Synthesis and Review of US Research on the Physical and Biological Factors Affecting Ocean Production of Salmon

Katherine W. Myers[1], **Robert V. Walker**[1], **H. Richard Carlson**[2]†, and **John H. Helle**[2]
[1]School of Aquatic and Fishery Sciences, University of Washington
Box 355020, Seattle, WA, USA 98195-5020
[2] NOAA, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory,
11305 Glacier Highway, Juneau, Alaska, USA 99801-8626

Myers, K.W., R.V. Walker, H.R. Carlson, and J. Helle. 2000. Synthesis and review of US research on the physical and biological factors affecting ocean production of salmon. N. Pac. Anadr. Fish Comm. Bull. No. 2: 1–9.

Keywords: NPAFC, Pacific salmon, research plan, United States, ocean, carrying capacity

Abstract: This paper is a synthesis and review of the results of US research in the 1990s on the physical and biological factors affecting ocean production of Pacific salmon (*Oncorhynchus* spp.). The review follows the outline of US research under the North Pacific Anadromous Fish Commission Science Plan, which addresses issues concerning the ocean production of salmon. The research includes studies on juvenile salmon in coastal waters, ecology of salmon in the Gulf of Alaska, retrospective analyses of long-term data series, development and application of stock identification techniques, and international cooperative high seas salmon research. Our review indicates that climate-induced variation in productivity and fishing are the two major factors affecting ocean production of salmon, but the underlying mechanisms are not well known. To understand the processes linking climate, ocean productivity, and salmon production, we need stock-specific information on salmon distribution, abundance, and migration patterns with respect to environmental conditions. We recommend continuation of this research, with a strong emphasis on (1) the development of new technologies and international baselines for salmon stock identification, (2) shipboard research and monitoring programs to provide a platform for process studies, as well as data on interannual variation in ocean growth, distribution, and run timing of key stocks, and (3) the development and dissemination of international databases useful for research on ocean production of salmon.

INTRODUCTION

This year the North Pacific Anadromous Fish Commission's (NPAFC) Science Sub-Committee (SSC) is charged with developing a new science plan for the year 2000 (Y2K) and beyond (NPAFC 1999). This task includes a review of the results of NPAFC's scientific research program in the 1990s, as well as new information presented at this symposium. The ultimate goal of NPAFC's research program is conservation of salmon (*Oncorhynchus* spp.). And so, we may ask, "Are Pacific salmon Y2K-safe?" The focus of this symposium and resulting bulletin is salmon in the ocean, but we must keep in mind that salmon begin and end their lives in fresh water. Without healthy freshwater ecosystems, there will be no salmon. Y2K-safe science, therefore, should consider factors that affect growth and survival of salmon over the entire salmonid ecosystem, including both freshwater and ocean habitats.

The picture of salmon on the cover of the symposium proceedings is a computer adaptation of an underwater photograph of salmon swimming on the high seas, taken in the 1960s by A.C. Hartt near Adak Island in the central Aleutians. According to Mr. Hartt, high-seas salmon are like "gray ghosts," that is, very difficult to see and photograph underwater. Over the next two days, we will be discussing the factors that affect the survival of these gray ghosts during their extensive ocean feeding migrations. There are many posters and papers presenting the detailed results of individual research projects and programs. Our objective in this paper is to "set the stage" for the presentations that follow by giving a brief overview of US high seas salmon research issues, programs, methods, results, and recommendations.

Research Issues

The main issue or question underlying the need for ocean salmon research has always been: "Why didn't the salmon come back from the sea?" This question, asked since time immemorial by native

† deceased

All correspondence should be addressed to K.W. Myers.
e-mail: kwmyers@u.washington.edu

salmon fishermen of the North Pacific Rim, was asked once again in 1997 and 1998, when Bristol Bay, Alaska, sockeye salmon (*O. nerka*) failed to return in forecasted numbers. The NPAFC treaty promotes conservation of salmon by prohibiting all directed fishing for anadromous stocks in international waters (NPAFC 1993). In the 1970s, fisheries scientists defined conservation as the wise use of (fishery) resources. In the 1990s, conservation has a much broader meaning involving "long-term sustainability of ecosystems." Accordingly, the present NPAFC Science Plan addresses two critical research issues: (1) factors affecting current trends in ocean productivity and impacts on carrying capacity (i.e., biomass of salmonids that can be supported by their ecosystem), and (2) factors affecting changes in biological characteristics (growth, size and age at maturity, oceanic distribution, survival, and abundance). These issues were formulated as areas of salmon research that could be conducted in cooperation with other research organizations, especially the North Pacific Marine Science Organization (PICES)—to bring to the NPAFC forum new scientific expertise and information, particularly in the areas of ocean and atmospheric sciences.

