the progressive loss of their genes favoring rapid growth has to some extent affected the other ages also, because of cross-age mating. This effect of selection is, however, opposed by within-age selection favoring the survival of larger size, and the age 0.4 fish, which are farthest from the selected size range, did exhibit a small *increase* in size with time.

In the Southern and Fraser Districts the difference in size between seined and gillnetted fish is much less than in the north, and is insufficient to explain the observed increase in mean age. No other explanation has been identified; it may be something related to the major fluctuation in abundance of the southern chums.

There is sporadic information on age and size of chums before 1951. The earliest is for the Strait of Georgia in 1916-1917, when chums caught did not differ significantly in age or size from modern catches. During 1945-49 chums caught were smaller in most Areas than since that time, as shown by independent length and weight samples. Because pink salmon also were small in some of those years, the effect of widespread, and as yet unidentified, unfavorable physical or biological conditions is indicated.

Both in British Columbia and in Alaska, size of chums at a given age has decreased since 1951 along with a general decrease in ocean temperatures. To determine whether this is an accidental or a meaningful coincidence, the residuals of temperature and size from their respective linear regression on time were computed and compared, during 1951-1975. Weight residuals were positively but weakly correlated with temperature residuals in the last year (approximately) of life, and negatively correlated with the temperature 1 or 2 years earlier. However, all such correlations were small; the corresponding regressions were only 1/3 to 1/10 of the change in weight actually observed, and were sometimes of the wrong sign. In addition, chums were small during the late 1940s when temperatures were high. Thus it is still problematical whether ocean temperature changes, within the range observed, have had any significant effect on the size of chum salmon in British Columbia.

Ricker, W.E. 1981. Changes in the average size and average age of Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 38: 1636-1656.

Of the five species of Pacific salmon in British Columbia, chinook salmon *(Oncorhynchus tshawytscha* and coho salmon *(0.kisutch) are harvested* during their growing seasons, while pink salmon (*0. gorbuscha)* chum salmon *(0.keta)*, and sockeye salmon (*0. nerka)* are taken only after practically all sf their growth is completed. The size of the fish caught, sf all species, has decreased, but to different degrees and over different time periods, and for the most part this results from a size decrease in the population. These decreases do not exhibit significant correlations with available ocean temperature or salinity series, except that for sockeye lower temperature is associated with bigger size. Chinook salmon have decreased greatly in both size and age since the 1920s, most importantly because nonmaturing individuals are taken by the troll fishery; hence individuals that mature at older ages are harvested more intensively, which decreases the percentage of older ones available both directly and cumulatively because the spawners include an excess of younger fish. Other species have decreased in size principally since 1950, when the change to payment by the pound rather than by the piece made it profitable for the gill-netters to harvest more sf the larger fish. Cohos and pinks exhibit the greatest decreases, these being almost entirely a cumulative genetic effect caused by commercial trolls and gill nets removing fish of larger than average size. However, cohos reared in the Strait of Georgia have not decreased in size, possibly because sport trolling has different selection characteristics or because of the increase in the hatchery-reared component of the catch. The mean size of chum and sockeye salmon caught has changed much less than that of the other species. Chums have the additional peculiarity that gill nets tend to take *smaller* individuals than seines do and that their mean age has increased, at least between 1957 and 1972. That overall mean size baas nevertheless decreased somewhat may be related to the fact that younger-maturing individuals grow much faster than older-maturing ones; hence excess removal of the smaller younger fish tends to depress growth rate. Among sockeye the decrease in size has apparently been retarded by an increase in growth rate related to the gradual cooling of the ocean since 1940. However, selection has had two important effects: an increase in the percentage of age-3 "jacks" in some stocks, these being little harvested, and an increase in the *difference* in size between sockeye having three and four ocean growing seasons, respectively.

Ricker, W.E. 1982. Size and age of British Columbia sockeye salmon (*Oncorhynchus nerka*) in relation to environmental factors and the fishery. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1115. ix + 117 p.

The major sockeye runs in British Columbia have experienced various changes in the relative abundance of fish of different freshwater and ocean ages. In Area 3, the Nass region, sockeye having 1 year of freshwater growth and 4 years of ocean growth (life-history type 1/4) have gradually become about twice as numerous as the 2/3 type since 1940, reversing the original situation. At the same time type 1/3 has increased from about 10% to 25%. In Area 4, the Skeena region, sockeye are now mainly of the I-freshwater type. The 2-freshwater fish were never a major component, coming mainly from several of the smaller lakes, and they have decreased. Among the I-freshwater type, the ratio of 3-ocean to 4-ocean fish has fluctuated greatly, but the various possible causes have not been sorted out. In part, the changes are related to an early 5-year and a later 4-year cycle of abundance. In Area 9, the Rivers Inlet run to Owikeno Lake has always been mainly I-freshwater. The ratio of 4-ocean to 3-ocean fish has varied, and there have been 5-year and 4-year cycles similar to those on the Skeena, but peaking one year later. Fraser River sockeye have always been mainly of the 1/3 type, although local stocks exhibit diversity. Most stocks exhibit dominance of one line out of the four. To-day the big populations are in different lines at different lakes, but in 1913 and earlier all studied upriver populations were dominant in the 1901 line.

On the whole, there have been only small changes in the average size of sockeye captured, from 1912 through 1980. However, from about 1950 most statistical Areas have registered small decreases in size, averaging 0.3-0.4 lb (140-180 g) over all Areas. Individually these decreases are non-significant statistically, but an overall effect is made probable by the preponderance of decreases over increases in different Areas (26 decreases, 10 increases); coupled with the fact that all but one of the increases are from Areas of very small catches. However, the negative trends since 1950 owe much to a 1950-54 interval of unusually large size in almost all Areas, so it is too soon to be sure there is a sustained decline in size.

Sockeye sizes of the 4 major runs are positively correlated, particularly when residuals from their linear trends are compared. The large sizes of 1950-54 were preceded and followed by small sizes in 1944-49 and 1955-61.

Mean size and quantity of fish landed each year are positively correlated. In the runs having two important ocean ages this is merely an arithmetic artifact. On the Fraser it occurs because fish of the 1902 line are congenitally larger than the other lines, and since 1926 that line has been the most abundant one.

A correlation analysis shows that the major contribution to similarity in adult size of two groups of sockeye is made by length of ocean life. Among fish of the same ocean age, similarity is increased if most or all of their ocean growth is in the same calendar years. Having the same length of freshwater life may make a contribution to similarity in adult size, but if so it is very minor. When all such differences are eliminated, it turns out that observed year-to-year variability in size is reduced by 30% to 47% (mean 38%), which is an estimate of the contribution of oceanic conditions to observed variability. The "noise" in the data is estimated as 45%, from the variability of the difference in size between males and females of the same age type and year-class, so that the contribution of oceanic conditions to the true year-to-year variability in size is increased to 69%.

In spite of this large influence of ocean conditions upon sockeye size, little success was achieved in the attempt to identify causal factors or their correlatives. Neither single-year nor 2-year mean salinities at Station P (50°N, 145°W) or at coastal stations exhibited promising correlations with sockeye sizes. Correlations with temperature were mostly negative, supporting an earlier discovery by Killick and Clemens. However, in combination with a decreasing trend in ocean temperatures, this would tend to increase mean size somewhat, the reverse of the observed trend since 1950.

Average sizes of sockeye caught have been greatest in the troll fishery, somewhat less in the gillnet fisheries, and least in the seine fishery. In runs of the central and northern coast, where two ocean ages occur in numbers, this has meant that spawning stocks contain more of the faster-growing 3-ocean fish and fewer of the larger but slower-growing 4-ocean fish. These two opposed factors make the net effect on average size unpredictable, and size has in fact not changed very much since 1950 (the average decrease is a non-significant 0.28 lb or 127 g). What is very striking is that the gillnet fisheries have harvested fish mainly from the middle of the size range, as described by Foskett. As a result, the 4-ocean sockeye have gradually become larger and the 3-ocean fish smaller, the difference between them having increased by more than a pound (about 500 g), as described by Godfrey. There have also been small changes in the relative size of the two sexes in fish of the same life-history type, which may be explicable in terms of the selectivity of the fishery if inheritance of size is partly sex-limited. At Owikeno the males have even become smaller than the females in the age 1/3 category, but not in the 1/4 category.

The Fraser run contains only one life-history type of major importance, 1/3, so the smaller fish that have been favoured for reproduction have not been younger ones having a fast growth rate, as in the north.

As a result, Fraser sockeye have decreased more in recent years (about 0.66 Ib or 300 g in 1951-75) than did those of the northern runs, in spite of the fact that the Fraser gillnet fishery has been less selective of the larger fish.

There is no good evidence for any effect, on growth, of competition between sockeye and the chum or pink salmon that mature in the same calendar year. However, for the Fraser run only there is a significant positive correlation between adult size of sockeye and adult size of the pink salmon that *go to sea* in the same calendar year. If this is a real effect, it probably reflects the fact that they share the same vicissitudes of life in the southern straits during part of their first year of marine life.

Ricker, W.E. 1995. Trends in the average size of Pacific salmon in Canadian catches. Pages 593-602 *in* R.J. Beamish, editor. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

From 1951 through 1975 the pink *(Oncorhynchus gorbuscha),* coho *(0. kisutch),* and chinook salmon *(0. tshawytscha)* caught in British Columbia waters decreased in average weight in almost all sections of the province by 5-25%. During 1976-91 this trend slowed down, was arrested, or was reversed in most areas of the northern and central regions, and in the case of chinook salmon a loss of 3 kg or 25% has been fully restored in the far north, and less completely elsewhere. In the southern region, however, decrease in size has continued for coho and pink salmon, these species being now 20-40% lighter than in the 1950s. Sockeye *(0. nerka)* and chum salmon *(0. keta)* have had no sustained trends in size since 1951. As yet none of the observed changes in size have been shown to be correlated with changes in environmental and other factors over the long term, but much additional study is needed. A poor growth rate can be related to unusual abundance of pink salmon in local regions. Effects of selective fishing on heritable aspects of growth rate and age of maturity may play a role in some cases, although the evidence for this is circumstantial. However, it provides a possible explanation for the absence of sustained trends among sockeye and chum salmon, because the 2 or 3 ages present in their stocks make the effect of selection by size ambiguous and unpredictable: maturing fish that have spent any given number of years in the ocean are smaller, but have grown faster, than those that have spent any greater number of years there.

Rogers, D. E. 1980. Density-Dependent growth of Bristol Bay sockeye salmon. Salmonid ecosystems of the North Pacific. Pages 267-283 *in* W.J. McNeil and D.C. Himsworth, editors. Oregon State University Press, Oregon.

[from Introduction] I will use data on the age and length of Bristol Bay sockeye gathered since 1957 by the Bureau of Commercial Fisheries, Fisheries Research Institute and Alaska Department of Fish and Game for the following purposes: 1) Review evidence on density-dependent growth of juveniles in Bristol Bay lakes; 2) Analyze statistics on immature sockeye at sea with respect to annual variations in size and abundance; 3) Calculate annual mean lengths and weights of adult sockeye in Bristol Bay; and 4) Evaluate density-dependent growth at sea.

Ruggerone, G.T., B.A. Agler, and J.L. Nielsen. 2011. Evidence for competition at sea between Norton Sound chum salmon and Asian hatchery chum salmon. Environmental Biology of Fishes 94(1): 149-163. DOI: 10.1007/s10641-011-9856-5

Increasing production of hatchery salmon over the past four decades has led to concerns about possible density-dependent effects on wild Pacific salmon populations in the North Pacific Ocean. The concern arises because salmon from distant regions overlap in the ocean, and wild salmon populations having low productivity may compete for food with abundant hatchery populations. We tested the hypothesis that adult length-at-age, age-at-maturation, productivity, and abundance of a Norton Sound, Alaska, chum salmon population were influenced by Asian hatchery chum salmon, which have become exceptionally abundant and surpassed the abundance of wild chum salmon in the North Pacific beginning in the early 1980s. We found that smaller adult length-at- age, delayed age-at-maturation, and reduced productivity and abundance of the Norton Sound salmon population were associated with greater production of Asian hatchery chum salmon since 1965. Modeling of the density-dependent relationship, while controlling for other influential variables, indicated that an increase in adult hatchery chum salmon abundance from 10 million to 80 million adult fish led to a 72% reduction in the abundance of the wild chum salmon population. These findings indicate that competition with hatchery chum salmon contributed to the low productivity and abundance of Norton Sound chum salmon, which includes several stocks that are classified as Stocks of Concern by the State of Alaska. This study provides new evidence indicating that large-scale hatchery production may influence body size, age-at maturation, productivity and abundance of a distant wild salmon population.

Takagi, K., K. V. Aro, A.C. Hartt, and M.B. Dell. 1981. Distribution and origin of Pink Salmon (*Onchorhychus gorbuscha*) in offshore waters of the North Pacific Ocean. International North Pacific Fish Commission Bulletin No. 40.

[Table 12 Caption:] Average body weight in kilograms of adult pink salmon caught in coastal areas of North America and Asia, 1962-1971.

