

2010 Arctic Yukon Kuskokwim (AYK) Sustainable Salmon Initiative Project Final Product¹

Climate-Ocean Effects on AYK Chinook Salmon



by

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ABSTRACT

A high-priority research issue identified by the Arctic-Yukon-Kuskokwim (AYK) Sustainable Salmon Initiative (SSI) is to determine whether the ocean environment is a more important cause of variation in the abundance of AYK Pacific salmon (*Oncorhynchus* spp.) populations than marine fishing mortality. At the outset of this project, however, data on ocean life history of AYK salmon were too limited to test hypotheses about the effects of environmental conditions versus fishing on marine survival. Our goal was to identify and evaluate life history patterns of use of marine resources (habitat and food) by Chinook salmon (*O. tshawytscha*) and to explore how these patterns are affected by climate-ocean conditions, including documentation of local traditional knowledge (LTK) of this high-priority issue. Synthesis of LTK from the Bering Straits region identified important changes in adult AYK Chinook salmon biological characteristics, climate, and fishing. Local experts observed later run timing, a decrease in body size and stomach contents, and an increase in diseases, parasites, and deformities in adult salmon; environmental changes, including strength and direction of wind, timing of freeze- and break-up, warming of ocean and river temperatures, accompanied by increases in algae, water grasses, jellyfish, and erosion events; an increase in marine subsistence harvests of salmon; and salmon bycatch in Bering Sea/Aleutian Islands (BSAI) trawl fisheries for walleye pollock. Multiple lines of scientific evidence indicated that Chinook salmon respond to variation in climate-ocean conditions and fishing by changes in distribution, diet, size and age at maturation, growth, and survival. Evidence from tagging and other stock identification methods suggested that AYK Chinook spend most of their ocean life in the Bering Sea. Distribution of immature AYK Chinook is farthest offshore in their second summer-fall at sea, extending into the Russian Exclusive Economic Zone in the northwestern Bering Sea. Unlike other species of AYK salmon, AYK Chinook overwinter in the BSAI fishery area. Limited data from electronic tags showed Chinook have a deeper vertical distribution than any other salmon species, with the known vertical range extending from the surface to a depth of 523 m (1,717 ft). These life-history traits make AYK Chinook more susceptible than other AYK salmon species to bycatch in winter BSAI trawl fisheries. Reconstructions of growth histories indicated growth of Yukon River Chinook salmon shifted to a positive phase in 1999-2000 that continued through 2009, but did not result in increased adult returns to the river. We completed the first study of winter diets of Chinook in the BSAI bycatch. The primary prey was squid, although many fish had empty stomachs. All age groups of Chinook in winter consumed fish offal, which is of low nutritional quality (identified by DNA analysis as walleye pollock, likely from fishery catch-processing activities). Bioenergetics models indicated that warm temperatures over Alaska and at sea and high quality diets are associated with increased growth of AYK Chinook. Climate-ocean variables most linked to increased AYK Chinook salmon growth – lower sea ice cover and warmer temperatures – are projected by climate models to change in the Bering Sea this century, with temperatures increasing at higher latitudes by 2°C (3.6°F) and ice cover diminishing and retreating earlier. We concluded that the low abundance of some populations of AYK Chinook makes them vulnerable to adverse changes in climate-ocean conditions and fisheries. Relationships among climate, fishery, and other factors affecting growth and survival of AYK Chinook in both marine and freshwater habitats are complex and point to critical needs for additional research, management, and restoration actions to ensure sustainability of this valuable natural resource.

KEY WORDS

Bering Sea, Chinook salmon, climate, fishing, local traditional knowledge, distribution, age, growth, diet, bioenergetics

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I. INTRODUCTION

This project, Alaska Sustainable Salmon Fund (AKSSSF) Project 45128 (700) addresses the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYK SSI) research priority: “Marine survival of salmon is more affected by variability in ocean temperature and environmental variables than by variability in marine fishing mortality.” At present, population-specific data on the ocean life history of AYK Chinook salmon (*Oncorhynchus tshawytscha*) are too limited to test hypotheses about the relative effects of environment vs. fishing on their marine survival. The goal of this project was to identify and evaluate life history patterns of use of marine resources (habitat and food) by Chinook salmon, and to explore how these patterns are affected by climate-ocean conditions in the Bering Sea and North Pacific Ocean. This project completes work begun in AKSSSF Project 45559 (Phase 1) and 45667 (Phase 2).

An issue of concern to Arctic-Yukon-Kuskokwim (AYK) salmon fishermen and managers is whether climate-induced changes in ocean conditions or ocean fisheries are contributing to unexpected fluctuations in the abundance of adult Pacific salmon (*Oncorhynchus* spp.) returns to the AYK region (AYK SSI 2006). Climate might affect the marine survival of AYK salmon directly (e.g., lethal sea temperatures) or indirectly by altering their distribution, migration patterns, growth, and trophic interactions. Similarly, fishing might affect salmon survival directly through harvest or indirectly through injury, stress, delayed mortality, and selection changes in growth and run timing (Hard et al. 2009). Climate and fishing effects might also work in concert to reduce salmon survival. For example, climate-induced ontogenetic effects on population structure and trophic dynamics might be modified through size-selective removals of fish by marine fisheries. If ocean distribution, migration patterns, and trophic interactions of AYK salmon vary by life history stage, then a single climatic or fishery event might have varied effects on different cohorts of salmon from the same population. To understand how climate and fishing affect the marine survival of AYK Chinook salmon, we first need to know when and where they migrate in the ocean and how they respond to changes in climate and ocean conditions.

Biological and ecological information on salmon in the ocean is sometimes regarded as “nice to know” but “not necessary” for management of salmon. On the other hand, many people now recognize that climate change can make the ocean environment unstable for salmon. Uncertainty about how climate-ocean conditions affect adult salmon returns to rivers leads to highly conservative management of marine and freshwater fisheries, sometimes including unnecessary closures of fisheries in an attempt to achieve biological escapement goals. Much of the uncertainty in the results of previous attempts to address this issue is due to a lack of understanding of the marine life history of salmon and their ecological role in marine ecosystems. Managers will not be able to use climate and oceanographic data to adjust inseason management of fisheries until we know when, where, and how AYK salmon respond to changes in these environmental conditions. As a result, salmon, salmon fisheries, and fishers in the AYK region stand to benefit greatly from a mechanistic understanding of biological and ecological responses of AYK salmon to variation in climate and ocean conditions.