North Pacific Research Programs

Concerns in the 1990s about salmon carrying capacity in the North Pacific Ocean, the effects of oil pollution, global warming, ocean interactions between hatchery and wild fish, endangered species, illegal high seas fishing, and salmon bycatch in non-target ocean fisheries have spawned a multitude of US and international programs that are investigating various aspects of ocean production of salmon and other marine species. Some of the major programs are as follows:

- Ocean Carrying Capacity (OCC) Program, US National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory—funded by the US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA)
- US Global Ocean Ecosystems Dynamics (GLOBEC) Northeast Pacific Program (US National Science Foundation Division of Ocean Sciences, NOAA Coastal Ocean Program Office)
- Fisheries Oceanography Coordinated Investigations (NOAA)
- Climate Change and Carrying Capacity (CCCC) Program (PICES)
- Exxon Valdez Oil Spill (EVOS) Trustee Council, including the Sound Ecosystem Assessment (SEA) Program and the Gulf Ecosystem Monitoring (GEM) Program
- North Pacific Marine Research Program (Federal grant to the University of Alaska Fairbanks)

The OCC Program, which is described in this paper, is the only program directly funded to conduct US salmon research in the NPAFC forum (National Marine Fisheries Service 1995).

Research Approaches

Most US programs are using similar research approaches, including (1) retrospective/comparative analysis, (2) mathematical modeling, (3) 3-dimensional (distribution and depth) surveys, (4) process (mechanism) studies, (5) data acquisition and management, and (6) long-term observation (monitoring) programs. The use of multiple approaches in investigations of ocean production of salmon is essential because of problems or difficulties associated with individual components.

Retrospective (historical) or comparative analyses are one of the major methodological approaches, but most historical salmon data were not collected with current research objectives in mind. For example, the number of salmon in commercial catches is often the only historical measure of salmon abundance, which is a poor substitute for total biomass in salmon carrying-capacity research. Salmon catch data are affected by changes in fishing strategy, effort, and gear, management activities, and other factors. Often, retrospective analyses show a correlation between various physical and biological factors and salmon growth or catch, but correlations are not proof of cause and effect and explain nothing about underlying mechanisms.

Mathematical modeling is a useful tool for generating hypotheses, but models can be designed to show whatever result we want. Models, therefore, must be validated with field data. Ocean field surveys are very expensive. Environmental data from remote sensing is becoming more readily available, but we still need to go to sea in ships to collect data on salmon and 3-dimensional environmental data. Process studies are vital to discovering underlying mechanisms, but difficult to carry out either in the laboratory or on ships at sea.

International systems to acquire, manage, and exchange long-term data series are essential to North Pacific salmon research, but salmon databases are often considered to be proprietary information. Long-term monitoring programs are the key to understanding variation in biological and physical factors affecting ocean production of salmon. Governments, however, are usually reluctant to fund long-term programs.

US SCIENCE PLAN

The US Science Plan under NPAFC includes five major areas of research (NPAFC 1999), (1) juvenile salmon studies, (2) Gulf of Alaska salmon ecology, (3) retrospective analyses, (4) stock identification, and (5) high seas salmon studies. Field and laboratory investigations are conducted on salmon in both coastal and high seas habitats, primarily in the Bering Sea, central North Pacific Ocean, and Gulf of Alaska, where US salmon are most abundant. Samples and data for retrospective analyses are obtained from historical high seas and Alaska salmon research and management programs, as well as from new techniques like sediment-core sampling. Accurate stock identification in mixed-stock ocean samples is a key aspect of every phase of the research.

Coastal Juvenile Salmon Studies

Ocean production of salmon in terms of numbers of fish is closely linked with their early ocean survival. Juvenile salmon spend their first summer at sea in open coastal areas over the continental shelf or in protected marine waters, straits, sounds, and river estuaries. Coastal studies are focusing on field monitoring, models of salmon production, and process studies, including (1) repeated measurements of habitat and stock-specific life history characteristics, (2) modeling salmon production based on interannual variability in early marine survival and growth, and (3) trophic dynamics of salmon and their predators.

At present, there are two main programs, one in southeastern Alaska and one in western Alaska. The southeastern Alaska program, initiated in 1997, is investigating seasonal (May–October) interactions between hatchery and wild salmon stocks and their potential impact on marine carrying capacity (Murphy et al., 1997, 1999; Orsi 1997; Orsi and Murphy 1997; Orsi et al. 1997, 1998a, b, c, d, e, this volume; Murphy 1998). The western Alaska Program, initiated in 1999, is investigating effects of climate on growth, migration, and distribution of juvenile Bristol Bay sockeye salmon in the eastern Bering Sea (Farley et al. 1999; Ocean Carrying Capacity Program 1999). Sampling for juvenile salmon was also conducted during broad-scale coastal surveys of the northeastern North Pacific, Gulf of Alaska, Bering Sea, and Aleutian Islands from 1996–1999 (Carlson et al. this volume).