Table reproduced as Table 20 in: Heard, W.R.1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pages 121-230 *in* C. Groot, and L. Margolis, editors. Pacific Salmon Life Histories. UBC Press, Vancouver, BC.

Temnykh O.S., A.V. Zavolokin, L.O. Zavarina, V.V. Volobuev, S.L. Marchenko, S.F. Zolotuhin, N.F. Kaplanova, E.V. Podorozhnyuk, A.A. Goryainov, A.V. Lysenko, A.M. Kaev, Y. I. Ignat'ev, E.V. Denisenko, Y. N. Khokhlov, and O.A. Rassadnikov. 2012. Interannual variability in size and age structure of Russian chum salmon stocks. North Pacific Anadromous Fish Commission Document 1413 (Rev.1). 20 p.

Data on trends in abundance, size and age composition of chum salmon stocks from all major Russian stocks are considered for the last 40-50 years. Increase in the total abundance of chum salmon were accompanied by decrease in average size in most major reproduction areas from the 1970s to 2010s.

Changes in size were accompanied by changes in age structure of chum salmon populations. The tendency of growth in average age of spawners due to an increase in the proportion of older chum salmon spawners was in most of examined areas (except Primorye chum salmon stocks). Statistically significant correlation coefficients between average sizes and total catches of chum salmon indicate that there is a close relation between chum salmon abundance and its production features. The reasons for the changes in the size-age structure of chum salmon stocks are discussed. Certain deficiency in food supply during marine life can negatively impact chum growth rate, but ocean food resources are not the limiting factor to the abundance of salmon.

Thomas , G.L., and O.A. Mathisen. 1993. Biological interactions of natural and enhanced stocks of salmon in Alaska. Fisheries Research 18: 1-17.

A workshop on 'Biological interactions of natural and enhanced stocks of salmon in Alaska', was held in autumn 1991 at the Prince William Sound Science Center in Cordova, AL, USA. The subject and site were relevant as the impacts of hatchery operations on wild salmon stocks have recently become an international concern and Prince William Sound contains one of the largest salmon hatchery operations in the world. This workshop was designed to review the evidence, or lack thereof, that hatchery salmon are affecting the growth, survival, and natural genetic diversity of wild salmon in Alaska. International, national, and regional perspectives identified the important biological interactions between hatchery and wild salmon stocks, and characterized them in terms of genetics, carrying capacity, and harvest management. The workshop participants unanimously agreed on the importance of 'maintaining genetic diversity within and between natural populations of salmon to sustain productivity of both wild and enhanced stocks'. An expansion of stock assessment and identification research and monitoring programs using new technologies (acoustics, optics, electronic mapping, marking, and gene sequencing) is the key to the acquisition of information needed to protect wild stocks from future over-exploitation.

Volobuev, V.V. 2000. Long-term changes in the biological parameters of chum salmon of the Okhotsk Sea. North Pacific Anadromous Fish Commission Bulletin No. 2: 175-180.

Chum salmon *(Oncorhynchus keta* of the Okhotsk Sea return to their rivers to spawn in early and late runs. Runs differ in spawning time, areas and periods of spawning, and age, size and fertility of the fish. Length, weight and fertility of chum salmon increase when spawning run abundance is low. During periods of high abundance of stocks, weight and fertility decrease. Age at maturity and run abundance are inversely related. The biological characteristics of the Okhotsk Sea chum salmon stock is presumably affected by the abundance of the local stocks as well as by the total salmon population in the North-West Pacific. Changes in the climatic and oceanological conditions may affect ocean carrying capacity, and in turn affect the biological characteristics of the chum salmon stock in the Okhotsk Sea.

Welch, D.W. and Noakes, D.J. 1993. Trends in catch and average size of Pacific salmon in Canada, with a report on 1992 escapement levels. North Pacific Anadromous Fish Commission Document 29. 47 p.

Total salmon catches in British Columbia waters increased beginning in the late 1970's, and are now at or above historic high levels. During the last ten years, catches have averaged 82,000 tonnes with peak catches of 108,000 tonnes recorded in 1985. This growth is due primarily to sharp increases in catches of both pink and sockeye salmon. Catches in these fisheries have nearly doubled in the last decade compared to the catches of pink and sockeye recorded during the 1970's. In contrast, catches of chinook salmon in both the commercial and sport fisheries have declined since 1971. 1992 chinook salmon catches were similar to those recorded during the 1950's and 1960's, but only half the peak catch of 1.6 million chinook recorded in 1971. Catches of coho salmon have remained relatively stable over the last 30 years with an average annual yield of about 3.7 million individuals. Chum salmon catches have increased slightly since the mid 1980's. 1992 catches (in numbers) were as follows; chinook: 860,259; sockeye: 8)84,730; coho: 3,626,706; pink: 10,309,776; and chum 4,011,410. Some significant changes in mean size at capture of salmon caught in British Columbia waters are also evident. These were reviewed by Ricker (1981), and are updated here to 1992. The mean size of pink and coho salmon has been declining since 1951. The average size of sockeye has been variable but without trend until recently; however, significant declines in mean size have been noted since 1990. The mean weight of chum salmon has also been quite variable, but without trend. Chinook salmon sizes decreased until the mid 1970's, but then began to increase; mean sizes are now near those recorded in the 1950's. For all species but pink salmon, some evidence for a negative influence of salmon abundance on marine growth rates is indicated. This suggests that limitations of the oceanic carrying capacity for Pacific salmon could therefore be of practical importance to salmon management efforts by Pacific Rim nations.

Welch, D.W., and J.F.T. Morris. 1994. Evidence for density-dependent marine growth in British Columbia pink salmon populations. North Pacific Anadromous Fish Commission Document 97. 33 p.

Data was recently discovered in the Pacific Biological Station's archives that was collected from British Columbia canneries between 1927-42. The data allows extension of the available time series on size of British Columbia pink salmon back to 1927. Size at maturity in the early 1930's was comparable to that of present day pink salmon stocks. Genetic selection for slower growing fish is therefore not the primary cause of the long term declines in the size of pink salmon observed since 1951, when the Dept. of Fisheries and Oceans (DFO) salmon stock assessment (SSA) database was first developed. The consequences of these density-dependent changes in marine growth rates now need to be assessed from three perspectives: *(i)* What are the full economic impacts of the observed declines in size of pink salmon? *(ii)* At what period during the marine life history of pink salmon is growth density-dependent, and how does this density-dependence contribute to determining the economic productivity of salmon stocks when compared with events happening in freshwater? *(iii)* To what degree will further increases in salmon population sizes impair the productivity of Pacific salmon stocks?

Wertheimer, A.C., W.R. Heard, J. M. Maselko, and W.W. Smoker. 2004. Relationship of size at return with environmental variation, hatchery production, and productivity of wild pink salmon in

Prince William Sound, Alaska: does size matter? Reviews in Fish Biology and Fisheries 14: 321–334.

Pink salmon (*Oncorhynchus gorbuscha*) returning to Prince William Sound (PWS), Alaska, have increased to historically high levels of abundance in recent years, but average body size at return has declined. We examined how body size at return of PWS pink salmon was related to 10 biophysical factors, including the scale of hatchery production. We also examined the effect of body size at return on productivity of wild pink salmon in PWS. For the 1975–1999 brood years, we found that an index of total abundance of pink salmon in the Gulf of Alaska and sea surface temperature during the year of return best explained the variation in pink salmon body size over time. Body size at return was significantly correlated with productivity of wild pink salmon. We used stepwise-regression to fit a generalized linear version of the Ricker spawner-recruit model to determine if body size would explain significant variation in wild-stock productivity in context with other environmental variation, including hatchery production. The results indicate that variability in wild-stock productivity is primarily driven by density-independent factors in the marine environment, but that body size of wild spawners also significantly affects productivity of wild PWS pink salmon. We conclude that the success of large-scale enhancement increasing the total run in PWS may have contributed to the decline in body size because of density-dependent growth in the Gulf of Alaska. We used a simulation model to estimate the impact of hatchery-induced changes in adult body size on wild-stock production in PWS. We estimated an annual wild-stock yield loss of 1.03 million pink salmon, less than 5% of the annual hatchery return of 24.2 million adult pink salmon for brood years 1990–1999.

3. Related methodological papers

Campana, S.E., and J.D. Neilson. 1985. Microstructure of fish otoliths. Canadian Journal of Fisheries and Aquatic Sciences 42: 1014-1032.

Otolith microstructure examination has found an increasing number of applications in recent years. However, few workers have critically assessed the assumptions upon which the age and growth inferences are based or considered the potential for environmental modification of microstructural features. This paper reviews present applications and their assumptions and suggests future directions. Particular attention is given to the premises that the frequency of increment formation is constant and that the width of increments is proportional to fish growth. A hypothesis of increment formation is presented which appears consistent with the numerous and often conflicting studies reported to date. The presence of an endogenous circadian rhythm of increment formation is invoked, entrained by photoperiod, but susceptible to modification by other cyclic environmental variables. increments formed as a result of the circadian rhythm (once per 24 h) may be induced by different processes than those induced through the action of environmental cues (often > 1 per 24 h), thus explaining apparent morphological differences in increment structure noted by some workers. Temperature fluctuations appear to be a primary source of subdaily increments and are a potential source of error in otolith interpretation.

Casselman, J.M. 1990. Growth and Relative Size of Calcified Structures of Fish. Transactions of the American Fisheries Society 119(4): 673-688. http://dx.doi.org/10.1577/1548-8659(1990)119<0673:GARSOC>2.3.CO;2

The relationship between size of calcified structures and the body offish has been used widely in fisheries science to estimate body size at a younger age by "back-calculation." I labeled the calcified tissue of northern pike *Esox lucius* with tetracycline to examine the concurrent linear growth of calcified structures and the body. I also conducted comparisons of the sizes of one or more calcified structures with body sizes of northern pike, lake trout *Salvelinus namaycush,* and muskellunge *Esox masquinongy.* Over a broad size and age range (juveniles and older), growth of scales, cleithra, and otoliths is only transitorily isometric in relation to body growth. Although scale growth is more strongly allometric than bone growth, allometry in both structures is positive during rapid growth and negative during slow growth. Slower-growing individuals have relatively smaller scales and cleithra. Calcified structure-body relations indicate that in older fish, growth of the scales virtually ceases while body growth continues, albeit at a greatly reduced rate as size approaches an asymptotic length. Cleithral growth in these fish, although greatly reduced, continues at a relatively greater rate than that of the scales. In contrast to scales and bones, otoliths grow relatively slower than the body during rapid growth and relatively faster than the body during slow growth. In slow-growing or old fish, otoliths grow more rapidly than the other structures and continue to record cyclic seasonal growth and age, whereas scales of these fish fail to grow in a regular fashion and can even resorb or erode and fail to provide an accurate record of age. Nutritional status, as indicated by prey availability, influences the size relations between calcified structures and the body. When more prey are available, northern pike have relatively larger cleithra. Hence, the relative size of calcified structures provides a sensitive indicator of growth and reflects subtle changes in growth rate and nutritional status.

Courtney, D.L, D.G. Mortensen, and J.A. Orsi. 2000. Digitized scale and otolith microstructures as correlates of juvenile pink salmon size. North Pacific Anadromous Fish Commission Bulletin No. 2: 337-345.

The purpose of this study was to determine whether scale or otolith microstructures were more strongly related to fish growth. Scales and otoliths were sampled from 231 juvenile pink salmon *(Oncorhynchus gorbuscha)* collected from the marine waters of Southeast Alaska during two periods in 1993 and 1994. A computerized image analysis system was used to measure several periodic and non-periodic scale and otolith microstructures from each specimen. The measurements from each fish were compared with each other and with fish length using nonparametric correlation analysis and parametric regressions. As expected, growth of most scale and otolith microstructures was significantly positively correlated with fish growth. Scales and otoliths also portrayed recent marine growth (growth near the time of capture) more reliably than earlier marine growth (growth more distant from the time of capture). An unexpected result was that the number and width of periodic scale microstructures (circuli) were more strongly related to fish length than were the number and width of periodic otolith microstructures (increments). These results indicate that, at least for pink salmon, there is a tradeoff between the finer temporal resolution available from otolith increments (near daily) and the stronger correlation with fish length available from scale circulus measurements.

Fukuwaka, M., and M. Kaeriyama. 1994. A method for estimating growth pattern of hatchery reared chum salmon by scale analysis and back-calculation. North Pacific Anadromous Fish Commission Document 77.

We examined a scale analysis and back-calculation method for estimating individual growth of marked juvenile chum salmon during early ocean life. The spacing of scale circuli decreased during the hatchery-rearing period, and increased during the early-ocean period. A check was formed on the scales immediately after release. The estimation of individual release size, back-calculated from the scale radius of the check, enabled calculation of the individual growth rate of juvenile chum salmon in the ocean. This method could be useful in estimating the individual growth of chum salmon in the first ocean year.