II. OBJECTIVES

This project had nine objectives that were successfully completed with no significant problems encountered during completion. Below we provide a brief description of results obtained from addressing each objective.

Objective 1: Develop a Comprehensive High Seas Chinook Salmon Database (1955-2009) for AYK SSI

We assembled a comprehensive database of historical and recent high seas Chinook salmon data (1955-2009) and local traditional knowledge (LTK) pertaining to Chinook, associated species, ocean conditions, and climate in the Bering Straits region (approximately 400,000 data records). We also develop a metadatabase that included biological, geographic, and database location information, data

formats, and descriptions of variables. The high seas database and associated metadata (approximately 20 gigabytes) were provided to AYK SSI on Universal Serial Bus (USB) flash drive as a final product.

Objective 2: Map Ocean Distribution and Migration Routes of Chinook Salmon

We developed a series of GIS maps (atlas) from high seas tag recovery data showing stock-specific ocean distribution and migration of AYK Chinook salmon and other species of AYK salmon in the Bering Sea and North Pacific Ocean. We evaluated existing data on ocean distribution and migration routes, identified size/age/maturity-specific migration patterns, and developed a new conceptual model of ocean distribution and migration of AYK Chinook salmon. We reviewed information on times and areas of overlap in distribution of AYK Chinook salmon with other species and stocks (hatchery and wild) of Asian and North American salmon, identified major gaps in information, and made recommendations for future research. Accomplishments included three peer-reviewed publications. These publications, along with tag data and distribution maps, were provided to AYK SSI as final products.

Objective 3: Reconstruct Histories of Ocean Age, Growth, and Size-Selective Mortality of Chinook Salmon

We reconstructed histories of ocean age, growth, and potential size-selective mortality of Chinook salmon using measurements of seasonal and annual growth increments on the scales. Three primary data sets were developed and analyzed: (1) NOAA Fisheries Observer (OBS) program samples from the Chinook salmon bycatch of U.S. pollock trawl fisheries in the eastern Bering Sea in winter 1997-2008 (ages 1.2, 1.3, and 1.4, n=1,837 fish), (2) Japanese research vessel *Wakatake maru* (WAK) Chinook salmon samples from the central Bering Sea in July 1991-2009 (age 1.2, n=573 fish), and (3) an existing time series (1964-2004; Ruggerone et al. 2007; 2009a,b) of adult Yukon (YUK) Chinook (ages 1.3 and 1.4) that we extended to include females caught in 2005-2009 (n=267 fish). Accomplishments include new scale measurement databases and corresponding digital images of scales, which were provided to AYK SSI as a final product. The results of our reconstructions of ocean age and growth histories were compared to results from other studies, used for bioenergetics models (Objectives 6), growth potential mapping (Objective 7), age and growth simulations (Objective 8), and simulations of climate change effects on Chinook salmon (Objective 9). Graduate student research on this objective is ongoing, and we anticipate a peer-reviewed publication of the results of this objective within the next year.

Objective 4: Map Climate and Ocean Conditions in Regions Where AYK Salmon Migrate

We mapped climate and oceanographic conditions in regions where AYK salmon migrate. Environmental data sets were used with distribution maps (Objective 2) to define critical salmon habitats, as well as for input to bioenergetics models (Objective 6), ocean growth potential maps (Objective 7), and climate change simulations (Objective 9). A digital database (atlas) of gridded (1-degree latitude by 1-degree longitude and month, 1954-2004, 50-m ocean surface layer) ecosystem data was provided as a final product.

Objective 5: Collect New Seasonal (Summer, Winter) Food Habits Data, and Evaluate Variation in Marine Diets of Chinook Salmon

Our objective was to collect and analyze new seasonal (summer, winter) food habits data and to evaluate variation in marine diets. This information was needed to understand how environmental conditions affect growth, maturation, and survival of AYK Chinook salmon. NOAA Fisheries Observer Program and port (Dutch Harbor) sampling of Chinook salmon bycatch in eastern Bering Sea groundfish fisheries provided an opportunity to sample Chinook salmon diets at times and in areas where no research information source was available. Collection and laboratory analysis of 2007-2009 (winter, summer) samples were completed. Our results provided the first data on winter diets of Chinook salmon in the eastern Bering Sea. Chinook salmon fed in winter; however, the proportion of fish with empty stomachs was higher in winter than summer. This suggested longer periods between meals in winter. Diversity of

squid species in Chinook salmon diets was higher in winter than summer, when more fish, particularly juvenile walleye pollock, were consumed. All age groups of Chinook salmon collected in winter consumed fish offal, likely generated by fishery catch-processing activities; however, fish offal was not observed in summer samples. In winter, the ratio of euphausiids and fish offal weight to Chinook salmon body weight was significantly higher in samples collected at shallow depths (< 200 m), and the ratio of squid was significantly higher in salmon collected at deeper depths (201–600 m). The ratio of euphausiids to fish body weight was significantly higher in immature than maturing Chinook salmon. Accomplishments included two peer-reviewed publications. Graduate student research on this objective is ongoing, and we anticipate a peer-reviewed publication of the results of this objective within the next year.

Objective 6: Estimate Consumption and Growth Efficiencies Modeled Under Different Climate Scenarios

We estimated consumption and growth efficiencies of Chinook salmon modeled under different climate scenarios. Bioenergetic models were used to evaluate the growth response (back calculated from scales) of female Yukon Chinook during the pre- (cool phase) and post-1977 (warm phase) Bering Sea ecosystem regime shifts. The increase in mean sea temperatures during the 5-yr period after the regime shift was similar to that projected by climate models to change in the Bering Sea this century, with mean sea temperatures increasing at higher latitudes by 2°C (3.6°F). Conversion efficiencies (net production/total prey consumption) were similar before and after the regime shift for most size/age/maturity groups of Yukon Chinook, except for juveniles during their first winter at sea (conversion efficiencies for juveniles more than doubled in the warmer later period). Seasonal growth rates indicated cooler summer conditions and warmer winter conditions favored higher growth rates. Accomplishments include new bioenergetics modeling tools. We anticipate a peer-reviewed publication of the results of this objective within the next year (September 1011).