The results of coastal juvenile salmon studies indicate that spatial and temporal variations in their distribution and migration patterns are most closely associated with changes in feeding conditions and distribution of prey. There is a strong relationship between early marine growth and survival. High growth rates are associated with high temperatures. As juvenile salmon grow, they move farther away from shore and the points of ocean entrance; they are better able to avoid fish, bird, and marine mammal predators; and they can feed on a greater diversity and size range of prey. Variations in early marine growth and survival are most often related to climate-induced changes in distribution and abundance of predator and prey populations. These are chaotic events that cannot be predicted with a high degree of certainty. Thus, coastal ocean field monitoring programs are needed if our objective to forecast salmon carrying capacity in the North Pacific Ocean is to be met.

Gulf of Alaska Salmon Ecology

The components of an ongoing program of research on Gulf of Alaska salmon ecology (1995-present) include studies of (1) broad-scale ocean distribution and migration patterns of salmon (Carlson et al. 1996, 1997, 1998a,b, 1999), (2) fine-scale processes or factors influencing distribution, behavior, and growth, (3) diet overlap and prey selectivity (Sturdevant et al. 1997; Auburn-Cook and Ignell this volume), (4) genetic stock identification (Guthrie et al. this volume), (5) distribution of thermally-marked hatchery salmon (Farley and Munk 1997; Carlson et al. this volume), and (6) salmon growth and size (Farley and Carlson this volume).

From 1996–1999, Gulf of Alaska salmon ecology studies focused on broad-scale field surveys of distribution and migration of salmon in the Alaska Coastal Current (ACC) and Alaska Gyre. The results have corroborated the findings of earlier studies conducted in the 1950s, 1960s, and 1970s. But with new stock identification techniques (genetics, thermal marking, coded-wire tags, and data-storage tags), we have enhanced capability over these earlier studies to investigate growth, distribution, and migration patterns of individual stocks at various life-history stages along their ocean migration routes.

Variation in life-history strategies of salmon, especially spatial and temporal variation in distribution and migration patterns, is a key to their evolutionary success. The results of Gulf of Alaska salmon ecology studies indicate that ocean distribution and migration patterns of salmon are stock-specific, although patterns may be broadly overlapping, particularly with those of other stocks originating from the same geographic region. Salmon in the Gulf of Alaska partition utilization of coastal and offshore feeding areas on the basis of species, maturity, age, size, feeding behavior, food preferences, run timing, and other factors. Productivity and predation by marine mammals, birds, and fish are higher in the ACC than in the Alaska Gyre. Availability of prey resources may not be a limiting factor for production and growth of juvenile salmon in the Gulf of Alaska. Body size of juvenile salmon increases as they migrate westward in the ACC, reducing predation risk and improving their ability to move against currents. Juvenile salmon move offshore in late fall or winter, coincident with decreasing sea temperature and prey availability in the ACC. Immature and adult salmon are able to optimize growth and survival potential through seasonal movements between the coastal and offshore areas. Salmon carrying capacity may be regulated primarily by climate-induced changes in productivity. Competition is most likely to occur among fish of the same species, stock, age, and maturity group, exhibited as density-dependent changes in ocean growth and survival.

Retrospective Analyses

Retrospective studies characterize past variability in climate and salmon population parameters over various time and space scales, and are a key component to understanding effects of climate change on the abundance and life-history of US salmon populations. Past and current research on Alaska salmon includes analyses of (1) freshwater scale growth patterns of Karluk lake sockeye salmon (early 1900s-present; Nelson, Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, U.S.A., personal communication), (2) marine scale growth patterns of Kvichak River sockeye salmon (1920–1997; Isakov et al. this volume), (3) marine scale growth patterns of Yukon River chum salmon (*O. keta*) (1965–1996; Sands, University of Alaska Fairbanks, School of Fisheries and Ocean Sciences, Juneau Center, personal communication), (4) Auke Creek pink salmon (*O. gorbuscha*) scale growth and total pink salmon production from Southeast Alaska (1979–1996; Jaenicke et al. 1994; Murphy et al. 1998), (5) historical salmon research in the Karluk Lake area (1880-present; Gard and Bottorff, University of Alaska Fairbanks, School of Fisheries and Ocean Sciences, Juneau Center, personal communication), (6) long-term changes in salmon abundance using high-resolution paleoenvironmental analysis of sediment cores (1500-present; Finney 1998), and (7) time-series of salmon catch, escapement, growth data and environmental data (Helle and Hoffman 1995; Bigler et al. 1996; Farley and Murphy 1997; Eggers 1998; Farley and Quinn 1998; Hare et al. 1998; Helle and Hoffman 1998; Wing and Pella 1998).