Fukuwaka, M. and M. Kaeriyama. 1995. Relationship between scale growth and somatic growth in sockeye salmon, *Oncorhynchus nerka.* North Pacific Anadromous Fish Commission Document 148.

The relationships between individual somatic growth and scale growth were examined by a rearing experiment using sockeye salmon *(Oncorhynchus nerka)* marked with PIT -tags. Circulus spacing is determined by formation rate of circuli and growth of scale radius. The relationship between absolute growth and increment of scale radius during the experiment was linear. The relationship between increment of scale radius and number of circuli formed during the experiment also was linear. From path analysis, number of circuli was directly correlated with absolute growth. A negative path coefficient (-0.200) between absolute growth and number of circuli was indicated that circulus spacing was positively correlated with somatic growth. The relationship between circulus spacing and absolute growth was linear [absolute growth (mm) = 1.90 * circulus spacing (µm) + 18.1]. Circulus spacing was useful for comparison of mean growth among kokanee, sockeye salmon, and their hybrids from this equation.

Fukuwaka, M. 1996. Formation periodicity of increment and allometric growth in juvenile chum salmon otolith. North Pacific Anadromous Fish Commission Document 207.

Otolith growth and rate of increment formation in juvenile chum salmon were examined to determine whether otoliths could be used to back-calculate body sizes at various juvenile life history stages. Sagittal otoliths were firstly observed in newly hatched chum alevines. At that time, the fish had an average total length of 19.5 mm and their sagittae were approximately 312 µm long. As the fish grew, the relationship between body length and sagitta length was allometric and equaled: sagitta length (µm) = 312 + 35.9 * $\{\text{body length (mm)} - 19.5\}^{0.790}$. Increment periodicity was found to occur on a daily basis and was ascertained by performing a fluorescent marking experiment. The results of this work show that individual growth in juvenile chum salmon can be estimated by features readily detected in their otoliths.

Fukuwaka, M., and M. Kaeriyama. 1997. Scale analyses to estimate somatic growth in sockeye salmon, *Oncorhynchus nerka.* Canadian Journal of Fisheries and Aquatic Sciences 54: 631-636.

The relationships between individual growth and scale pattern were examined for juvenile sockeye salmon (*Oncorhynchus nerka*) marked with passive integrated transponder (PIT) tags to assess the usefulness of scale analyses for estimating somatic growth. The relationship between absolute somatic growth and increment of scale radius was linear. The relationship between increment of scale radius and number of circuli was also linear. Path analysis showed that the number of circuli was directly correlated with absolute growth. A negative path coefficient (-0.200) between absolute growth and number of circuli indicated that circulus spacing was positively correlated with somatic growth. The relationship between circulus spacing and absolute growth was linear (circulus spacing (µm) = 0.528 * absolute growth (mm) -9.57). Results indicate that somatic growth affects circulus spacing directly. Circulus spacing was useful for comparing mean growth from the above equation, while back-calculation was useful for estimating individual growth.

Fukuwaka, M. 1998. Scale and otolith patterns prove growth history of Pacific salmon. North Pacific Anadromous Fish Commission Bulletin No. 1: 190-198.

Scale and otolith patterns are frequently used for age determination, growth estimation, and stock identification of Pacific salmon. However, little information is available about their formation mechanism such as circulus, check in the scale, and growth increment in the otolith. I clarified the formation mechanisms of scale and otolith patterns by rearing experiments using juvenile sockeye and chum salmon. Circulus spacing was positively correlated with somatic growth in juvenile chum salmon. A check was formed soon after release from a hatchery in juvenile chum salmon and at the time of tagging in juvenile sockeye salmon. Growth increments were produced in otolith on a daily basis. An allometric equation was fitted to the relationship between fish length and otolith length. These results indicate that growth history of individual fish can be back-calculated from scale and otolith patterns. Circulus spacing is also useful as an indicator of somatic growth. Scale and otolith patterns are influenced by somatic growth rate and by environmental conditions. From this, scale and otolith patterns are useful for the estimation of fish growth through the life history.

Hyun, S., K.W. Myers, and J.G. Sneva. 1998. The time of annulus formation in Chinook salmon caught in Washington coastal waters. North Pacific Anadromous Fish Commission Document 352.

We analyzed a large database (5,066 fish) of information on time of formation of the last ocean annulus on scales collected from coded-wire tagged chinook salmon recovered in Washington State coastal waters from 1988 to 1993. Variation in the time of formation of the last ocean annulus by year, recovery age, behavioral type, recovery season, recovery area, and stock was investigated. The most important finding was that time of annulus formation varied by freshwater age or behavioral type. Chinook salmon that migrated to the ocean in their first year (ocean-type; freshwater age-O.) completed formation of the last ocean annulus in March, and chinook salmon that migrated to the ocean in their second year (stream-type; freshwater age-I.) completed annulus formation in April. Many of the stream-type chinook salmon in the analysis were artificially (hatchery) produced, that is, their natural life history is ocean-type. Inter- and intra-specific differences in time of annulus formation on salmon scales may reflect differences in growth rates, regulated by feeding conditions.

Myers, K.W. 1998. NPAFC sockeye scale aging test. North Pacific Anadromous Fish Commission Document 361.

At the March 1997 NPAFC research planning meeting in Vancouver, B.C., the Working Group on Stock Identification and Growth discussed the need to test inter-laboratory variation in scale age and growth data. In this document, sockeye salmon scale age determinations by experts at nine laboratories in Canada, Japan, Russia, and the United States are compared. The results indicate that ocean age determinations are consistent among laboratories. However, there was substantial variation among the laboratories in freshwater age determinations. The results suggest that there may be need for international review and standardization of methods and criteria used to interpret freshwater age and growth patterns on salmon scales.

Ricker, W.E. 1964. Ocean growth and mortality of pink and chum salmon. Journal of the Fisheries Research Board of Canada 21: 905-931.

Records of length of pink and chum salmon computed from scale annuli are summarized, and are converted to show rate of growth in weight. Information is available on 11 pink stocks or groups of stocks originating at points from the Strait of Georgia to Sakhalin and Primorye, and for 7 chum stocks taken from Tillamook Bay to the Amur River and Sakhalin. Estimates of increase in weight from the time of formation of the final annulus to time of capture near shore vary from 190% to 590% for pinks maturing at age 1+, and from 60% to 92% for chums maturing at age 3+. At the end of the first year, pinks are computed to average 356 g in weight, and chums 287 g. Average instantaneous rate of growth per month in the final year is 0.28 for pinks and, 0.12 for chums, each available locality being given equal weight. The seasonal distribution of growth in the final year has been estimated for pink salmon of the Bering Sea (by Birman) and for those of the central British Columbia coast (by LeBrasseur and Parker); for chum salmon an approximate seasonal distribution can be deduced from comparisons of growth rates. Combining these with the best available estimate of natural mortality (0.02 per month for salmon more than 30 cm long), calculations of net yield from high-seas fishing can be made for any desired date, and compared with the yield from a purely coastal fishery (the same escapement being provided in both cases). In all situations the catch taken on the high seas is less than that taken from the survivors of the same fish in coastal waters. The loss of yield exceeds 50% for pinks taken early in their final season, and also for chums taken early in their penultimate season.

4. Marine growth indices

Agler, B.A., G.T. Ruggerone, and L.I. Wilson. 2012. Historical scale growth of Bristol Bay and Yukon River, Alaska, chum salmon (*Oncorhynchus keta)* in relationship to climate and inter- and intra-specific competition. North Pacific Anadromous Fish Commission Technical Report No. 8: 108-111.

[From text of article] We used salmon scales to determine whether marine growth of chum salmon varied with climate and interspecific competition. We examined annual growth using scales collected from Bristol Bay (age- 0.3, 1965-2006; age-0.4 1966-2006) and Yukon River (age-0.3, 1965- 2006; age-0.4, 1967-2006) chum salmon (Fig. 1). We compared the growth data with climate indices, abundance of Asian chum salmon, and the odd- and even-year abundance pattern of pink salmon.

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

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

Blackbourn, D.J., and M.B. Tasaka. 1983. Adult scale growth and population dynamics of pink salmon from the Fraser River, British Columbia. International Pacific Salmon Fisheries Commission, New Westminster.

Standard measurements were taken from the scales of adult Fraser River pink salmon (*Oncorhychus gorbuscha*) samples every odd-numbered year from 1957 to 1981. When these measurements were compared with other population parameters, possible density-dependent scale growth was evident for various period of the life history. However, fry-to-adult survival has not been density-dependent in this stock. Scale measurement data may aid in the assessment of theories of Fraser River pink population dynamics; in the in-season prediction of adult abundance; and in the analysis of inter-stock and inter-species interactions.

Blackbourn, D.J., and M.B. Tasaka. 1990. Marine scale growth in Fraser river pink salmon: a comparison with sockeye salmon marine growth and other biological parameters. Pages 58-63 *in* Knutsen, P.A., editor. Proceedings of the 14th Northeast Pacific Pink and Chum Workshop. Feb. 22-24, 1989. Washington State Department of Fisheries, Olympia.

http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/search-recherche/display-afficher/133023

Brodeur, R.D., K.W. Myers, and J.H. Helle. 2003. Research conducted by the United States on the early ocean life history of Pacific salmon. North Pacific Anadromous Fish Commission Bulletin No. 3: 89–131.

Research on juvenile Pacific salmon in coastal U.S. waters began almost 50 years ago in Southeast Alaska, and has continued somewhat sporadically since then. The National Marine Fisheries Service (NMFS), through its various laboratories in Alaska and along the West Coast of the United States, has done much of the research on the early life history of many Pacific salmon stocks in all habitats of U.S. waters, including their period of residence in coastal and oceanic waters. In addition, several of the leading universities in this region (University of Washington, Oregon State University, University of Alaska) have contributed greatly to our knowledge of salmon in their early ocean residency. Much of the early research was done using fine-mesh purse seines, but recently surface fine-mesh trawl nets and gill nets have been used more widely. A large number of programs are actively sampling in coastal waters at the present time, and the geographic and temporal coverage is the most complete it has ever been. In this paper, we provide a brief overview of many of the studies that have been done, synthesize their major findings, and discuss some of the areas where we believe future efforts should be concentrated.

Bumgarner, J.D. 1993. Long-term trends in the growth of sockeye salmon (*Oncorhychus nerka*) from the Chignik Lakes, Alaska. Master's thesis. University of Washington.

Sockeye scale collections from the Chignik Lakes were analyzed for the periods 1952-1992 for age 1.3 sockeye, and 1954-1992 for age 2.3 sockeye. Annual growth zones on the scales were measured using the Optical Pattern Recognition System (OPRS). Positive relationships between scale radius and body length were found in both juvenile and adult scales. Growth trends between the two age groups were similar. Noticeable increases in scale growth over time were observed for freshwater residence, and in first and second year of ocean residence. Noticeable decreases in scale growth were observed in the last few months at sea before returning to spawn. No trends in scale growth were observed in the plus growth, third year of ocean residence, or the second year of freshwater residence in the 2.3 age group. Changes in the ocean and freshwater age compositions were found in both age groups. First and second year marine growth were positively correlated with Chignik run size. Second year marine growth was positively correlated with numbers of sockeye (based on adult returns) that returned to Central Alaska and Bristol Bay. Final spring growth was negatively correlated with numbers of sockeye, indicating density-dependent growth. No density-dependent relationships were observed for freshwater growth in either of the two lakes. Growth trends recorded on the scales may be useful in predicting long-term changes in abundance or environmental parameters.

Farley, E.V., Jr., J.M. Murphy, M.D. Adkison, L.B. Eisner, J.H. Helle, J.H. Moss, and J.L. Nielsen. 2005. Critical-size, critical-period hypothesis: an example of the relationship between early marine growth of juvenile Bristol Bay sockeye salmon, subsequent marine survival, and ocean conditions. North Pacific Anadromous Fish Commission Technical Report No. 6.

Bristol Bay sockeye salmon (*Oncorhynchus nerka*) from the eastern Bering Sea were used to test the critical size, critical-period hypothesis (Beamish and Mahnken 2001; Beamish et al. 2004). We examined a time series (42 years) of survival (brood year return per spawner from the Kvichak and Egegik river systems in southwest Alaska) and early marine growth (mean circuli spacing for the first marine year) from preferred scales (Clutter and Whitesel 1956) collected from returning adult salmon to these river systems. Four major age classes of sockeye salmon return to Bristol Bay, including 1.2, 1.3, 2.2, and 2.3, where the numbers to the left and right of the decimal point indicate the number of years spent in freshwater lakes and the number of years in the ocean, respectively. The data were lagged to reflect growth during the first year at sea (1958–2000) for freshwater age 1.0 and 2.0 sockeye salmon. Early marine growth was compared with survival of adult sockeye salmon using regression analysis and was found not to be significantly related to survival of Bristol Bay sockeye salmon. We also compared early marine growth between river systems for each freshwater age class and between freshwater age classes. Average circuli spacing between Egegik and Kvichak age 1.0 and 2.0 salmon was relatively uniform as was average circuli spacing between age 1.0 and 2.0 fish. A lack of relationship between adult sockeye salmon survival and early marine growth as observed from scales of surviving adult sockeye salmon may indicate a threshold relationship between early marine growth and survival, implying that those fish failing to achieve a sufficient size undergo higher mortality rates (Crozier and Kennedy 1999). Moreover, the similarity in early marine growth between river systems and freshwater age classes is an indication that the early marine growth threshold is correlated among geographically well-separated river systems and between freshwater age classes.