Objective 7: Map Spatial and Temporal Variability in Ocean Growth Potential

Bioenergetic models and field-based observations of temperature, diet, and growth were used to develop seasonal, spatially explicit prey consumption and conversion estimates for AYK Chinook in the Bering Sea. The highest conversion efficiencies were estimated for juvenile fish on the northeastern Bering Sea shelf (NEBS) in summer and fall. In the central Bering Sea, conversion efficiencies of immature Chinook in summer were approximately double those of fish in SEBS continental shelf-break habitats in winter. Higher diet quality enabled growth at lower feeding rates and a wider range of thermal habitats than lower quality diet. Juveniles (ocean age .0) had substantially higher growth rates (g/g/day) than older fish, e.g., ten times higher than immature ocean age .4 fish consuming the same quality diet, over a broader range of thermal habitats than older fish. Optimal temperature for growth occurred at 11°-14°C (52°-57°F). Fish with an improved diet grew at higher temperatures than fish consuming a lower quality diet. The optimal temperature for growth declined with consumption rate in all age-maturity groups. Based on our analysis, Bering Sea habitats most favorable for AYK Chinook growth and survival have minimum winter temperatures above 2.5°C (36.5°F) and maximum summer temperatures below approximately 13°C (55°F). We anticipate a peer-reviewed publication of the results of this objective within the next year (September 1011).

Objective 8: Simulate Climate Effects on Age and Growth

We developed a size-structured model with age- and size-specific maturation rates to simulate response of AYK Chinook to climate-induced changes in growth and mortality rates. Age, sex, length, run size, and scale measurement data from age 1.3 and age 1.4 adult female Chinook salmon returning to the Yukon River during 1997-2004 were used in the analysis. Logistic regression analysis identified significant (positive) effects of length on the probability of maturing at age 1.3. Brood year effects were not statistically significant. Results were robust to assumptions about mortality, and threshold size at

maturity (50% probability of maturing) was relatively insensitive to changes in mortality rates. An optimal rule of size and age at maturity for female Chinook salmon was predicted for different growth rates and assumptions about mortality. Fish with low growth rates initiated maturation at an older age and smaller size than fish with high growth rates, and results were sensitive to changes in mortality rates. There was a good fit between the observed length threshold value for age 1.3 female Yukon River Chinook salmon and the model at relatively high mortality rates and growth rates. Estimated optimal ocean growth rates for 1992-1998 brood year females were low for both age groups. A simulation of average age and size at maturity indicated at low growth rates that no females would mature at age 1.3 and at high growth rates that all females would mature at age 1.3. Size of age 1.3 fish at maturation (in January) increased with growth rate. Observed (back-calculated from scale growth) average sizes of maturing age 1.3 female Yukon River Chinook salmon in January were comparable to simulated sizes at intermediate growth rates. Observed average sizes of age 1.3 female Chinook salmon in January samples from the bycatch of the BSAI trawl fishery were smaller than simulated sizes. We anticipate a peer-reviewed publication of our synthesis within the next year (September 1011).

Objective 9: Synthesize Information on the Ocean Life History and Climate-Ocean Effects on Chinook Salmon

Multiple lines of evidence indicated that Chinook salmon respond to climate-ocean conditions and fishing by changes in size and age at maturation, growth, and survival. Synthesis of local traditional knowledge in the Bering Straits region identified important changes in salmon and potential climate and fishery effects: (1) decrease in adult salmon body size and stomach contents; (2) increase in salmon with diseases, parasites, and deformities; (3) environmental changes, including strength and direction of wind, timing of freeze- and break-up, warming of ocean and river temperatures, accompanied by increases in algae, water grasses, jellyfish, and erosion events; (4) increase in marine subsistence harvests of salmon, primarily in response to freshwater fishery closures; and (5) salmon bycatch in Bering Sea trawl fisheries for walleye pollock. Our results indicated that warm temperatures over Alaska and at sea and high quality diets are associated with increased growth of AYK Chinook salmon. Climate-ocean variables most linked to increased salmon growth – lower sea ice cover and warmer temperatures – are projected by climate models to change in the Bering Sea this century, with temperatures increasing at higher latitudes by 2°C (3.6°F) and ice cover diminishing and retreating earlier. In 1999-2000, growth of Yukon R. Chinook shifted to a positive phase (Objective 3) that did not result in increased adult returns to the river. The current low abundance of Chinook in the Arctic-Yukon-Kuskokwim (AYK) region and their susceptibility to interception by Bering Sea trawl fisheries makes them vulnerable to adverse changes in climate-ocean conditions. Trawl fisheries have also affected Bering Sea food webs, as indicated by fish-processing wastes found in winter diets of Chinook salmon (Objective 5). Relationships among climate, fishery, and other factors affecting growth and survival of AYK Chinook salmon in both marine and freshwater habitats are complex and point to critical needs for additional research, management, and restoration actions to ensure sustainability of this valuable natural resource. We anticipate a peer-reviewed publication of our synthesis within the next year (September 1011).

III. METHODS

To address our objectives we used a comprehensive mechanistic approach including: (1) retrospective analyses of existing time series; (2) field and laboratory process studies; (3) computer mapping, modeling and simulations; and (4) use of local traditional knowledge (LTK) to generate hypotheses and interpret or validate results.

Methods: Study Areas and Field Research

Local Traditional Knowledge (LTK) Study Area, 2007-2008

Organizations and individuals performing the work: Julie Raymond-Yakoubian, Social Scientist, Kawerak, Inc., Nome, Alaska. Interview participants and methods are described in Methods: Objective 1.