Retrospective analyses using a variety of techniques have established that there are interannual, decadal, and longer-term fluctuations in the ocean growth and production or survival of salmon. Variation in salmon scale growth patterns reflects changes in feeding behavior and conditions. When salmon are not feeding, circuli are not formed on scales, and in starving fish scales may be resorbed, e.g., in spawning adult salmon. Density-dependent survival is correlated with early ocean (coastal) growth on scales, and density-dependent growth is correlated with scale growth in subsequent years, when fish are distributed offshore. Spatial and temporal trends in scale growth patterns reflect trends in ocean productivity and climate indices. Differences in scale growth between years of high and low salmon production indicate size-selective mortality, where predation risk is higher for slower-growing individuals. The results of the historical Karluk Lake research and sedimentary ^{15}N analyses from core samples indicate that the long-term decline in Karluk Lake sockeye salmon was primarily precipitated by, and continued by, overfishing in the commercial fishery, not from insufficient spawning but from changes to the fertility of Karluk Lake. Overfishing greatly reduced the quantities of marine-derived nutrients released back into Karluk Lake each year in the decomposing bodies of sockeye salmon adults. Time series analyses of catch, escapement, and growth data indicate that both management (e.g., changes in escapement policy and fishing) and climatic factors have significantly affected Alaska sockeye salmon populations in the past.

Stock Identification Research

NPAFC-related stock identification research is focused on the development of international genetic baselines (e.g., Hawkins et al. 1998; Seeb et al. 1998), standardization and coordination of otolith marking methods (e.g., Hagen 1999; Munk 1999; Volk and Hagen 1999), and application of new and historical techniques (tagging, parasites, and scale pattern analysis) to research and high-seas enforcement questions (e.g., Bernard and Myers 1996; Myers et al. 1996; McKinnell et al. 1997; Patton et al. 1998; Urawa et al. 1998; Wilmot et al. 1998; Winans et al. 1998; Wilmot et al. 1999; Guthrie et al. this volume; Walker et al. 2000).

Thermal marking of otoliths is a promising new technique for high seas stock identification, but the number of available marks is limited (Ignell et al. 1997; Farley and Munk 1997; Hagen 1999; Carlson et al. this volume). International standardization and supplementation with other marks may be necessary for future high seas applications (Munk 1999; Volk and Hagen 1999).

International genetic baselines have been established for chum, sockeye, and chinook salmon (*O. tshawytscha*). International genetic baselines for sockeye salmon can accurately separate Asian and North American fish, but are not accurate at distinguishing among North American stocks. There is no international baseline for coho salmon (*O. kisutch*). All baselines need more samples from Russian stocks.

The combined results of genetic stock identification, scale pattern analysis, and parasite analysis suggest that the areas of intermingling of Asian and North American salmon in the Bering Sea and North Pacific Ocean are wider than that shown by direct evidence from tag experiments. Our present understanding of stock-specific distribution, migration patterns, and abundance of salmon in offshore waters is limited. Much work remains to validate the results of genetic and other indirect methods of stock identification of salmon on the high seas.

International Cooperative High Seas Salmon Research

Cooperative research on the high seas (international waters) is critical to understanding salmon carrying capacity (density-dependent growth) in the North Pacific Ocean and Bering Sea. The US high seas salmon research program involves international cooperative studies with Canadian, Japanese, and Russian scientists, including: (1) shipboard field studies on salmon distribution, migration patterns, abundance, and growth (e.g., Davis and Tadokoro 1994; Carlson et al. 1998b; Ishida et al. 1998a,b; Ueno et al. 1998; Carlson et al. 1999; Yamaguchi et al. 1999), (2) food habits studies and bioenergetic modeling (e.g., Tadokoro et al. 1996; Aydin 1998; Davis et al. 1998; Aydin et al. this volume; Davis et al. this volume; Walker et al. this volume), (3) growth studies using historical scale collections (e.g., Walker et al. 1998), (4) salmon life-history and carrying capacity modeling (e.g., Pearcy et al. 1999, Aydin et al. this volume), and (5) behavior studies using data storage tags (e.g., Walker et al. 2000).