The threshold size of sockeye salmon was compared to the size of juvenile Bristol Bay sockeye salmon collected during eastern Bering Sea research cruises in August–October of 2000–2004. The results indicate that juvenile sockeye salmon were significantly smaller during 2000 and 2001 and not significantly different during 2002–2004 than the threshold size. We speculate that the larger size of juvenile Bristol Bay sockeye salmon during 2002–2004 is related to higher early marine growth rates that may be due to improved or changing ocean conditions along the eastern Bering Sea shelf beginning in 2002. These results indicate that growth of juvenile Pacific salmon may be an excellent indicator of ecosystem change.

Farley, E.V., Jr., E.V. , J.M. Murphy, M.D. Adkison, L.B. Eisner, J.H. Helle, J.H. Moss, and J.L. Nielsen. 2007. Early marine growth in relation to marine-stage survival rates for Alaska sockeye salmon (*Oncorhynchus nerka*). Fisheries Bulletin 105: 121–130.

We tested the hypothesis that larger juvenile sockeye salmon (*Oncorhynchus nerka*) in Bristol Bay, Alaska, have higher marine stage survival rates than smaller juvenile salmon. We used scales from returning adults (33 years of data) and trawl samples of juveniles (*n*= 3572) collected along the eastern Bering Sea shelf during August through September 2000−02. The size of juvenile sockeye salmon mirrored indices of their marine-stage survival rate (e.g., smaller fish had lower indices of marine-stage survival rate). However, there was no relationship between the size of sockeye salmon after their first year at sea, as estimated from archived scales, and brood-year survival size was relatively uniform over the time series, possibly indicating size-selective mortality on smaller individuals during their marine residence. Variation in size, relative abundance, and marine-stage survival rate of juvenile sockeye salmon is likely related to ocean conditions affecting their early marine migratory pathways along the eastern Bering Sea shelf.

Fukuwaka, M., and K. Morita. 2008. Increase in maturation size after the closure of a high seas gillnet fishery on hatchery-reared chum salmon *Oncorhynchus keta.* Evolutionary Applications 1(2): 379-387. DOI: 10.1111/j.1752-4571.2008.00029.x

Gillnet fisheries are strongly size-selective and seem to produce changes in size at maturity for exploited fishes. After World War II, large-scale gillnet fisheries targeted Pacific salmon (*Oncorhynchus* spp.) in the high seas area of the North Pacific and the Bering Sea, but these fisheries were closed in 1993. To assess the effects of this high seas gillnet fishery (and its closing) on size at maturity, we examined long-term trends in size at 50% probability of maturing (L50) for chum salmon (*O. keta*) from three populations in Hokkaido, Japan. The L50 trends were statistically different among rivers, but showed similar temporal patterns with decreases in the 1970s and early 1980s and increases after the 1985 brood year. While fishery-induced evolution seemed largely responsible for this temporal change in L50 during the fishing period, natural selection and phenotypic plasticity induced by environmental changes could contribute to the increases in L50 after the relaxation of fishing pressure.

Hagen, P.T., D.S. Oxman, and B.A. Agler. 2001. Developing and deploying a high resolution imaging approach for scale analysis. North Pacific Anadromous Fish Commission Document 567. 11 p.

Collecting and analyzing salmon scales to obtain age information is a fundamental component of fishery management and monitoring programs. In Alaska, tens of thousands of salmon scales are routinely collected and examined each year and then archived. These collections can be extensive. For example, there has been over 45 years of uninterrupted sampling for some stocks. In addition to yielding age information, scale patterns can also be measured and used to discriminate among stocks, and to relate growth patterns to production and environmental trends. However, the methods used to extract measurements from scales are labor-intensive, rely on subjective determinations, and utilize technology that in many cases is obsolete and no longer available. As a result, measurements have been extracted from a relatively small number of scales, and the data obtained are generally not accessible for additional analysis and cannot be combined with other datasets for comparison.

Helle, J.H. 1980. Influence of marine environment on age and size at maturity, growth, and abundance of chum salmon, *Oncorhynchus keta* (Walbaum) from Olsen Creek, Prince William Sound, Alaska. PhD thesis, Oregon State University.

Chum salmon returned to Olsen Creek as predominately 3-, 4-, and 5-year fish; however, age composition varied from year to year. The mean age composition for the brood years 1956-72 for males was 15%, 66%, and 19% for 3-, 4-, and 5-year fish, respectively. Mean age composition for females of the same broods showed slightly higher percentages of older fish: 9%, 67%, and 23% for 3-, 4- and 5-year fish, respectively. Some 6-year chum salmon returned to Olsen Creek between 1968 and 1975; but, only in 1973 did the number of 6-year fish (3%) represent more than 1% of the returns. Population sizes tended to be larger during these years, and mean age increased as the number of fish in a brood increased. Intraseasonally, age of new chum salmon spawners at Olsen Creek decreased as the season progressed. Mean size of older spawners was greater than the mean size of younger spawners; but, the ranges in size of the three age groups overlap each other so size is not a good criterion for estimating size of chum salmon.

Measurement of circuli and distances on adult scales were used to estimate growth of chum salmon during the first two years of marine life. Both number of circuli and distances on scales of juvenile chum salmon after their first summer in Prince William Sound were shown to be related to length of the fish. Growth during the first season at sea was not related to age at maturity; however, amount of growth acquired during the second marine season was negatively related to age at maturity. Growth during the first summer at sea was related to sea surface temperatures and marine weather parameters in Prince William Sound and in the northern Gulf of Alaska. Location of chum salmon from Olsen Creek during their second year at sea is unknown.

Fluctuations in size (length) at maturity were most similar between fish from different broods returning during the same year than they were for fish that matured at different ages from the same broods. Length at maturity was related to marine weather factors during their last summer at sea in the northern Gulf of Alaska and Prince William Sound. Length at maturity was also related to mean summer sea surface temperature in Prince William Sound during the year of return.

Total survival of each brood was estimated from the ratio of number of progeny (returns) to number of parents (spawners). No direct relationships were found between survival and growth during the first or second season in the sea, sea surface temperatures, or upwelling indices along the coast. However, a highly significant relationship was found between the survival of progeny and mean length of the parents.

Helle, J.H., and M. Fukuwaka. 2009. Body size of maturing salmon in relation to sea surface temperatures in the eastern Bering Sea. North Pacific Anadromous Fish Commission Bulletin No. 5: 303–319.

During their last season at sea, some chum salmon from North America and Japan are known to forage in the southeast Bering Sea. Body size of mature chum salmon from North America and Japan was compared with sea surface temperatures in the winter, spring, and summer in the southeast Bering Sea during three time periods: pre-regime shift 1960–76, regime shift 1977–94, and post-regime shift 1995–2006. During the 1977–94 time period, mean correlation coefficients between body size and sea surface temperatures were positive and largest during the winter and spring. During the 1960–76 and 1995–2006 time periods, correlation coefficients were usually smaller and often negative. We conclude that chum salmon from many locations around the Pacific Rim were present in the eastern Bering Sea during the winter and spring of 1977–1994. We suggest that differences in oceanographic parameters and population density of salmon during the three time periods may influence migration pathways of salmon in the North Pacific Ocean and Bering Sea. Research on migration patterns of salmon in relation to these factors is necessary to elucidate these issues.

Isakov, A.G. 1998. Ocean growth of sockeye salmon from the Kvichak River, Bristol Bay based on scale analysis. Master's thesis. University of Alaska Fairbanks.

The primary task of this study was to reveal any changes in the marine growth of Kvichak sockeye salmon for the period from 1920 to 1997 using historical scale collections. I measured 0,414 legible scales of Kvichak sockeye salmon, out of 135,420 available. Examination of the first and second ocean annuli revealed an increase in average growth over time, while for the third annulus, a decrease in average growth occurred form the mid-1960s to 1997. Total ocean growth showed an increase starting from the mid-1960s. Visual and correlation analyses of scale growth showed there was similarity between sockeye of the same ocean age despite their freshwater history. Bristol Bay sockeye catch, Fraser River, sockeye run, and sea surface temperature explained very little variation In the scale growth data in a stepwise multivariate regression analysis.

Isakov, A.G., O.A. Mathisen, S.E. Ignell, and T.J. Quinn. 2000. Ocean growth of sockeye salmon from the Kvichak River, Bristol Bay based on scale analysis. North Pacific Anadromous Fish Commission. Bulletin No. 2: 233-245.

Growth measurements were taken from 9,414 legible scales of Kvichak sockeye salmon *(Oncorhynchus nerka),* yielding a long time series (1914-1997) of ocean growth data. Scale growth rates in the first, second, and third ocean years all declined prior to the late 1950s and early 1960s after which they began to steadily increase until 1970 when the three growth patterns diverged: first year growth continued to increase, but at a lower rate, second year growth showed no further increase, and third year growth began to steadily decrease. Scale growth of sockeye salmon with the same ocean history (but different broods) was highly correlated, illustrating the importance of the environment in affecting growth rates of sockeye salmon, not only in the early marine environment but later in their life history when the sockeye are more dispersed. The importance of sea surface temperature (SST), particularly during the growing season, was noted in many of the regression models. SST had its greatest influence (positive) on scale growth in the first ocean year where sockeye are migrating out of Bristol Bay and into the Aleutian Islands region.

Ishida, Y., S. Ito, M. Kaeriyama, S. McKinnel l, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (*Oncorhynchus keta)* in the North Pacific Ocean and possible causes. Canadian Journal of Fisheries and Aquatic Sciences 50: 298-295.

Changes in age composition and size of adult chum salmon (*Oncorhynchus keta*) from rivers in japan, Russia, and Canada were examined based on body weight and scale measurement data collected from 1953 to 1988. A significant increase in mean age was found in Japanese and Russian stocks after 1970 when the number of Japanese chum salmon began to increase exponentially, but not in the Canadian stock. Significant decreases in mean body weight, mean scale radius, and mean width of the third-year zones of age 4 chum salmon also occurred in Japanese and Russian stocks after 1970. Based on the Japanese salmon research vessel data from 1972 to 1988, significant negative relationships between catch-per-unit-effort and mean body weight of chum salmon were observed in summer in the central North Pacific Ocean where the distribution of Japanese and Russian stocks overlaps. These results suggest that density dependence is one of the possible causes for the recent changes in age and sine of chum salmon in the North Pacific Ocean.

Ishida. Y, S. Ito., and K. Murai. 1995. Density dependent growth of pink salmon *(Oncorhynchus gorbuscha)* in the Bering Sea and Western North Pacific. North Pacific Anadromous Fish Commission Document 140. 17p.

Growth variations of pink salmon and the factors influencing them were examined using data collected by Japanese salmon research vessels in the Bering Sea and Western North Pacific during 1972-1995. Catch-per-unit-effort (CPUE) of pink salmon changed between odd and even year stocks in the Bering Sea and western North Pacific. Coefficients of variation (C.V.) in the second year ocean growth (8.1-11.8%) were larger than those for coastal growth (3.2-4.8%) or the first year ocean growth (4.0-5.0%) for all stocks in both areas. Analysis of relationships between fork length and scale measurements demonstrated that pink salmon growth variations occur in the first and second ocean life, but not in the coastal period. The first and second year ocean growth was negatively related to CPUE, especially strong for the second year ocean growth for odd year stocks. CPUEs of other salmon species partly showed a significant negative relationship with pink salmon growth, but sea surface temperature and zooplankton biomass did not show such a relationship. These results suggest that density of pink salmon is one of the major factors influencing growth variations in pink salmon, especially in the second year ocean life.

Ishida, Y., T. Azumaya, M. Fukuwaka, and T. Nagasawa. 2005. Density dependent growth of pink salmon *Oncorhynchus gorbuscha* in the Bering Sea. North Pacific Anadromous Fish Commission Technical Report No. 6.

Growth variations of pink salmon and the factors influencing them were examined using data collected by Japanese salmon research vessels in the Bering Sea during 1974–1995. Catch-per-unit-effort (CPUE) of pink salmon changed differently for odd and even year stocks in the Bering Sea (Fig. 1). CPUE in odd years increased after 1989, but those in even years remained at a low level. Mean fork lengths of pink salmon in odd years were larger than those in even years from 1974 to 1987, but mean fork lengths in odd years decreased to the size of the fish in even years during 1989 and 1993 (Fig. 2). Scale measurement data indicated that coefficients of variation in the second year ocean growth (8.1–8.8%) were larger than those for coastal growth (3.6–4.8%) and the first year ocean growth (4.0–4.6%) for both stocks. CPUE of pink salmon showed a negative relationship with the coastal and second year ocean growth (Fig. 3, 4). Pink salmon growth partly showed a significant negative relationship with the CPUE of other salmon species, but was not significantly correlated to sea surface temperature and zooplankton biomass. These results suggest that the density of pink salmon is one of the factors influencing growth variations of pink salmon, especially in the coastal and second year ocean life.