Data on LTK of Chinook salmon, other species of salmon, other non-salmonid species, and climate and environmental changes were collected in the Bering Strait region during 2007 and 2008 (Fig. 5). The region covers 570 mi of coastline in the southern Chuckchi Sea, the Bering Sea, and Norton Sound, and is home to three distinct linguistic and cultural groups of Eskimo people; the Inupiaq, Central Yupik, and Saint Lawrence Island Yupik. There is documented evidence of human habitation dating as far back as 10,000 and 11,000 years. A subsistence lifestyle of hunting, gathering, and dependence on environmental resources continues throughout the region along with limited wage-based employment. Food gathering is a year around activity. In the springtime whale and walrus are hunted, eggs are gathered, greens, berries, and roots are gathered; during the summer and fall fishing and waterfowl hunting take place; caribou (*Rangifer tarandus*) and moose (*Alces alces*) are hunted in the fall; in the winter tomcod (*Microgadus proximus*) and king crab (*Paralithodes camtschaticus*) fishing takes place. Seal hunting is a year-round activity. Reindeer herding was introduced to the region about a hundred years ago and continues to this day. Muskox (*Ovibos moschatus*) were reintroduced to the region in 1970.

The total population of the Bering Strait region is about 9,000 people (75% Alaska Native people; Norbert et al. 2008). Nome is the largest community in the region (3,653 people, 2009 census), and is the transportation and service hub for the region. There are 15 year-round villages outside of Nome, extending from Shishmaref in the north to Stebbins in the south, including Little Diomed Island and St. Lawrence Island.



Figure 1. Map of the Bering Strait region, showing the three communities that participated in this study (Brevig Mission, Golovin, and Unalakleet). Map Image Source: ©2006 TerraMetrics and ©2005 Google.

We conducted LTK interviews in three villages: Unalakleet, Brevig Mission, and Golovin (Fig. 1). Unalakleet (752 people), the largest Kawerak-region community, is located in southern Norton Sound. Unalakleet had the historically highest harvest of Chinook salmon of the three communities, and has experienced the most significant declines in Chinook salmon abundance (e.g., Ahmasuk et al. 2008;

Conger and Magdanz 1990; Georgette and Utermohle 2000; Georgette et al. 2002, 2003, 2004). Brevig Mission (278 people) and Golovin (145 people) were chosen in an effort to have representation from throughout the geographical range of the region – Brevig Mission to the north and Golovin located centrally. The most recent subsistence salmon harvest data indicates harvests of 1,495 Chinook salmon (1,230 marine, 265 inriver) in Unalakleet in 2009 (Kent and Bergstrom 2009), 30 in Brevig Mission in 2006 (Ahmasuk et al. 2008), and 98 in Golovin in 1988 (Conger and Magdanz 1990).

R/V Wakatake maru Study Area, 2007-2009

Organizations and individuals performing the work: N. Davis, SAFS/UW participated in the summer 2007-2009 surveys of the R/V *Wakatake maru*. Japanese organizations and individuals performing the work included Captain Y. Murata (2007-2008), Captain T. Yoshino (2009), and the officers, crew, teachers, and students aboard the R/V *Wakatake maru*; M. Fukuwaka, Chief Scientist (2007-2008), Hokkaido National Fisheries Research Institute (HNFRI), Fisheries Research Agency, Kushiro, Japan; and T. Kaga, Chief Scientist (2009), National Salmon Resources Center, Fisheries Research Agency, Sapporo, Japan.

Comprehensive salmon research vessel surveys have been conducted aboard the *Wakatake maru* since 1991. These surveys were initially designed to investigate the carrying capacity of salmon in the North Pacific Ocean and Bering Sea. At the beginning of this project, the time series of *Wakatake maru* data, collected along a survey line at 180° longitude (Fig. 2), was long enough (15 years) to provide statistically and ecologically meaningful results. The time series includes fishing catch and effort data, biophysical oceanographic data (salinity, temperature, zooplankton), and biological data on Chinook salmon and ecologically related species.

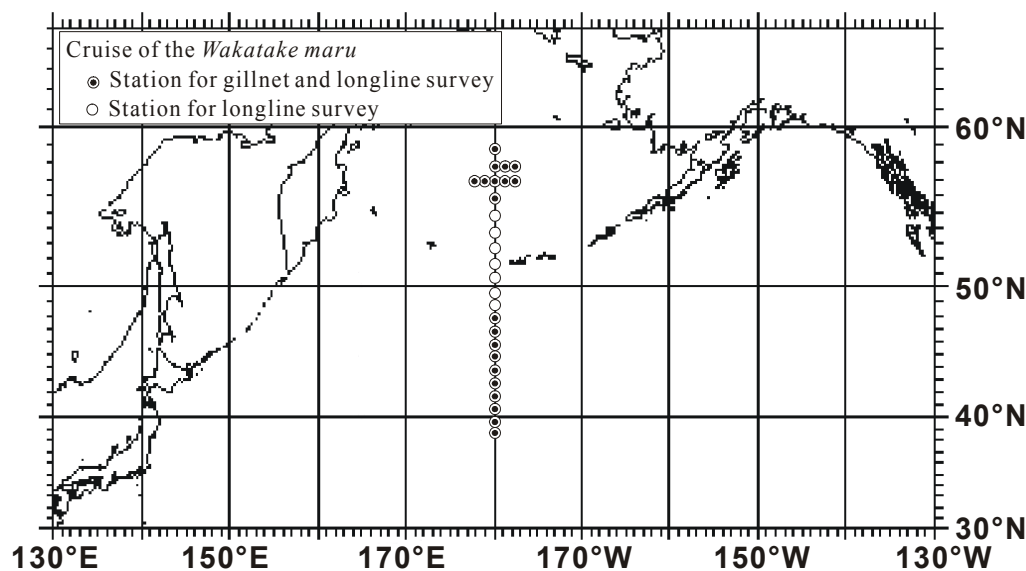


Figure 2. The survey area of the annual (June-July 1991-2010) salmon research cruise of the R/V *Wakatake maru*. Note: *Wakatake maru* surveys were terminated after the July 2010 survey.