The results of international cooperative research indicate that high seas distribution of salmon is most closely associated with distribution of their prey. Most growth occurs in summer months. Sea temperature is the most important physical factor affecting growth, but bioenergetic models indicate that prey consumption is more important to growth in offshore waters than temperature. Density-dependent prey limitation probably takes place in winter, when lipid stores are critical to salmon survival. High seas food-habit and bioenergetic studies provide evidence of feeding competition and density-dependent growth in summer. Behavior studies using data storage tags are providing significant new information on behavior of salmon with respect to ambient sea temperatures and depth. Summer data from tagged fish show considerable diurnal and shorter-term variation in ambient temperatures and swimming depth, indicating that non-lethal sea surface temperatures do not regulate the behavior of salmon on the high seas. These results do not minimize the potential problems associated with global warming, but warmer ocean temperatures in winter are associated with increased production of Alaska salmon. In the absence of large-scale high seas salmon fisheries, climate-induced change in ocean productivity, acting through the food chain, is the major factor affecting high seas production of salmon.

CONCLUSION

Our review of US research indicates that climate-induced variation in productivity and fishing are the two major factors affecting ocean production of salmon, but the underlying mechanisms are not well known. To understand the processes linking climate, ocean productivity, and salmon production, we need stock-specific information on salmon distribution, abundance, and migration patterns with respect to environmental conditions. We recommend continuation of this research, with a strong emphasis on (1) the development of new technologies and international baselines for salmon stock identification, (2) shipboard research and monitoring programs to provide a platform for process studies, as well as data on interannual variation in ocean growth, distribution, and run timing of key stocks, and (3) the development and dissemination of international databases useful for research on ocean production of salmon.

"The historical perspective suggests that salmonid stocks waxed and waned in different parts of their range with interdecadal, centenary, and millenary fluctuations in past ocean climates. Since anadromous salmonids of the genus *Oncorhynchus* have persisted during the past 50–100 million years (McPhail 1997), they must have evolved mechanisms to enable them to adapt to large-scale climatic changes" (Pearcy 1997). Fluctuations in salmon abundance and climate are normal. This underscores the importance of ocean conservation of salmon and protection of freshwater habitats during periods of low ocean productivity.

ACKNOWLEDGMENTS

We thank S. Ignell for providing information on unpublished OCC Program retrospective studies. Funding for preparation of this manuscript was provided by the Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA Contract No. 50ABNF000008.

REFERENCES

Auburn, M.E., and S.E. Ignell. This volume. Food habits of juvenile salmon in the Gulf of Alaska July–August 1996. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Aydin, K.Y. 1998. Abiotic and biotic factors influencing food habits of Pacific salmon in the Gulf of Alaska. *In* Workshop on climate change and salmon production, Vancouver, B.C. March 26–

27, 1998. *Edited by* K. Myers. NPAFC Tech. Rep. pp. 39–40.

Aydin, K.Y., K.W. Myers, and R.V. Walker. This volume. Variation in summer distribution of the prey of Pacific salmon (*Oncorhynchus* spp.) in the offshore Gulf of Alaska in relation to oceanographic conditions, 1994–98. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Bernard, R.L., and K.W. Myers. 1996. The performance of quantitative scale pattern analysis in the identification of hatchery and wild steelhead (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 53: 1727–1735.

Bigler, B.S., D.W. Welch, and J.H. Helle. 1996. A review of size trends among North Pacific salmon (*Oncorhynchus* spp.). Can. J. Fish. Aquat. Sci. 53: 455–465.

Carlson, H.R., K.W. Myers, E.V. Farley, H.W. Jaenicke, R.E. Haight, and C.M. Guthrie III. 1996. Cruise report of the F/V Great Pacific survey of young salmon in the North Pacific—Dixon Entrance to western Aleutian Islands—July–August 1996. (NPAFC Doc. 222) 50p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Carlson, H.R., E.V. Farley, R.E. Haight, K.W. Myers, and D.W. Welch. 1997. Survey of salmon in the North Pacific Ocean and Southern Bering Sea—Cape St. Elias to Attu Island—July–August, 1997. (NPAFC Doc. 254) 24p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Carlson, H.R., E.V. Farley, E.C. Martinson, and C.M. Kondzela. 1998a. Survey of salmon in the North Pacific Ocean and Gulf of Alaska—Dixon Entrance to Unimak Pass July–August, 1998. (NPAFC Doc. 345) 25p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Carlson, H.R., E.V. Farley, K.W. Myers, E.C. Martinson, J.E. Pohl, and N.M. Weemes. 1998b. Survey of salmon in the southeastern Bering Sea, Gulf of Alaska, and northeastern Pacific Ocean April–May, 1998. (NPAFC Doc. 344) 33p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Carlson, H.R., J.M. Murphy, C.M. Kondzela, K.W. Myers, and T. Nomura. 1999. Survey of salmon in the northeastern Pacific Ocean, May 1999. (NPAFC Doc. 450) 33p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Carlson, H.R., E.V. Farley, Jr., and K.W. Myers. This volume. The use of thermal otolith marks to determine stock-specific ocean distribution and migration patterns of Alaskan pink and chum salmon in the North Pacific Ocean, 1996–1999. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Davis, N.D., and K. Tadokoro. 1994. Japan-US cooperative high seas salmonid research in 1994: summary of research aboard the Japanese research vessel *Wakatake maru*, 10 June to 24 July. (NPAFC Doc. 78) 32p. University of Washington, USA; National Research Institute of Far Seas Fisheries, Japan.