Kaeriyama, M. 1996. Changes in body size and age at maturity of a chum salmon, *Oncorhynchus keta,* population released from Hokkaido in Japan. North Pacific Anadromous Fish Commission Document 208. 9 p.

The body size of Hokkaido chum salmon *(Oncorhynchus keta)* at maturity showed a significant decreasing trend from 1979 to 1984 and has leveled off since 1985. A significant negative relationship between the population size and the fork length was observed ($r < -0.8$, $P < 0.001$). In Hokkaido chum salmon population, an average age of a brood-year population at maturity has gradually increased from 3.7 years in 1972 to over 4 years since 1980 brood year. A significant positive relationship between population size and average age of a brood-year population at maturity was observed in the Hokkaido chum salmon population ($r = 0.909$, $P < 0.001$). The result of growth analysis backcalculated from scales showed that the growth reduction occurs after the second year, especially in the third year of oceanic life in Japanese chum salmon population. These synchronous phenomena of both the decrease in body size and the increase in age at maturity would be caused by the negative population-density effect led by the intraspecific competition because of a rise of survival rate and favorable oceanic conditions for Hokkaido chum salmon population. In salmonid enhancement production, therefore, it is extremely important to control a optimum of population system by clarifying the mechanism of population regulation such as density-dependent effect, and by monitoring biological characters of population such as migration pattern, body size, age composition, fecundity, and egg size.

Kaeriyama, M. 1998. Dynamics of chum salmon, *Oncorhynchus keta,* populations released from Hokkaido, Japan. North Pacific Anadromous Fish Commission Bulletin No. 1: 90-102.

Body size of Hokkaido chum salmon *(Oncorhynchus keta)* at maturity showed a significant decreasing trend from the late 1970s to the early 1980s and has remained relatively constant since the late 1980s. A significant negative relationship between population abundance and fork length was observed. In Hokkaido chum salmon population, average age at maturity in cohorts increased from 3.7 years in the 1972 cohort to over 4 years in cohorts after 1980. A significant positive relationship between population abundance and average age at maturity of cohorts was observed in the Hokkaido chum salmon population. Growth analysis back-calculated from scales showed that a growth reduction occurred after the second year, especially in the third year of oceanic life of Hokkaido chum salmon. The synchronous decreasing body size and increasing age at maturity of Hokkaido chum salmon occurred in face of rising marine survival rates and ocean conditions favorable for growth. This suggested that reduced growth and increasing age at maturity was due to density dependent intraspecific competition and high abundance of chum salmon on the North Pacific Ocean.

Kaeriyama, M., A. Yatsu, M. Noto, and S. Saitoh. 2007. Spatial and temporal changes in the growth patterns and survival of Hokkaido chum salmon populations in 1970–2001. North Pacific Anadromous Fish Commission Bulletin No. 4: 251–256.

The survival strategies of Pacific salmon (*Oncorhynchus* spp.) offer a useful framework for quantifying both inter- and intra-specific interactions and also climate-related risk factors around the North Pacific Rim. The annual growth patterns of adult chum salmon (*O. keta*) returning to the Ishikari River were estimated with the back-calculation method based on scale analysis. Their growth increased during the first year in the Okhotsk Sea in the 1990s. The growth in the first year was negatively correlated with the sea ice concentration in winter, and positively correlated with the sea surface temperature (SST) during summer and fall in the Okhotsk Sea, despite the lack of a relation between SST and zooplankton biomass. The positive correlation between the growth in the Okhotsk Sea and survival was also observed in Hokkaido chum salmon. In the Bering Sea, the relationship between residual carrying capacity and growth patterns of Hokkaido chum salmon indicated that the growth reduction is affected by changes in population density-dependence. Results of stepwise multiple regression analysis of the survival rate of Hokkaido chum salmon population on body size at release from the hatchery and growth in the Okhotsk Sea showed that chum salmon have periods of critical mortality in the early marine period and the first winter at sea.

Kaeriyama, M. 2008. Ecosystem-based sustainable conservation and management of Pacific Salmon. Pages 371-380 *in* K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, Jr. and M. J. Kaiser, editors. Fisheries for Global Welfare and Environment, 5th World Fisheries Congress.

Pacific salmon (*Oncorhynchus* spp.) play an important role as a keystone species in North Pacific ecosystems, where their populations are influenced by natural factors and human impacts. Carrying capacity for Pacific salmon is related to the long-term climate change, and also to density-dependent effects. For example, the residual carrying capacity of chum salmon (*O. keta*) was positively correlated with body size of adult salmon but negatively correlated with age at maturity. The abundance of wild chum salmon in the North Pacific in the 1990s declined to about 50% of what it was in the 1930s, despite significant increases in introduction of hatchery-produced salmon. This indicates that fisheries management has limitations at the population level, and that biological interactions between wild and hatchery-produced populations of Pacific salmon should be considered. Global warming has affected growth and survival of Asian chum salmon since the 1990s, and has had a positive effect on Hokkaido populations but negative effects for more southern populations in Iwate Prefecture and in Korea. Predictions about global warming effects on chum salmon suggest that their area of distribution will change resulting in a displacement to the northern area such as the Arctic Ocean, and the loss of migration routes such as the Okhotsk Sea. This paper presents a framework for ecosystem-based sustainable conservation and management of Pacific salmon, which takes account of climate change and interactions between wild and hatchery fish.

Kaeriyama, M., H. Seo, H. Kudo, and M. Nagata. 2012. Perspectives on wild and hatchery salmon interactions at sea, potential climate effects on Japanese chum salmon, and the need for sustainable salmon fishery management reform in Japan. Environmental Biology of Fishes 94: 165–177. DOI: 10.1007/s10641-011-9930-z

Pacific salmon (*Oncorhynchus* spp.) play an important role as a keystone species and provider of ecosystem services in the North Pacific ecosystem. We review our studies on recent production trends, marine carrying capacity, climate effects and biological interactions between wild and hatchery origin populations of Pacific salmon in the open sea, with a particular focus on Japanese chum salmon (*O. keta*). Salmon catch data indicates that the abundance of Pacific salmon increased since the 1976/77 ocean regime shift. Chum and pink salmon (*O. gorbuscha*) maintained high abundances with a sharp increase in hatchery-released populations since the late 1980s. Since the 1990s, the biomass contribution of hatchery returns to the total catch amounts to 50% for chum salmon, more than 10% for pink salmon, and less than 10% for sockeye salmon (*O. nerka*). We show evidence of density-dependence of growth and survival at sea and how it might vary across spatial scales, and we provide some new information on foraging plasticity that may offer new insight into competitive interactions. The marine carrying capacity of these three species is synchronized with long term patterns in climate change. At the present time, global warming has positively affected growth and survival of Hokkaido populations of chum salmon. In the future, however, global warming may decrease the marine carrying capacity and the area of suitable habitat for chum salmon in the North Pacific Ocean. We outline future challenges for salmon sustainable conservation management in Japan, and recommend fishery management reform to sustain the hatchery supported salmon fishery while conserving natural spawning populations.

Kaeriyama , M., H. Seo, and Y. Qin. 2014. Effect of global warming on the life history and population dynamics of Japanese chum salmon. Fisheries Science 80: 251–260. DOI: 10.1007/s12562-013-0693-7

We have reviewed the effects of long-term climatic/oceanic conditions on the growth, survival, production dynamics, and distribution of Hokkaido chum salmon *Oncorhynchus keta* in Japan during the period 1945–2005 using path analysis, back-calculation, and scale analyses, and applied a prediction method based on the SRES-A1B scenario of the intergovernmental panel on climate change. The populations of Hokkaido chum salmon were found to have had high growth rates at age 1 year since the late 1980s. Path analysis indicated that the growth at age 1 year in the Okhotsk Sea was directly affected by warm sea surface temperature associated with global warming, with the increased growth at age 1 year resulting in higher rates of survival and large population sizes. Predictions on the global warming effects on the chum salmon were (1) decreased carrying capacity and distribution area, (2) occurrence of a strong density-dependent effect, and (3) loss of migration route to the Sea of Okhotsk, especially for Hokkaido chum salmon. We have also outlined the future challenges of establishing a sustainable conservation management scheme for salmon that include adaptive management and precautionary principles, as well as conservation of natural spawning populations and recovery of natural river ecosystems in Japan despite the warming climate.

Kaev, A.M. 2000. Recent reduction in chum salmon (*Oncorhynchus keta*) growth and its consequences for reproduction. North Pacific Anadromous Fish Commission Bulletin No. 2: 247-253.

A statistically significant decrease in body length and fecundity of the Iturup Island chum salmon *(Oncorhynchus keta)* after 1985 coincided with an increase in mean age and decline in adult returns. These changes were accompanied by an increase in ocean mortality, but conditions of fry growth in the coastal zone appeared to be the determining factor in changes in overall chum salmon survival in the sea. The rate of sexual maturation was positively related to age at maturity of parents. Increased age of chum salmon spawners, associated with low spawning numbers, partially compensated for decreasing fecundity. This is an example of reproductive homeostasis.

Karpenko, V.I. 1996. Early marine period life of the Pacific salmon. North Pacific Anadromous Fish Commission Document 236. 7 p.

[Summary of a book that is written in Russian; from the summary:] Pink salmon entering the sea are small, and most of the juveniles have a residual yolk sac of 20% of body weight in the rivers and of 12 % in the coastal waters. Such fishes have been adopted rather worth to the sea habitats being prey to a great extent. Maximum growth rate in pink salmon juveniles is marked at the beginning of August when assimilating feeding resources off-shore of the bays. During this period daily linear and mass growth take 2-3 mm and 6-8 % accordingly. Growth variability and circuli dynamics in different reproductive regions have been examined.

Martinson, E.C. 2013. Early marine growth as an indicator for chum salmon production. North Pacific Anadromous Fish Commission Technical Report No. 9: 150-152.

Faster early marine growth rates have been linked to higher marine survival rates in salmon (Mortensen et al. 2000). Ecological interactions with pink salmon that influence chum salmon growth may influence the production of chum salmon. For example, density-dependent reductions in the growth of juvenile pink salmon, due to higher adult pink salmon abundances, were shown to reduce the marine survival of pink salmon (Blackbourn and Tasaka 1990; Beamish 2012). Adult and juvenile pink salmon also consume similar prey items as juvenile chum salmon, such as euphausiids, pteropods, amphipods, and other zooplankton. Therefore, the relationship between early marine growth and returns of chum salmon may differ during years of higher and lower pink salmon abundances. The possible mechanism is the density-dependent effects of adult and juvenile pink salmon on the feeding and growth of juvenile chum salmon. The main goal of this project was to develop a time series for forecasting chum salmon returns. The specific objectives were to (1) evaluate the early marine growth of juvenile chum as an indicator for the returns of chum salmon three years later and (2) evaluate the influence of juvenile and adult pink abundances on the early marine growth and returns of chum salmon.

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

We examined whether the relationship between climate and salmon production was linked through the effect of climate on the growth of sockeye salmon (*Oncorhynchus nerka*) at sea. Smolt length and juvenile, immature, and maturing growth rates were estimated from increments on scales of adult sockeye salmon that returned to the Karluk River and Lake system on Kodiak Island, Alaska, over 77 years, 1924 –2000. Survival was higher during the warm climate regimes and lower during the cool regime. Growth was not correlated with survival, as estimated from the residuals of the Ricker stock-recruitment model. Juvenile growth was correlated with an atmospheric forcing index and immature growth was correlated with the amount of coastal precipitation, but the magnitude of winter and spring coastal downwelling in the Gulf of Alaska and the Pacific Northwest atmospheric patterns that influence the directional bifurcation of the Pacific Current were not related to the growth of Karluk sockeye salmon. However, indices of sea surface temperature, coastal precipitation, and atmospheric circulation in the eastern North Pacific were correlated with the survival of Karluk sockeye salmon. Winter and spring precipitation and atmospheric circulation are possible processes linking survival to climate variation in Karluk sockeye salmon.

Martinson, E.C., M.M. Masuda, and J.H. Helle. 2000. Back-calculated fish lengths, percentages of scale growth, and scale measurements for two scale measurement methods used in studies of salmon growth. North Pacific Anadromous Fish Commission Bulletin No. 2: 331-336.

Scale measurements, percentages of annual scale growth, and back-calculated fish lengths were examined for the INPFC method (75 0 anterior reference line) and Traditional method (anterior-posterior reference line) on scales of chum salmon *(Oncorhynchus keta)* for three ages, two stocks, and two brood years. Mean measurements of annual increments of scale growth were greater for the INPFC method than the Traditional method. Differences in percentages of scale growth and back-calculated fish lengths for the two methods were tested using the Hotelling one sample T^2 test. Percentages of annual scale growth differed significantly ($p \leq 0.003$) between the two methods for seven of nine tests. Mean percentage of annual scale growth was greater in the first year for the Traditional method and in the final year for the INPFC method; intermediate years were similar. Back-calculated fish lengths computed by the Fraser-Lee method differed significantly between the INPFC and Traditional method ($p \leq 0.004$) for seven of nine tests. Although differences in back-calculated lengths of the two methods were statistically significant, the biological differences were small (-1 cm).