In 2007-2009, the *Wakatake maru* salmon survey continued a fishing strategy established in the beginning of the survey series. Outside the US 200-mile exclusive economic zone (EEZ) both gillnet and longline-fishing gear was used, and within the US EEZ only longline fishing gear was used. A non-selective research gillnet, 2.4 km in length with variable mesh sizes (48-157 mm), was used to catch Chinook salmon of all size and age groups. The gillnet was set overnight for 12 hours. The surface

longline was 3.3 km long, and was set for one hour at sunset. Longline catches were primarily designed for live capture of fish for tagging experiments, however, Chinook salmon not suitable for tagging were available for biological sampling. Oceanographic data (temperature, depth, salinity) were collected by CTD at each fishing station, and combinations of CTD, XCTD, and XBTs were used to collect oceanographic data on the outbound and inbound transit.

During shipboard operations, M. Fukuwaka (2007-2008) and T. Kaga (2009) were responsible for managing accurate measurement and recording of Chinook salmon biological characteristics including fork length (FL, mm), body weight (BW, g), sex, and gonad weight (GW, g). Two scales, one from each side of the fish, were mounted on gummed cards, and additional scale scrape samples were collected for genetic analysis (in cooperation with J. Seeb, SAFS). Collection of new biological data on size, maturity, and scales for age and growth contributed to compilation of a comprehensive biological database (Objective 1), reconstruction of histories of age, growth, and size-selective mortality (Objective 3), bioenergetics modeling (Objectives 6 and 7), and syntheses of climate-ocean effects on Chinook salmon (Objective 9). During the survey, all Chinook salmon were inspected for clipped adipose fins (indicating the presence of a coded-wire tag (CWT)). New recoveries of CWT-tagged Chinook salmon would contribute to information on stock-specific ocean distribution of Chinook salmon (Objective 2, see below). To our knowledge, Canadian Yukon Chinook salmon (hatchery fish) are the only CWT salmon released into AYK-region rivers.

During the cruise, N. Davis was responsible for analysis of stomach contents, coordinating exchange of electronic data, and managing the collection of Chinook salmon samples. Analysis of Chinook salmon stomach samples was conducted in a shipboard laboratory. Detailed methods of stomach content analysis are described in Methods Objective 5. Data from shipboard stomach content analyses was used for analyses of variation in Chinook salmon food habits (Objective 5), estimates of prey consumption (Objective 6), and to assist in evaluating spatial and temporal variation in ocean growth potential (Objective 7).

During longline operations aboard the *Wakatake maru*, all viable Chinook salmon were tagged and released by Japanese scientists (M. Fukuwaka). AYK-SSI funding was used to tag Chinook salmon and associated salmon species with two types of tags for AYK-region recoveries. All viable salmon were tagged with traditional high seas salmon tags, which are solid red plastic Petersen disks tags imprinted with a unique identification number and addresses of the SAFS, the National Salmon Resources Center (NASREC) in Japan, and the Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO) in Russia. In addition, up to 20 Chinook salmon per year were tagged with data storage tags (DST) that record sea temperature and depth. Based on previous *Wakatake maru* salmon tagging operations, 20 fish was the expected number of Chinook salmon per year that would be viable for DST tagging. We budgeted for the purchase of 50 DSTs (Lotek model LAT 1400) for this 3-year study. All Chinook salmon tagged and released during previous years of *Wakatake maru* tagging in the Bering Sea in July were immature fish that would have spent one or more additional years at sea before returning to spawn. While recovery rates of high-seas tags from immature fish are low (approximately 5%), any new temperature-depth data time series obtained for AYK region recoveries would provide invaluable information on the seasonal behavior and habitats of Chinook salmon in the Bering Sea (see Objective 2 for additional methods and results of tagging).

The High Seas Salmon Research Program staff (K. Myers, N. Davis, R. Walker) coordinated cooperative salmon tagging aboard the *Wakatake maru*, and advertising for recovery of tagged fish within the AYK region (including Canadian Yukon) fishers, processors, and fishery management agencies, as well as in Japan and Russia (principal contacts, M. Fukuwaka and KamchatNIRO). Fishermen returning tags were provided information letters with data on their tagged fish and a reward cap embroidered with the international cooperative high seas salmon tagging logo. In addition, they were included in a drawing for cash prizes by the North Pacific Anadromous Fish Commission at their annual meeting in fall 2009.

***Oshoro maru* – International Polar Year (IPY) Study Area, 2007**

Organizations and individuals performing the work: Japanese organizations included primarily the Faculty of Fisheries, Hokkaido University (HU) and HU's research vessel *Oshoro maru*. Individuals performing the work included Captain Meguro and crew, S. Saitoh, Chief Scientist, M. Kaeriyama, Chief Salmon Scientist. AK SSF-funded personnel included K. Myers (SAFS), and H. Herter (UAF, Sea Grant, Nome). AK SSF funds covered travel costs and shipboard per diem. As part of the survey, we carried out public outreach activities in the AYK (Nome, Alaska) region with the assistance of R. Fosdick and A.C. Odden, Kawerak, Inc., and H. Herter (UAF, Sea Grant, Nome).

The HU's research vessel *Oshoro maru* (72.85 m long, 1,792 tons) was used in July and August 2007 for a special International Polar Year (IPY) research survey in the Bering and Chukchi seas (Fig. 3). IPY research in 2007-2009 was focused on the three fastest warming regions on the planet in the last two decades (Alaska, Siberia, and parts of the Antarctic Peninsula) and concerns about the effects of climate change, the future of polar ecosystems, and Arctic society (<http://www.ipy.org/>). The overall goal of this cruise was to investigate marine ecosystem responses to global climate change in the Bering and Chukchi Seas. Shipboard activities focused on AYK salmon research in cooperation and coordination with an international team of experts on climate, oceanography, fish, and other marine biota. The objectives of the Salmon Research Group (M. Kaeriyama, Chief Scientist) during the survey were to collect samples and data for evaluation of ecosystem dynamics, and growth, feeding ecology, and trophic dynamics of salmon in the Bering Sea and Chukchi Sea. Bongo nets were used to collect zooplankton samples. Fishing gear available for catching salmon during the survey included a surface longline, a bottom trawl, and angling with rods and reels. A research gillnet, used to collect salmon specimens during portions of Leg 1 of the *Oshoro maru* survey, was not authorized for use inside the US EEZ.