Davis, N.D., K.W. Myers, and Y. Ishida. 1998. Caloric value of high-seas salmon prey organisms and simulated salmon ocean growth and prey consumption. N. Pac. Anadr. Fish. Comm. Bull. No. 1: 146–162.

Davis, N.D., K.Y. Aydin, and Y. Ishida. This volume. Diel catches and food habits of sockeye, pink, and chum salmon in the central Bering Sea in summer. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Eggers, D.E. 1998. Historical trends in rate of fishing and productivity of Bristol Bay and Chignik sockeye salmon. *In* Workshop on climate change and salmon production, Vancouver, B.C. March 26–27, 1998. *Edited by* K. Myers. NPAFC Tech. Rep. pp. 30–31.

Farley, Jr., E.V., and H.R. Carlson. This volume. Spatial variations in early marine growth and condition of thermally marked juvenile pink and chum salmon in the coastal waters of the Gulf of Alaska. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Farley, E.V., and K. Munk. 1997. Incidence of thermally marked pink and chum salmon in the coastal waters of the Gulf of Alaska. Alaska Fish. Res. Bull. 4: 181–187.

Farley, E.V., and J.M. Murphy. 1997. Time series outlier analysis: evidence for management and environmental influences on sockeye salmon catches in Alaska and Northern British Columbia. Alaska Fish. Res. Bull. 4: 36–53.

Farley, E.V., and T.J. Quinn. 1998. Bristol Bay sockeye salmon production: an exploratory analysis of the 1996 and 1997 decline in sockeye salmon returns. (NPAFC Doc. 343) 27p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Farley, E.V., J.M. Murphy, R.E. Haight, G.M. Guthrie, C.T. Baier, M.D. Adkison, V.I. Radchenko, and F.R. Satterfield. 1999. Eastern Bering Sea (Bristol Bay) coastal research on Bristol Bay juvenile salmon, July and September 1999. (NAFC Doc. 448) 22p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Finney, B.P. 1998. Long-term variability in Alaska sockeye salmon abundance determined by analysis of sediment cores. N. Pac. Anadr. Fish Comm. Bull. No. 1: 388–395.

Guthrie III, C.M., E.V. Farley, Jr., N.M.L. Weemes, and E.C. Martinson. This volume. Genetic stock identification of sockeye salmon captured in the coastal waters of Unalaska Island during April/May and August 1998. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Hagen, P. 1999. A modeling approach to address the underlying structure and constraints of thermal mark codes and code notation. (NPAFC Doc. 395) 12p. Alaska Department of Fish and Game, USA.

Hare, R.H., R.C. Francis, E.V. Farley Jr., and J.M. Murphy. 1998. A comment and response on time series outlier analysis. Alaska Fish. Res. Bull. 5: 67–73.

Hawkins, S., N. Varnavskaya, J. Pohl, and R.L. Wilmot. 1998. Simulations of the even-year Asian pink salmon (*Oncorhynchus gorbuscha*) genetic baseline to determine accuracy and precision of stock composition estimates. N. Pac. Anadr. Fish Comm. Bull. No. 1: 213–219.

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. *In* Climate change and northern fish populations. *Edited by* R.J. Beamish. Can. Sp. Pub. Fish. Aquat. Sci.. 121: 245–260.

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. N. Pac. Anadr. Fish Comm. Bull. No. 1: 81–89.

Ignell, S.E., C.M. Guthrie, J.H. Helle, and K. Munk. 1997. Incidence of thermally-marked chum salmon in the 1994–96 Bering Sea pollock B-season trawl fishery. (NPAFC Doc. 246) 16p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Isakov, A.G., O.A. Mathisen, S.E. Ignell, and T.J. Quinn II. This volume. Ocean growth of sockeye salmon from the Kvichak River, Bristol Bay based on scale analysis. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Ishida, Y., T. Azumaya, Y. Ueno, G. Anma, T. Meguro, H. Yamaguchi, Y. Kajiwara, S. Takagi, Y. Kamei, K. Sakaoka, N.D. Davis. R.V. Walker, and K. W. Myers. 1998a. Stock abundance and fish size of Pacific salmon in the North Pacific Ocean, 1998. (NPAFC Doc. 323) 25p. National Research Institute of Far Seas Fisheries, Japan; Hokkaido University, Japan; University of Washington, USA.