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

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

Martinson, E.C., J.H. Helle, D.L. Scarnecchia, and H.H. Stokes. 2009. Alaska sockeye salmon scale patterns as indicators of climatic and oceanic shifts in the North Pacific Ocean, 1922–2000. North Pacific Anadromous Fish Commission Bulletin No. 5: 177-182.

Climate regime shifts can alter the community structure of marine species in the North Pacific Ocean. In this study, we use a regime shift detection algorithm to determine whether regime shifts are recorded as shifts in the mean fish length indices at the smolt, juvenile, immature, and mature life stages based on measurements of increments on scales of adult age-2.2 sockeye salmon (*Oncorhynchus nerka*) that returned to the Karluk River, Kodiak Island over a 77-year time period (1924–2000). Fish length was expected to increase with cool-to-warm climate shifts (1926, 1958, 1977, and 1998) and decrease with warm-to-cool climate shifts (1943, 1947, 1971, and 1989). Regime shifts were not consistently observed as statistical shifts in the time series of fish length indices. At contemporaneous lags, shifts in the mean temperature of the North Pacific were detected as shifts in length in 1958 (+), but not in 1926 (+), 1943 (-), 1971 (-), and 1977 (+). Shifts in the atmospheric circulation and sea level pressure of the North Pacific were detected as negative shifts in length in 1989 (-), but not in 1926 (+), 1947 (-), 1977 (+), 1998 (+). Shifts in length indices were associated with the 1957-58 El Niño, the warm-to-cool shift in 1989, and preceded the 1976–77 climate shift in the North Pacific Ocean. Fish length indices from salmon scales may be useful predictors for major and more recent shifts in the status of the ecosystem of the North Pacific Ocean.

McKinell, S.M. 1995. Age-specific effects of sockeye abundance on adult body size of selected British Columbia sockeye stocks. Canadian Journal of Fisheries and Aquatic Sciences 52: 1058-1063.

Annual mean body lengths of adult sockeye salmon (*Oncorhynchus nerka*) covary systematically from year to year in major northern and central British Columbia stocks (Nass River, Skeena River, and Rivers Inlet). These positive correlations are greatest between sexes within rivers, followed by age-classes among rivers. A common factor or factors affecting sockeye length in the North Pacific Ocean is suggested. The mean length of age 1.3 sockeye salmon but not age 1.2 sockeye caught annually in these B.C. fisheries was negatively correlated with the magnitude of Bristol Bay (western Alaska) sockeye catches. During the spring of maturation, age 1.3 sockeye from these B.C. stocks were further from their natal streams, and likely subject to more intense competition with Bristol Bay sockeye than age 1.2 sockeye. The pattern of annual marine growth measured from Skeena River sockeye scales collected during the 1960s provides additional evidence that the length of age 1.3 sockeye was related to Bristol Bay sockeye abundance in the year of maturation. No such correlation was evident in scales collected from age 1.2 sockeye. These results suggest that sockeye populations have more systematic distributions in the North Pacific Ocean than has been previously reported.

McKinnell, S.M., C.C. Wood, D.T. Rutherford, K.D. Hyatt, and D.W. Welch. 2001. The demise of Owikeno Lake sockeye salmon. North American Journal of Fisheries Management 21: 774–791.

A persistent period of low abundance in what was once the second largest fishery for sockeye salmon *Oncorhynchus nerka* in British Columbia has kept the Rivers Inlet fishery closed since 1996. Initial speculation about the cause of the decline focused on factors such as reduced egg-to-fry survival, declining quantity and quality of spawning habitat, and reduced fry-to- smolt survival in Owikeno Lake (the only nursery lake in Rivers Inlet). We developed an index of juvenile sockeye salmon abundance by combining direct estimates of abundance from trawl surveys with indirect estimates of abundance inferred from density-dependent growth of juvenile sockeye salmon. Juvenile growth data were available as either direct samples of presmolt weight or as measurements of freshwater growth from the scales of returning adults. Collectively, these data do not indicate a long-term decline in juvenile sockeye salmon abundance since the 1950s. Throughout the 1970s and 1980s and even more recently (1991 and 1994 brood years), the juvenile abundance index exceeded the long-term mean. If freshwater abundance was either untrended or increasing, the most likely cause of the population decline would have been lower survival after the fry stage, which would have been noticeable in the 1970s and especially from 1992 to 1998. Poor marine survival is the most parsimonious explanation for the declining fry-to-adult survival in Owikeno Lake, particularly in light of coincident declines in sockeye salmon returns per spawner at Long Lake (a nearby pristine watershed) and declines in adult sockeye salmon abundance in other populations to the north of Rivers Inlet.

Morita, S. H., Morita, K., and Sakano, H. 2001. Growth of chum salmon (*Oncorhynchus keta*) correlated with sea-surface salinity in the North Pacific. ICES Journal of Marine Science 58: 1335–1339.

The average adult size-at-return of North Pacific salmon (*Oncorhynchus* spp.) has decreased since the 1970s and several hypotheses regarding the cause of this decrease have been proposed. These have included fishing pressure, change of sea-surface temperature (SST) and density-dependence. This paper re-examines recent trends in the catch per unit effort (cpue) of chum salmon (*Oncorhynchus keta*), SST, sea surface salinity (SSS) and the Aleutian Low Pressure Index (ALPI), and compares them with trends in growth to determine if any of these factors related to the growth of chum salmon in the Sub-Arctic

Domain of the Western North Pacific. From 1979 to 1998 chum salmon cpue increased, but fork length and back-calculated year-specific growth-increment size decreased significantly. SST showed no consistent pattern but SSS decreased significantly over time. Of total salmon cpue, chum salmon cpue, SST and SSS, only SSS was significantly correlated with growth-increment size; this relationship was positive. Residuals of the year-SSS relationship were also correlated with residuals of the year-growth increment-size relationship, indicating that SSS was consistently linked to growth-increment size.

Myers, K. W. 1994. Scale growth and life history patterns of pink salmon in periods of low and high abundance North Pacific Anadromous Fish Commission Document 64. 16 pp.

A comparison of the scale patterns of maturing pink salmon caught in the North Pacific Ocean (just south of the central Aleutian Islands) in the 1970s showed statistically significant differences in both early ocean growth and winter growth between periods of low (1970-75) and high (1977-1978) abundance of Eastern Kamchatkan (odd-year) and western Alaskan (even-year) stocks. Fork lengths offish in the low and high abundance groups were not significantly different. Statistically significant differences in scale growth and life history patterns suggest that western Alaskan pink salmon in the high abundance group spent more time rearing in coastal areas during their first summer at sea. The scales of both eastern Kamchatkan and western Alaskan stocks had significantly better winter growth (more circuli and larger size) in the high abundance group than in the low abundance group. These results may reflect the direct response of pink salmon to a climate change event that occurred in the winter of 1976-77. Pink salmon are the most abundant species of Pacific salmon in the North Pacific Ocean, and abrupt changes in their growth and life history patterns may have significant short- and long-term effects on North Pacific ecosystems. Better evidence, however, is needed to determine if the observed differences in scale growth are due to a single, major climatic disturbance or just due to year-to-year variation in the environment. In future analyses, the scale growth and life history patterns of pink salmon and other species of Pacific salmon sampled from years within climatic periods (and identified in the analysis to year of observation) will be measured to evaluate such a climatic effect.

Myers. K.W., R.V. Walker. N.D. Davis, W.S. Patton, K.Y. Aydin. E.K. Pikitch, and R.L. Burgner. 1995. Migrations, abundance and origins of salmonids in offshore waters of the North Pacific. North Pacific Anadromous Fish Commission Document 152. 84 p.

This report summarizes research on high seas salmonids conducted in 1995 by the Fisheries Research Institute (FRI), University of Washington, under contract to the U.S. National Marine Fisheries Service. The work is largely in response to U.S. research and enforcement commitments to the North Pacific Anadromous Fish Commission (NPAFC). The research was in three major areas: (1) international cooperative high seas sampling and tagging, (2) ocean ecology, stock assessment, and carrying capacity research, and (3) scale pattern analyses to determine age, growth, and stock origins of salmon. Sampling and tagging were carried out onboard two Japanese research vessels in June and July in the central North Pacific Ocean, Bering Sea, and Gulf of Alaska. Salmonids were tagged, marked with oxytetracycline for experimental age and growth validation research, and released. Ten U.S. high seas salmon tags were returned between 1 September 1994 and 31 August 1995. The results from pink salmon tagging in the central Gulf of Alaska (10% tag recovery rate) indicate extensive mixing of South Peninsula, Kodiak, Prince William Sound, and Southeast Alaska pink salmon during their last month at sea. Salmonids were examined for missing fins, and coded-wire tags were recovered from three fish (all Washington origin steelhead). Research gillnet catch, age, weight, and length data, and stomach contents data from cooperative Japan-U. S. cruises were summarized by oceanographic region. Cooperative Japan-U.S. research on salmonid food habits in the North Pacific indicates that there is a limitation in the capacity of crustaceous zooplankton to provide energy for salmon production. Bioenergetic modeling of pink salmon using high seas field data showed that at a constant ration salmonids have much better growth in the cooler water temperatures of the Bering Sea than in the warmer waters of the Transition Domain of the central North Pacific. Prey energy density is being measured from new field collections of salmonid prey organisms. Graduate student research begun in 1995 involves the development of a generalized model of system organization and carrying capacity. Scales, otoliths, and biological data from the chum salmon bycatch in the 1994 B-season pollock fishery in the Bering Sea were analyzed. A scale pattern study of the stocks of chum salmon in the B-season bycatch, initiated in fall of 1994 was continued. The results will be used in a Master's thesis to estimate fleet-wide bycatch of chum salmon by region-of-origin. Chum scale measurement techniques were standardized with Fisheries Agency of Japan (FA) researchers, who are collecting the Asian chum scale data for this analysis and cooperative studies of chum salmon growth. The utility of the historical FA chum baseline in stock identification was investigated. Measurement of scales for the 1994 North American chum salmon baseline was completed, and preliminary analysis indicates three major clusters of North American stocks. A time series of scale measurement data from salmonids caught on the high seas is being collected to investigate trends in salmonid abundance and growth by major ocean production region. FRI is cooperating with Japanese researchers in a study of the relationships between fish size, scale growth, and rates of protein synthesis (determined by RNA-DNA analysis) in chum, pink, and sockeye salmon caught on the high seas. The longterm (1907-1991) Bristol Bay (Nushagak commercial fishery) sockeye salmon scale growth time series was updated with 1992-1994 data. Paired otolith and scale samples are being collected from salmonids during international cooperative high seas research cruises for the development of indices of ocean growth.

Oka, G., C.A. 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 No. 8. 112 p.

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 analysing scales from fish captured on the spawning grounds at ages three (3_1) and four (4_1). 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. North Pacific Anadromous Fish Commission Document 1429. 13 p.

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.

Rogers, D.E., and G.T. Ruggerone. 1993. Factors affecting marine growth of Bristol Bay sockeye salmon. Fisheries Research 19: 89-103.

[from abstract] Growth increments of Nushagak Bay sockeye salmon in their first and second years at sea (from scale measurements) were correlated with temperatures but not with the abundances since 1975.

Ruggerone, G.T., J. Nielsen, e. Farley, S. Ignell, P. Hagen, B. Agler, D. Rogers, and J. Bumgarner. 2002. Long-term trends in annual Bristol Bay sockeye salmon scale growth at sea in relation to

sockeye abundance and environmental trends, 1955–2000. North Pacific Anadromous Fish Commission Technical Report No. 4.

We measured annual marine scale growth of Bristol Bay and central Alaska sockeye salmon, 1955 to 2000, in order to test whether annual salmon growth at sea was positively or negatively associated with the large increase in salmon abundance that began in the mid-1970s (see Hagen et al. 2001; Davis et al. 1990 for scale methods). Bristol Bay and central Alaska sockeye salmon runs more than doubled after the mid-1970s, a trend that was common to many stocks.

Ruggerone, G.T., M. Zimmerman, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fisheries Oceanography 12(3): 209–219.