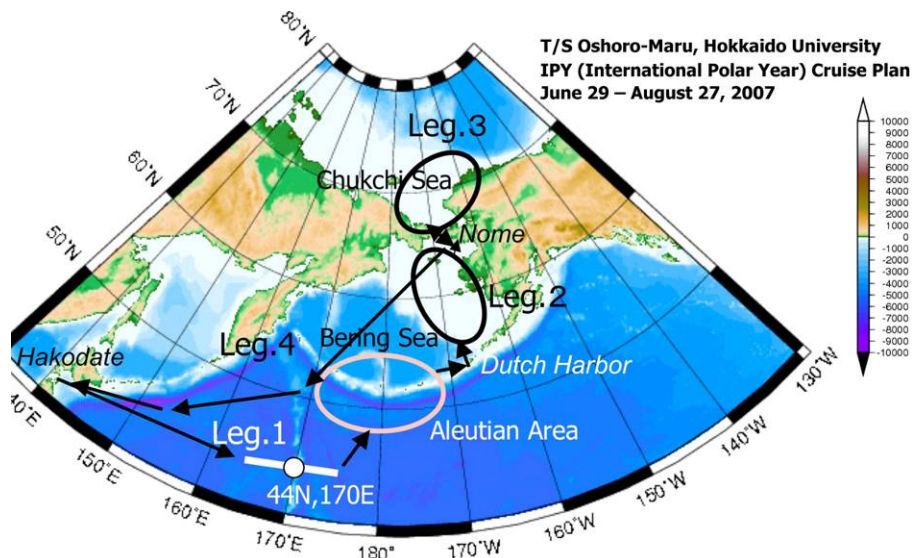


Figure 3. *Oshoro maru* International Polar Year study area, June 29-August 27, 2007. Arrows indicate the direction of the survey. Leg 1: June 29, 2007 (Hakodate, Japan) to July 21, 2007 (Dutch Harbor, Alaska); Leg.2: July 24, 2007 (Dutch Harbor) to August 3, 2007 (Nome, Alaska); Leg.3: August 5, 2007 (Nome) to August 15, 2007 (Nome). Port calls were at Dutch Harbor on July 21-24, 2007 and at Nome on August 3-5 and 15-16, 2007.

Observations and sampling gear included conductivity, temperature, depth, and water samples from multiple depths in the water column (CTD/Rosette sampler), physical and chemical analyses (temperature, salinity, dissolved oxygen, total carbonate, dissolved Fe, total Fe, Radium-223, Radium-224, pH,

nutrients, primary productivity and Chl *a*), XCTD measurements, bio-optical measurements for calibrating satellite data, fish larvae collection (Bongo net), plankton collection (twin-NORPAC net and closing NORPAC net), bottom trawling, frame trawling, long-line and ROV sampling for fish, beam-trawling for benthic organisms, and a cetacean sighting survey.

Processing Plant Sampling Study Area, 2009

Organizations and individuals performing the work: W. Fournier (Graduate Research Assistant, SAFS/UW). The fieldwork was coordinated with the U.S. National Marine Fisheries Service (NMFS) Observer Program, Fisheries Monitoring and Analysis (FMA) Division, Alaska Fisheries Science Center, Seattle (M. Loeffled and J. Berger), P. Wilkins, NMFS Observer Program (Dutch Harbor, Alaska), D. Boisseau (Westward Seafoods, Dutch Harbor), D. Goodfellow (Alyeska Seafoods, Dutch Harbor), and D. Graves (Unisea Seafoods, Dutch Harbor).

In January and September 2009, Chinook salmon caught as by-catch from commercial pollock trawlers (Fig. 4) were sampled at fish-processing plants in Dutch Harbor, Alaska. Due to the restricted status of by-caught Chinook salmon in the commercial pollock fishery, a limited number of fish were approved by NMFS for removal of tissue samples from the processing plant ($n = 40$ fish). Fish were sampled for scales, length, weight, sex, maturity, stomach fullness, stomach contents, muscle tissue, gonad weights, gonad tissue, and bioelectrical impedance analysis (BIA) measures. Whole fish were frozen, cut into sections with a reciprocating saw, and then homogenized by a meat grinder. A sub-sample of homogenate and whole gonads were retained to be analyzed for total caloric content via bomb calorimetry at the University of Washington. Laboratory analysis methods are described in Methods: Objective 5.



Figure 4. Observer data map showing relative abundance of Chinook salmon (catch per unit effort, as a percentage of observed catch) in the bycatch of pelagic trawl fishery in the Bering Sea Aleutian Islands area in 2009. Plant sampling of Chinook salmon bycatch was conducted at Dutch Harbor, Alaska.

NOAA Ship Oscar Dysan Study Area, 2009

Organizations and individuals performing the work: W. Fournier (Graduate Research Assistant, SAFS). The work was coordinated with NOAA Ship *Oscar Dysan* officers, crew, and scientists (Chief Scientist, E. Farley, NOAA, Alaska Fisheries Science Center, Auke Bay Laboratories, Juneau).

To supplement summer-fall samples of immature (ocean age .1 or older) Chinook salmon collected at processing plants in Dutch Harbor, W. Fournier participated in the September 2009 U.S. BASIS survey of the NOAA Ship *Oscar Dysan* (63.8 m long) in the eastern Bering Sea (Fig. 5). Fishing stations were sampled with a mid-water rope trawl (198 m long, 55 m horizontal spread, 15 m vertical spread; 1.2-cm mesh liner in the codend). The trawl was towed for 30 minutes during daylight hours at approximately 6-9 km/h with the head rope at or near the surface. Methods of shipboard processing and analysis of salmon samples were similar to those previously described for processing plant sampling in Dutch Harbor.