Ishida, Y., Y. Ueno, A. Shiomoto, T. Watanabe, T. Azumaya, M. Koval, and N.D. Davis. 1998b. Japan-Russia-U.S. cooperative survey on overwintering salmonids in the western and central North Pacific Ocean and Bering Sea aboard the *Kaiyo maru*, 3 Feb.–2 March, 1998. (NPAFC Doc. 329) 18p. National Research Institute of Far Seas Fisheries, Japan.

Jaenicke, H.W., M.J. Jaenicke, and G.T. Oliver. 1994. Predicting northern Southeast Alaska pink salmon returns by early marine scale growth. *In* Proceedings of the 16th Northeast Pacific pink and chum salmon workshop, Alaska Sea Grant College Prog. Rep. No. 94-02. pp. 97–109.

McKinnell, S., J.J. Pella, and M.L. Dahlberg. 1997. Population-specific aggregations of steelhead trout (*Oncorhynchus mykiss*) in the North Pacific Ocean. Can. J. Fish. Aquat. Sci. 54: 2368–2376.

McPhail, J.D. 1997. The origin and speciation of *Oncorhynchus* revisited. *In* Pacific salmon and their ecosystems. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, International Thomson Publishing, New York. pp. 29–37.

Munk, K. 1999. Discrimination of multi-country thermal mark codes by augmentation of coding schemes or marking mechanisms. (NPAFC Doc. 396) 14p. Alaska Department of Fish and Game, USA.

Murphy, J.M. 1998. Cruise report JC-98-05. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Murphy, J.M., A. Brase, L. Hulbert, E. Martinson, and J.A. Orsi. 1997. Cruise report JC-97-17. (14p.) Auke Bay Laboratory, National Marine Fisheries Service, USA.

Murphy, J.M., H.W. Jaenickie, and E.V. Farley. 1998. The importance of early marine growth to interannual variability in production of southeastern Alaska pink salmon. *In* Workshop on climate change and salmon production, Vancouver, B.C. March 26–27, 1998. *Edited by* K. Myers. NPAFC Tech. Rep. pp. 18–19.

Murphy, J.M., A.L.J. Brase, and J.A. Orsi. 1999. Survey of juvenile Pacific salmon in the northern region of southeastern Alaska, May–October 1997. NOAA Tech. Memo. NMFS-AFSC-105. 40p.

Myers, K.W., K. Y. Aydin, R.V. Walker, S. Fowler, and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956–1995. (NPAFC Doc. 192) 4p. + figs. University of Washington, USA.

National Marine Fisheries Service. 1995. Ocean carrying capacity program: an implementation plan for the Gulf of Alaska. (NPAFC Doc. 119) 34p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

North Pacific Anadromous Fish Commission. 1993. Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean, Vancouver, B.C.

North Pacific Anadromous Fish Commission. 1999. N. Pac. Anadr. Fish Comm. Annu. Rep. 1999: 34–63

Ocean Carrying Capacity Program. 1999. An Ocean

Carrying Capacity (OCC) strategic plan for eastern Bering Sea (Bristol Bay) coastal research on Bristol Bay salmon. (NPAFC Doc. 447) 14p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Orsi, J.A. 1997. Cruise reports JC-97-06 (6p.), JC-97-09 (8p.), and JC-97-11 (8p.). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, USA.

Orsi, J.A and J.M. Murphy. 1997. Cruise report JC-97-14 (8p.). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., J.M. Murphy, and A.L.J. Brase. 1997. Survey of juvenile salmon in marine waters of southeastern Alaska, May–August 1997. (NPAFC Doc. 277) 27p. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., D.G. Mortensen, and L. Hulbert. 1998a. Cruise report JC-98-18 (10p.). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., J.M. Murphy, and D.G. Mortensen. 1998b. Survey of juvenile salmon in marine waters of southeastern Alaska, May–August 1998. (NPAFC Doc. 346) 26p. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., J.M. Murphy, D.G. Mortensen, and W.R. Heard. 1998c. Cruise report JC-98-15 (10p.). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., J.M. Murphy, D.G. Mortensen, and A.C. Wertheimer. 1998d. Cruise report JC-98-11 (10p.). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., J.M. Murphy, M.V. Sturdevant, and J. Boldt. 1998e. Cruise report JC-98-08 (9p.). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA.