The importance of interspecific competition as a mechanism regulating population abundance in offshore marine communities is largely unknown. We evaluated offshore competition between Asian pink salmon and Bristol Bay (Alaska) sockeye salmon, which intermingle in the North Pacific Ocean and Bering Sea, using the unique biennial abundance cycle of Asian pink salmon from 1955 to 2000. Sockeye salmon growth during the second and third growing seasons at sea, as determined by scale measurements, declined significantly in odd-numbered years, corresponding to years when Asian pink salmon are most abundant. Bristol Bay sockeye salmon do not interact with Asian pink salmon during their first summer and fall seasons and no difference in first year scale growth was detected. The interaction with odd-year pink salmon led to significantly smaller size at age of adult sockeye salmon, especially among younger female salmon. Examination of sockeye salmon smolt to adult survival rates during 1977–97 indicated that smolts entering the ocean during even-numbered years and interacting with abundant odd-year pink salmon during the following year experienced 26% (age-2 smolt) to 45% (age-1 smolt) lower survival compared with smolts migrating during odd-numbered years. Adult sockeye salmon returning to Bristol Bay from even year smolt migrations were 22% less abundant (reduced by 5.9 million fish per year) compared with returns from odd-year migrations. The greatest reduction in adult returns occurred among adults spending 2 compared with 3 years at sea. Our new evidence for interspecific competition highlights the need for multispecies, international management of salmon production, including salmon released from hatcheries into the ocean.

Ruggerone, G.T. & J. L. Nielsen. 2004. Evidence for competitive dominance of Pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Reviews in Fish Biology and Fisheries 14: 371–390. DOI: 10.1007/s11160-004-6927-0

Relatively little is known about fish species interactions in offshore areas of the world's oceans because adequate experimental controls are typically unavailable in such vast areas. However, pink salmon (*Oncorhynchus gorbuscha*) are numerous and have an alternating-year pattern of abundance that provides a natural experimental control to test for interspecific competition in the North Pacific Ocean and Bering Sea. Since a number of studies have recently examined pink salmon interactions with other salmon, we reviewed them in an effort to describe patterns of interaction over broad regions of the ocean. Research consistently indicated that pink salmon significantly altered prey abundance of other salmon species (e.g., zooplankton, squid), leading to altered diet, reduced total prey consumption and growth, delayed maturation, and reduced survival, depending on species and locale. Reduced survival was observed in chum salmon (*O. keta*) and Chinook salmon (*O. tshawytscha*) originating from Puget Sound and in Bristol Bay sockeye salmon (*O. nerka*). Growth of pink salmon was not measurably affected by other salmon species, but their growth was sometimes inversely related to their own abundance. In all marine studies, pink salmon affected other species through exploitation of prey resources rather than interference. Interspecific competition was observed in nearshore and offshore waters of the North Pacific Ocean and Bering Sea, and one study documented competition between species originating from different continents. Climate change had variable effects on competition. In the North Pacific Ocean, competition was observed before and after the ocean regime shift in 1977 that significantly altered abundances of many marine species, whereas a study in the Pacific Northwest reported a shift from predation- to competition-based mortality in response to the 1982/1983 El Nino. Key traits of pink salmon that influenced competition with other salmonids included great abundance, high consumption rates and rapid growth, degree of diet overlap or consumption of lower trophic level prey, and early migration timing into the ocean. The consistent pattern of findings from multiple regions of the ocean provides evidence that interspecific competition can significantly influence salmon population dynamics and that pink salmon may be the dominant competitor among salmon in marine waters.

Ruggerone, G.T, E. Farley, J. Nielsen, and P. Hagen. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) in relation to competition with Asian pink salmon (*O. gorbuscha*) and the 1977 ocean regime shift. Fishery Bulletin 103(2): 355-370.

Recent research demonstrated significantly lower growth and survival of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) during odd-numbered years of their second or third years at sea (1975, 1977, etc.), a trend that was opposite that of Asian pink salmon (*O. gorbuscha*) abundance. Here we evaluated seasonal growth trends of Kvichak and Egegik river sockeye salmon (Bristol Bay stocks) during even- and odd numbered years at sea by measuring scale circuli increments within each growth zone of each major salmon age group between 1955 and 2000. First year scale growth was not significantly different between odd- and even-numbered years, but peak growth of age-2 smolts was significantly higher than age-1 smolts. Total second and third year scale growth of salmon was significantly lower during odd- than during even numbered years. However, reduced scale growth in odd-numbered years began after peak growth in spring and continued through summer and fall even though most pink salmon had left the high seas by late July (10−18% growth reduction in odd *vs.* even years). The alternating odd and even year growth pattern was consistent before and after the 1977 ocean regime shift. During 1977−2000, when salmon abundance was relatively great, sockeye salmon growth was high during specific seasons compared with that during 1955−1976, that is to say, immediately after entry to Bristol Bay, after peak growth in the first year, during the middle of the second growing season, and during spring of the third season. Growth after the spring peak in the third year at sea was relatively low during 1977−2000. We hypothesize that high consumption rates of prey by pink salmon during spring through mid- July of odd-numbered years, coupled with declining zooplankton biomass during summer and potentially cyclic abundances of squid and other prey, contributed to reduced prey availability and therefore reduced growth of Bristol Bay sockeye salmon during late spring through fall of odd-numbered years.

Ruggerone, G.T., J.L. Nielsen, and J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955–2002. Deep-Sea Research II 54: 2776–2793. DOI: 10.1016/j.dsr2.2007.08.016

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

Saito, T. 2005. Factors that affect the first year growth of chum salmon released from Japanese hatcheries. North Pacific Anadromous Fish Commission Technical Report No. 6.

The first year growth of individual fish was estimated by their scale increments at age 0.1 (i.e., radius at the first annulus). Scale measurements were conducted using a microscope (× 25) equipped with a scale measurement system (ARP/W, Version 3.20. Ratoc system engineering Co. Ltd., Tokyo, Japan). The measurements were directly used as an indicator for the first year growth of individual fish. Although sample size varied from six to 114 between sexes, as well as among the populations and brood years, 202 (87.8%) of 230 samples (2 sexes × 5 populations × 23 brood years) consisted of more than 30 fish. In total, scales from 10,917 fish were measured. Brood-year averages were then obtained for both sexes from the five populations.

Saito, T., and K. Nagasaw. 2009. Regional synchrony in return rates of chum salmon (*Oncorhynchus keta*) in Japan in relation to coastal temperature and size at release. Fisheries Research 95: 14-27.

Fish scales were used to investigate the interannual variability in chum salmon growth rates at specific ages in relation to climatic/environmental changes during the 1980s–1990s. Scales were obtained from adult salmon returning to the east coast of Korea between 1984 and 1998. Assuming proportionality between scale size increments and fish length, distances between scale annuli were regarded as the growth conditions in different habitat areas with respect to the life stages of chum salmon. In estuarine and coastal areas, growth rates of fingerling salmon were higher in the 1990s than in the 1980s. Zooplankton abundance off the east coast of Korea increased after the late 1980s, which may have provided favorable growth conditions for young salmon in the 1990s. Growth of juvenile chum salmon during the first summer (Okhotsk Sea) was relatively stable, and neither SST nor zooplankton biomass fluctuated significantly during the study period. However, in the Bering Sea, salmon growth rates between age-2 and age-4 (i.e. ocean-phase immature salmon) were higher in the 1980s than in the 1990s. Variability in salmon growth in the Bering Sea was correlated to zooplankton biomass. These results suggest that the climate regime shift of 1988/1989 in the subarctic North Pacific affected salmon growth mediated by changes of zooplankton biomass, revealing a bottom-up process.

Saito, T., I.Shimizu, J. Seki, T. Kaga, E. Hasegawa, H. Saito, and K. Nagasawa. 2010. Can research on the early marine life stage of juvenile chum salmon *Oncorhynchus keta* forecast returns. Fisheries Science 76: 909–920. DOI: 10.1007/s12562-010-0286-7

To examine the efficacy of juvenile salmon research as a tool for forecasting adult returns, the results from a study on the early marine life stage of juvenile chum salmon, conducted in the Nemuro Strait during 1999–2002 (i.e., 1998–2001 brood years), were compared with the return rates of adult salmon. Among the four brood years, the 2000 brood year (i.e., salmon migrating to the sea in 2001) was previously reported as showing higher abundance, higher growth rate and better somatic condition during the coastal residency period. Consequently, we expected it to have the highest return rate, under a hypothesis that juvenile survival in coastal residency regulates brood-year strength. Contrary to this expectation, the 2000 brood year had almost the lowest return rate. Alternatively, a statistical model in which sea surface temperature during the first year of marine life and size at release were utilized as explanatory variables reconstructed the actual variability in return rates more accurately than that based on the early marine life stage. Possible reasons for the discrepancy between the results of the juvenile salmon research and adult returns are discussed, and we suggest improvements for future research on juvenile salmon.

Saito, T., T. Kaga, E. Hasegawa, and K. Nagasawa. 2011. Effects of juvenile size at release and early marine growth on adult return rates for Hokkaido chum salmon (*Oncorhynchus keta*) in relation to sea surface temperature. Fisheries Oceanography 20(4): 278–293.

Using path analyses, we investigated relationships between size at release from hatcheries, the early marine growth of juveniles, and adult return rates for chum salmon from five river stocks of Hokkaido, Japan, in relation to sea surface temperature during ocean residence. Marine growth was estimated using scales collected from 11 760 adults of age 0.3 (1980– 2004). The growth and survival of each stock appeared to have a different suite of regulatory processes. Interannual variability in return rates was mainly regulated by size at release in two stocks from the Sea of Okhotsk. A similar relationship was found in one stock from the Sea of Japan, but growth during coastal residency also affected their return rates. In two stocks from the Pacific coast of Hokkaido, variability in return rates was not related to size at release or to the coastal growth of juveniles, but with offshore growth in the Sea of Okhotsk, the nursery area for juveniles after leaving Japanese coastal waters. Whereas coastal growth tended to be negatively correlated with size at release in some stocks, offshore growth was positively associated with the August–November sea surface temperature in all stocks. This study confirmed that mortality of juvenile salmon occurred in two phases, during the coastal residency and the late period of the growing season, but the relative importance of both phases varied by stock and region, which probably regulated year-class strength of Hokkaido chum salmon.

Seo, H., S. Kim, K. Seong, S. Kang. 2009. Spatiotemporal change in growth of two populations of Asian chum salmon in relation to intraspecific interaction. Fisheries Science 75: 957–966. DOI: 10.1007/s12562-009-0126-9

Spatiotemporal changes in growth patterns of chum salmon *Oncorhynchus keta* that returned to the Ishikari (Japan) and Namdae (Korea) rivers in 1984–1998 were investigated using scale analysis. Juvenile chum salmon from both populations left coastal marine areas after spring at a size of over 8 cm fork length (FL). In summer, juvenile salmon from the Namdae River entered the Okhotsk Sea at a larger FL than did Ishikari River juveniles. There were no significant differences in annual growth between populations of 1-, 2-, and 4-year-old fish. For 3-year-old fish, however, Namdae River salmon had significantly higher synchronous and sympatric growth than did Ishikari River salmon. Mean FL of adults was also larger in Namdae River salmon than in Ishikari River salmon. Analysis of covariance (ANCOVA) results showed (1) negative linear relations between FL and catch, (2) homogeneous slopes of those relations at regional and species levels, and (3) nonhomogeneous slopes at the population level, indicating that density-dependent effects on growth were most significant at this level. We concluded that growth of chum salmon was concurrently influenced by stronger effects of intrapopulation competition and weaker effects of inter- and intraspecific interactions in the Bering Sea.

Seo, H., H. Kudo, and M.Kaeriyama. 2011. Long-term climate-related changes in somatic growth and population dynamics of Hokkaido chum salmon. Environmental Biology of Fishes 90: 131–142. DOI: 10.1007/s10641-010-9725-7

We used multiple regression and path analysis to examine the effects of regional and larger spatial scales of climatic/oceanic conditions on the growth, survival, and population dynamics of Hokkaido chum salmon (*Oncorhynchus keta*). Variability in the growth of chum salmon at ages 1 to 4 was estimated from scale analysis and the back-calculation method using scales of 4-year-old adults returning to the Ishikari River in Hokkaido, Japan, during 1943– 2005. Growth of chum salmon at age 1 was less during the period from the 1940s to the mid-1970s compared to the period from the mid-1980s to the present. On the other hand, growth of chum salmon at ages 2, 3, and 4 has declined since the 1980s. Path analysis indicated that growth at age 1 in the Okhotsk Sea was directly affected by warmer sea surface temperatures associated with global warming. The increased growth at age 1 led directly to higher survival rates and indirectly to larger population sizes. Subsequently, in the Bering Sea, the larger population size was directly associated with decreased growth at age 3 and indirectly associated with shorter adult fork lengths despite the lack of relationships among sea surface temperature, zooplankton biomass, and growth at ages 2 to 4. Therefore, higher growth at age 1 related to global warming positively affected the survival rate of juvenile chum salmon in the Okhotsk Sea. The higher survival rates in turn appear to be causing a population density-dependent effect on growth at ages 2 to 4 and maturation in the Bering Sea due to limited carrying capacity.