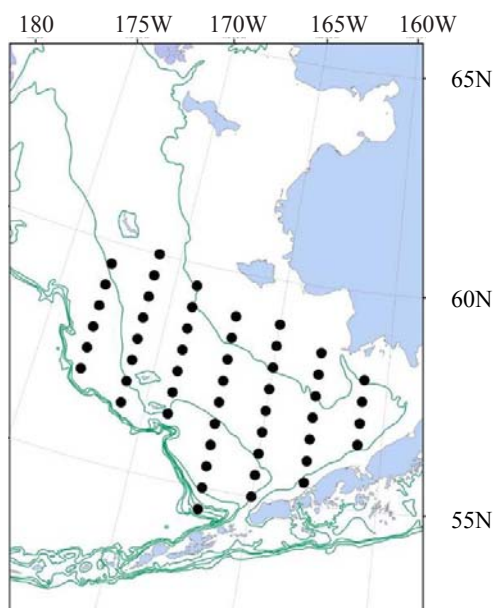


Figure 5. Surface trawl stations sampled during the September 1-30, 2009 BASIS research cruise on the NOAA Ship *Oscar Dyson*. (Source: http://bsierp.nprb.org/results/documents/B90_pr_Oct09.pdf).

Methods Objective 1: Develop a Comprehensive High Seas Chinook Salmon Database

Organizations and individuals performing the work: K. Myers, R. Walker, N. Davis, J. Armstrong, and W. Fournier (SAFS/UW) assembled the historical high seas salmon database. J. Raymond-Yakoubian, Kawerak Social Scientist conducted LTK interviews and assembled LTK interview data; three local assistants worked on LTK interviews: M. Nayokpuk (Brevig Mission), C. Oliver (Golovin) and M. Eakon (Unalakleet); local experts in Brevig Mission were R. Rock, Sr., R. Olanna, H. Seetot, E. Seetot and D. Seetot; local experts in Golovin were I. Aukongak, M. Olson, R. Amarok, T. Punguk, and T. Anungazuk, and D. Anungazuk. Local experts in Unalakleet were S. Johnson, B. Eakon, J. Ivanoff, L. Paniptchuk, L. Eakon, M. Katongan, D. Katongan, O. Koutchak, and M. Koutchak.

Historical High Seas Salmon Research Database

Our first objective was to assemble a comprehensive high seas Chinook salmon database. As part of our high seas salmon research over the past 50 years, SAFS/UW has accumulated a unique historical collection of research vessel catch, effort, biological, and tagging data, as well as commercial fishery data, on Chinook salmon and associated oceanographic data. Most of the data were collected during U.S., Canadian, and Japanese INPFC-related high seas research cruises and observer programs (1955-1992), cooperative U.S.-U.S.S.R. high seas salmon research (1983-1991, cooperative NPAFC-related research (1992-present), and sampling of prohibited species bycatch by the US NMFS North Pacific Groundfish Observer Program (1977-1982, 1997-1999). At the beginning of this project, these data were stored on magnetic media in a variety of different data formats (e.g., ASCII or text, Microsoft (MS) Office Excel, MS Office Access).

The data were edited to standardize variable names, formats, and measurement units across all data time series to the greatest extent possible. Data editing and coding were verified by crosschecking with original data records. This database was updated annually with new data collected during our study, i.e., research vessel data, ocean-climate data, scale growth measurement data and images, and stomach contents data and images.

We also developed a metadatabase that included biological, geographic, and database location information, data formats, and descriptions of variables. For final distribution, we determined that most potential users preferred data formatted in MS Office Excel workbooks. Therefore, each distinct time series of data were formatted in separate MS Excel Workbooks that include one metadata worksheet and one or more data worksheets. File names are descriptive of the file contents, including the country and agency, organization, or program that collected the original data, the data type, and the years covered by the time series. Finally, the files were grouped into folders according to five major categories of data (catch, specimen, tag, food habits, and scale measurement data). Copies of the data files (on USB flash drive) were provided to AK SSF and AYK SSI.

Local Traditional Knowledge Database

All LTK research was carried out by Kawerak, Inc., with the consent of local regional tribal councils and individual participants, in 2007 and 2008. To collect data for this project, in-depth semi-structured ethnographic interviews were conducted with Local Experts in each of the three participating communities. Local Experts were defined as individuals who have lived in the area for an extended period and are intimately familiar with salmon fishing activities and the local environment. Local Experts were identified by their respective tribal councils and were paid an honorarium for their participation; a symbolic recognition of the fact that the time and knowledge of Local Experts is valuable. The interviews were conducted by Kawerak Social Scientist Julie Raymond-Yakoubian and a local assistant from each community. The interviews were semi-structured and used a standard interview protocol to guide the topics of conversation (Appendix 4), but were open-ended in nature, allowing participants to dictate the pace and specific details of the interview. In addition to the general flexibility of the interviews, interviewees were also given an opportunity at the conclusion of the session to bring up any other topics that they felt were relevant to the interview objectives, but had not yet been addressed. The majority of Local Experts were interviewed independently, but several married couples were interviewed together (the Anungazuk's, the Katongan's, and the Koutchak's – see Appendix 5). Tribal councils had the opportunity to review and comment on the interview guide prior to the start of work. All interviews were digitally recorded. One Local Assistant was hired in each community to assist with interviews and to act as a local guide. J. Raymond-Yakoubian trained each Local Assistant in the interview protocol and recording equipment operation prior to the start of work.

Some key topics discussed during Local Expert interviews included the following:

- Changes in Chinook population numbers over the lifetime of the interviewee
- Changes in Chinook health over the lifetime of the interviewee

- Changes in Chinook behavior over the lifetime of the interviewee (e.g. colonization of new streams, run timing)
- Chinook fishing locations and harvest strategies
- Changes in other species of salmon over the lifetime of the interviewee
- Changes in the environment/climate in and around the community over the lifetime of the interviewee (e.g. timing and character of spring ice break-up, water temperatures)

While the focal species of this project was Chinook salmon, LTK data were also gathered on other species of salmon and non-salmonid fish, as well as on terrestrial climate and environmental changes observed by participants over the course of their lifetimes. As some of this information may be relevant or useful in determining climate-ocean effects on Chinook salmon, it has been included here. This project was carried out concurrently with AYK SSI project #601, for which detailed information was collected on a variety of topics relating to salmon, other species and environmental changes.