Orsi, J.A., M.V. Sturdevant, J.M. Murphy, D.G. Mortensen, and B.L. Wing. This volume. Seasonal habitat use and early marine ecology of juvenile Pacific salmon in Southeastern Alaska. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Patton, W.S., K.W. Myers, and R.V. Walker. 1998. Origins of chum salmon caught incidentally in the eastern Bering Sea walleye pollock trawl fishery as estimated from scale pattern analysis. N. Am. J. Fish. Manage. 18: 704–711.

Pearcy, W.E. 1997. Salmon production in changing ocean domains. *In* Pacific salmon and their ecosystems. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, International Thomson Publishing, New York. pp. 331–352.

Pearcy, W.G., K.Y. Aydin, and R.D. Brodeur. 1999. What is the carrying capacity of the North Pacific Ocean for salmonids. PICES Press 7: 17–23.

Seeb, J.E., C. Habicht, J.B. Olsen, P. Bentzen, J.B. Shaklee, and L.W. Seeb. 1998. Allozyme, mtDNA, and microsatellite variants describe structure of populations of pink and sockeye salmon in Alaska. N. Pac. Anadr. Fish Comm. Bull. No. 1: 300–318.

Sturdevant, M.J., S.E. Ignell, and J. Morris. 1997. Diets of juvenile salmon off southeastern Alaska, October, 1995. (NPAFC Doc. 275) 16p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Tadokoro, K., Y. Ishida, N.D. Davis, S. Ueyanagi, and T. Sugimoto. 1996. Change in chum salmon (*Oncorhynchus keta*) stomach contents associated with fluctuations of pink salmon (*O. gorbuscha*) abundance in the central subarctic Pacific and Bering Sea. Fish. Oceanogr. 5: 89–99.

Ueno, Y., N.D. Davis, M. Sasaki, and I. Tokuhiro. 1998. Japan-U.S. cooperative high-seas salmonid research aboard the R/V *Wakatake maru* from June 9 to July 25, 1998. (NPAFC Doc. 326) 55p. National Research Institute of Far Seas Fisheries, Japan; University of Washington, USA; Japan Marine Fisheries Resources Research Center, Japan; Tokyo University of Fisheries, Japan.

Urawa, S., K. Nagasawa, L. Margolis, and A. Moles. 1998. Stock identification of chinook salmon (*Oncorhynchus tshawytscha*) in the North Pacific Ocean and Bering Sea by parasite tags. N. Pac. Anadr. Fish Comm. Bull. No. 1: 199–204.

Volk, E., and P. Hagen. 1999. On using an adaptive approach to minimize thermal mark duplication and using strontium marking as a means to increase the variety of marking options. (NPAFC Doc. 394) 5p. Alaska Department of Fish and Game, USA.

Walker, R.V., K.W. Myers, and S. Ito. 1998. Growth studies from 1956–95 collections of pink and chum salmon scales in the central North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. No. 1: 54–65.

Walker, R.V., K.W. Myers, N.D. Davis, K.Y. Aydin, and K.D. Friedland. This volume. Using temperatures from data storage tags in bioenergetic models of high-seas salmon growth. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Walker, R.V., K.W. Myers, N.D. Davis, K.Y. Aydin, K.D. Friedland, H.R. Carlson, G. Boehlert, S. Urawa, Y. Ueno, and G. Anma. 2000. Diurnal variation in thermal environment experienced by salmonids in the North Pacific as indicated by data storage tags. Fish. Oceanogr. 9: 171–186.

Wilmot, R.L., C.M. Kondzela, C.M. Guthrie, and M.M. Masuda. 1998. Genetic stock identification of chum salmon harvested incidentally in the 1994 and 1995 Bering Sea trawl fishery. N. Pac. Anadr. Fish Comm. Bull. No. 1: 285–299.

Wilmot, R.L., C.M. Kondzela, C.M. Guthrie, A. Moles, E. Martinson, and J.H. Helle. 1999. Origins of sockeye and chum salmon seized from the Chinese vessel *Ying Fa*. (NPAFC Doc. 410) 20p. Auke Bay Laboratory, National Marine Fisheries Service, USA.

Winans, G.A., P.B. Aebersold, Y. Ishida, and S. Urawa. 1998. Genetic stock identification of chum salmon in highseas test fisheries in the Western North Pacific Ocean and Bering Sea. N. Pac. Anadr. Fish Comm. Bull. No. 1: 220–226.

Wing, B.L., and J.J. Pella. 1998. Time series analyses of climatological records from Auke Bay, Alaska. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-91. 90p.

Yamaguchi, H., S. Takagi, Y. Kamei, T. Yoshida, J. Kimura, G. Anma, H. Ohnishi, R.V. Walker, S. T. Shoji, S. Urawa. 1999. The 1999 international cooperative salmon research cruise of the *Oshoro maru*. (NPAFC Doc. 419) 26p. Hokkaido University, Japan.