Sviridov, V.V., O.S. Temnykh, A.V. Zovolokin, and E.A. Panchenko. 2004. Interannual dynamics in Anadyr River chum salmon biological characteristics and scale parameters. Izvestiya TINRO 139: 61-77. (in Russian with English abstract)

The analysis of long-term (1962-2000) data on Anadyr River chum salmon has shown significant interannual variability in body size and weight, scale structure and growth rates. In addition to the previous data, this testifies for interannual differences in Anadyr River chum salmon marine feeding environment. Interannual differences in Anadyr River chum salmon marine feeding environment resulted in reduction of average, minimum and maximum values of Anadyr River chum salmon size and weight. This size and weight reduction is indirect evidence for decrease in growth rates during the period of high salmon abundance. This reduction was observed both in .3 and .4 age groups of Anadyr River chum salmon. However, .4 age group experienced sharper decrease in body weight and length compared to .3 age group. Scale structure analysis has shown negative correlation between overall abundance of North Pacific salmon and length increments during 2, 3 and 4 years of marine life. The parameters of first annulus parameters were quite stable in terms of interannual variability. Our results showed that average circuli widths in the second, third and fourth annual zones and annuli widths of these zones could be used to estimate density-dependent scale growth reduction. The utilization of back-calculated length-at-age using the direct proportion method also provides accurate data for an estimation of growth reduction. The utilization of equation coefficients, which describe relationship between natural logarithms of age and length, is another way to quantify interannual variability in growth. Average circuli counts of Anadyr River chum salmon do not show significant interannual dynamics and therefore cannot be used to quantify interannual differences. Changes in Anadyr River chum salmon scale structure and biological parameters do not show correlation with Anadyr River chum salmon catch rates. On the contrary, these characteristics are strongly correlated with overall abundance of North Pacific chum salmon and North Pacific salmon. However, the mechanisms of observed interannual differences are still poorly understood and the observed changes in Anadyr River chum salmon biological parameters cannot be attributed exclusively to the increased rates of artificial reproduction of Japanese chum salmon.

Temnykh, O.S. 1998. Primorye pink salmon growth at high abundance. North Pacific Anadromous Fish Commission Technical Report No. 1.

[from text] A scale structure analysis showed that beginning from 1970s there were essential changes in the growth rate of pink salmon. The number of circuli within the first annual zone has increased and the number of circuli within the second year of life zone has decreased in fish caught during 1971-1990. The analysis of scale radii showed similar results.

Urbach, D., M. Kang, S. Kang, K.B. Seong, S. Kim, U. Dieckmann, M. Heino. 2012. Growth and maturation of Korean chum salmon under changing environmental conditions. Fisheries Research 134-136: 104-112.

Salmon populations in the North Pacific have been subject to major changes in environmental and fishing pressure since the early 1980s, including a climate regime shift in 1988–1989, the closure of the high-seas fisheries in 1993, and a subsequent climatic event in 1998. In the present work, we evaluate whether any of these three events has triggered changes in the life-history traits of chum salmon (*Oncorhynchus keta*) from the Namdae River, on the eastern coast of South Korea, using data collected on females and males from 1984 to 2008. We find that the 1988–1989 regime shift had the most pervasive effects on female and male maturation schedules and growth. We also demonstrate sex-specific responses: whereas growth showed similar patterns of variation in both sexes, age and length at maturation behaved differently in males and females. Our findings contribute to growing evidence that abrupt transitions in climatic conditions can trigger detectable changes in life-history traits. They also strengthen the observation that biological records of salmon populations of the North Pacific carry a stronger signal for the effects of the 1988–1989 regime shift than for the effects of the subsequent environmental changes.

Walker, R.V. 1998. Scale growth studies from 1982-97 collections of chum and sockeye salmon scales in the Gulf of Alaska. North Pacific Anadromous Fish Commission Document 364. 14 p.

Studies were conducted of growth on scales collected from salmon caught during high seas research cruises in the Gulf of Alaska. Measurements were made of scales from June and July 1982-1997 of ocean age .2 chum (*Oncorhynchus keta*) and sockeye salmon (*O. nerka*) that were also examined for stomach contents. Measurements were taken to the end of each annular mark and at the edge of the scale, and to every circulus on the scale. Scale measurements (particularly growth at the edge of the scale) were then compared to indices of stomach fullness and other measures of condition and growth. No correlations were found between three food habits variables (fullness, prey weight, and stomach content index) and edge growth variables (size, circulus spacing, and number of circuli of the last ocean zone, and size of the last circulus and last three circuli in that zone) for either sockeye or chum. Length and all edge growth variables on sockeye scales were significantly less in 1990s samples than in 1980s samples. Growth measures of the second and third ocean years on chum scales, and length, weight, and condition factor were also significantly smaller in 1990s samples. Sockeye salmon length and weight were positively correlated with growth variables in the second ocean year, while chum salmon length, weight, and condition factors were positively correlated with growth variables in all three ocean years. Sockeye salmon condition factor and edge growth variables were positively correlated with their counterparts in chum salmon. The results for sockeye salmon indicate that final size and trigger to mature may be at least partially set in the second ocean year. Successful chum salmon growth may be set relatively early, with a positive feed-forward effect of good growth leading to more good growth.

Walker, R.V., K.W. Myers, and S. Ito. 1998. Growth studies from 1956-1995 collections of pink and chum salmon scales in the central North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin No. 1: 54-65.

This study was initiated to investigate whether long-term collections of scale samples could provide further information on recent observations related to ocean growth and abundance of Pacific salmon *(Oncorhynchus* spp.): size-at-return of salmon of *several* stocks has decreased in recent years; and oceanographic conditions changed around 1976-1977, possibly affecting abundance and growth of salmon. We examined growth patterns on scales of pink (0. *gorbuscha)* and chum (0. *ketal* salmon to determine if there were differences in growth between the periods before and after the oceanographic change and if changes in *relative* abundances of the two species were correlated with any changes in growth. The scales were collected by the Fisheries Research Institute of the University of Washington (1956-91), the U.S. Bureau of Commercial Fisheries (1967-71), and the Fisheries Agency of Japan (1981-95). Scales collected in late June from adult age 0.1 pink salmon and primarily immature age 0.2 chum salmon were measured. The scales were from fish caught in the North Pacific Ocean south of Adak Island in the central Aleutians. Measurements were made of each circulus in the last year of ocean residence and to the edge of each preceding annular mark. Chum salmon caught in this area in 1983-95 had significant decreases in fork length and in growth at the edge of the scale compared to those caught in earlier years (1956-70). Pink salmon showed fewer differences in growth between periods, although odd-year pinks were smaller in 1983-95 than in 1959-67. Scale-edge growth of chum salmon was negatively correlated with Asian pink and chum salmon abundance. Adult pink salmon abundance may exert an influence on the third-year growth of chum salmon in this area.

Welch, D.W. 1994. Variation in marine growth rates of British Columbia pink and sockeye salmon stocks. North Pacific Anadromous Fish Commission Document 94. 30 p.

Scale collections for three stocks of sockeye salmon *(Oncorhynchus nerka)* and two stocks of pink salmon (0. *gorbuscha)* from British Columbia were used to examine the changes occurring in freshwater and marine growth rates of salmon since the 1950s. Substantial between-stock differences in patterns of marine growth over time were evident, even for stocks whose natal rivers were nearby. In stocks with multiple ages at return, different age groups generally showed similar patterns of variation over time when specific ocean ages were considered. However, there is some evidence that the patterns are most consistent when considered as "offshore" (open ocean, pelagic), and "coastal" life history periods. Marine growth rates for ages when sockeye are far from the coast showed variation in scale growth rates, but no long-term trend. In contrast, marine growth during either or both the first and last years in the ocean (when sockeye pass through the coastal zone) often showed evidence of a trend towards decreasing marine growth rates with time. Similar patterns are evident for the more limited pink salmon time series, except here the pattern is reversed: marine growth during the coastal phase of the first year shows little or no trend. This suggests that the numbers of pink salmon smolts in coastal waters may be insufficient to affect their food supply at this time. Further work is needed to relate the annual changes in marine growth rates to the terminal size of salmon at return to coastal waters, and to establishing the oceanographic factors that lead to large changes in growth rates between years and life history periods.

Zavolokin, A.V., E.A. Zavolokina, and Y.N. Khokhlov. 2009. Changes in size and growth of Anadyr chum salmon (*Oncorhynchus keta*) from 1962-2007. North Pacific Anadromous Fish Commission Bulletin No. 5: 157–163.

Annual changes in body size and growth of Anadyr chum salmon (ages 0.3 and 0.4) in 1962–2007 were studied. Regression analysis showed that the fork length and weight of Anadyr chum salmon significantly decreased from the 1960s to the 2000s. Mean body length of Anadyr chum salmon was highest in 1972 and 1979, and lowest in 1991 and 1994. The most pronounced decrease in chum salmon body size occurred from the early 1980s to the mid 1990s. In 1962–1980 and 1997–2007, mean fork length and weight remained relatively stable. The first-year growth of Anadyr chum salmon, estimated from intersclerite distances, did not change significantly from 1962 to 2007. Growth reduction began in the second year, and the greatest reduction occurred in the third year. There was a significant negative correlation between annual total catches of Pacific salmon and Anadyr chum salmon fork length, body weight, and growth during the second, third and fourth years. Our results may corroborate the conclusions of other researchers that climatic and oceanic conditions can strongly affect the carrying capacity for Pacific salmon and other fish.

Zavolokin A.V., Kulik V.V., Khokhlov Y.N. 2011. Changes in size, age, and intra-annual growth of Anadyr chum salmon (*Oncorhynchus keta*) from 1962-2010. North Pacific Anadromous Fish Commission Document 1330. 11 p.

Inter-annual changes in body size, age composition, and intra-annual changes in growth of Anadyr chum salmon collected in 1962-2010 were studied. From the 1960s to the 2000s, body size of Anadyr chum salmon significantly decreased and the average age of spawners slightly increased. Annual growth dynamics showed different patterns. Estimated from measuring intersclerite distances on scales, first-year growth of Anadyr chum salmon samples collected in 1962 to 2007 was enhanced. After the first year, growth was reduced. The greatest reduction occurred in the third (ages 0.3 and 0.4) and forth (age 0.4) years. Intra-annual scale increments showed that growth reduction after the first year occurred both in over-wintering and foraging areas. This contrasts with the wide-spread suggestion that chum salmon size decreased due to a poor foraging conditions during the winter period. Based on published results and our data, it seems the growth of at least two salmon species (chum and pink salmon) changed similarly in recent decades. Hence there are some large-scale factors that influenced these species and had an effect in the vast areas of the North Pacific and marginal seas. Our results don’t corroborate the decisive importance of density-dependent interactions for Pacific salmon productivity in the last 50 years. Negative correlations between some climatic indices (ocean surface temperature, ground air temperature, and heat content of North Pacific Ocean) and scale increments of Anadyr chum salmon in the second, third and fourth year zones suggest that warming of North Pacific may have adverse impact on chum salmon growth after the first year of life. Chum salmon growth reduction after the early marine period may be a mixture of increasing abundance of Pacific salmon combined with warming ocean.

Zavolokin, A.V. , V.V. Kulik, I.I. Glebov, E.N. Dubovets, and Y.N. Khokhlov. 2012. Dynamics of body size, age, and annual growth rate of Anadyr chum salmon *Oncorhynchus keta* in 1962–2010. Journal of Ichthyology 52(3): 207–225.

Interannual variability of body length, body weight, age structure, and seasonal growth rate of Anadyr chum salmon *Oncorhynchus keta* was studied using the monitoring data obtained in 1962–2010 in Anadyr River and Anadyr Firth. Body size of spawning adults has decreased significantly for the decade of 1990-2000s compared to the period of 1960-1970s, and the ratio of elder specimens was higher. Annual growth dynamics showed different patterns. Estimated from measuring intersclerite distances on scales, first_ year growth of Anadyr chum salmon samples collected in 1962 to 2007 was enhanced. After the first year, growth was reduced. The greatest reduction occurred in the third and fourth years. Analysis of seasonal growth of scale evidences to the relaxation of the growth rates of Anadyr chum salmon after the first year of life preconditioned by both the over-wintering and foraging period. These data are in contradiction with the widespread suggestion of decreasing of chum salmon body length during winter due to bad feeding conditions. According to the similarity of the dynamics of body length and growth rates of chum salmon and pink salmon *O. gorbuscha* observed for the last decades, we assume that this may be preconditioned by the same large-scale limiting factors that affect similarly these salmon species inhabiting vast areas. Our data do not support the idea about high-density population of chum salmon as a main factor affecting the productivity characteristics of this species in the northern Pacific Ocean in the second half of the 20th–beginning of the 21st century. Reasons for decrease of chum salmon body length are discussed.

Zavolokin, A.V., V.V. Kulik, and Y.N. Khokhlov. 2012. Changes in size, age, and intra-annual growth of Anadyr Chum Salmon (*Oncorhynchus keta*) from 1962 to 2010. North Pacific Anadromous Fish Commission Technical Report No. 8: 76-80.

[from text] Adult chum salmon were sampled annually from 1962 to 2010. Fish samples were collected in the Anadyrskiy estuary using a trap net and on the spawning grounds. We analyzed scales of age-0.3 and -0.4 chum salmon. A total of 2,506 chum salmon was sampled (for details on methods, see Zavolokin et al. 2011, 2012 above).