Transcripts of the Local Expert's interviews were reviewed in detail and examined to determine if there was consensus among interviewees on particular subjects. The results detail where and if consensus exists between interviewees in each community, and across all three communities. Areas of disagreement, novel observations, or areas where there is lack of information are also presented. Reports documenting harvest survey-type data most typically present information in table, chart or other numerical format, however, such an approach was not suitable for the amount and type of data collected for this project. The data are presented in summary format, with direct quotes from interviewees, which is more fitting to the ethnographic nature of the information and the number of Local Experts it was derived from.

Methods Objective 2: Map Ocean Distribution and Migration Routes of Chinook Salmon

Organizations and individuals performing the work: K. Myers, R. Walker, and N. Davis (SAFS/UW) mapped ocean distribution and migration routes of AYK salmon. W. Fournier (SAFS/UW) collected and analyzed stable isotope samples for model validation. E. Farley and J. Murphy, Auke Bay Laboratories provided U.S. BASIS data on juvenile Chinook salmon in the eastern Bering Sea. M. Fukuwaka, Hokkaido National Fisheries Research Institute, provided Japanese salmon research vessel and mothership fishery data on Chinook salmon in the Bering Sea. J. Seeb (SAFS/UW) and W. Templin (ADFG) provided genetic stock-identification data on Chinook salmon bycatch of the U.S groundfish fishery in the southeastern Bering Sea. A. Bugaev, KamchatNIRO, provided Russian BASIS data on Chinook salmon migrating in the Russian Exclusive Economic Zone (EEZ) in the western Bering Sea.

There were four steps to completion of this objective: (1) evaluate existing data to validate historical conceptual models of ocean distribution and migration patterns of AYK Chinook salmon and develop new conceptual model(s) if necessary, (2) identify size-specific patterns in AYK Chinook salmon distribution, (3) identify times and areas of overlap in distribution of AYK Chinook salmon with other species and stocks (hatchery and wild) of Asian and North American salmon, and (4) identify major gaps in information and make recommendations for future research. Because of the limited amount of stock-specific data on AYK Chinook salmon this was a graphical (not spatial statistical) analysis. We analyzed, reviewed, and synthesized both published and unpublished information from tags, scale pattern analysis, and genetic stock identification research.

Salmon Age and Maturity Designation

We counted the number of freshwater and ocean annuli on scales to determine age of salmon. Throughout this report, we use the European method of age designation for salmon (Koo 1962), which is the number of freshwater annuli and ocean annuli separated by a dot, e.g., an age 1.2 fish has one freshwater annulus and two ocean annuli on its scale, and was in its fourth year of life. An unknown freshwater or ocean age was designated by the letter "X". If we refer only to ocean age or

only to freshwater age, we used one Arabic numeral to indicate the number of annuli on the scale. For example, an ocean age-0 fish does not have an ocean annulus on the scale, and an ocean age-1 fish has one ocean annulus on its scale. In winter (January-March) samples, all fish were aged as one year older on January 1, even if an annulus was not visible at the edge of the scale. Throughout this report, salmon in their first summer-fall in the ocean were designated as “juveniles” (ocean age-0). Fish older than the juvenile stage were designated as “immature” or “maturing” if sexual maturity at time of sampling was known.

Horizontal Distribution Information from Tags

Primarily, we used our high seas tag databases (Objective 1) to develop a series of GIS maps (atlas) of information on stock-specific ocean distributions of AYK Chinook salmon and other species of AYK salmon in the Bering Sea and North Pacific Ocean. Myers et al. (2009) published these maps. Because of the lack of uniformity in tag release and recovery efforts and incomplete spatial and temporal coverage of salmon stock identification research over the past 50 years (e.g., Myers et al. 1996), data used in this analysis were pooled over all years (1956-present) and stratified by month or season, ocean size (age) group, and maturity stage. The methods used for high seas salmon tagging experiments were similar throughout the entire period of high seas salmon research (e.g., Davis et al. 1990; Myers et al. 2004a). Salmon used in high seas tagging experiments were caught by a variety of types of fishing gear (most frequently floating longlines and purse seines) during research vessel operations at sea. After capture, scales were collected for age determination, fork lengths (FL, tip of snout to fork of tail) are measured, and viable fish are tagged and released. The tags most frequently used were plastic Petersen disk tags attached to the fish near the dorsal fin. Each disk was labeled with a unique number and additional information identifying the release agency. Release locations, dates, tag numbers, species, and other pertinent information were recorded and reported in annual documents submitted to the International North Pacific Fisheries Commission (INPFC) or North Pacific Anadromous Fish Commission (NPAFC) by the release agency. Age was determined by counting the freshwater and ocean annuli on scales.

Because of the large study area (Bering Sea and North Pacific Ocean) and relatively small number of tagged fish released each year, high seas salmon tagging experiments have largely relied on voluntary return of tags by fishermen, processors, and others finding tagged fish in coastal marine or freshwater areas. In addition, there are occasional marine recoveries of coded-wire-tagged (CWT) Chinook salmon during research vessel surveys and in the salmon bycatch of commercial trawl fisheries. Recoveries from high seas tagging experiments and high seas recoveries of CWT salmon are reported in annual documents submitted to the INPFC (1956-1991) or NPAFC (1992-present).

All high seas tag recovery data for AYK salmon (1956-2006) were stratified by species, watershed of recovery (Norton Sound, Yukon, Kuskokwim), month of release, and age and maturity group at release, and a computer mapping software package was used to plot the high seas release locations (latitude, longitude) of salmon that were later recovered in the AYK region. Quantitative estimates of the stock composition in the high seas tagging area cannot be determined from high seas release and recovery tag data because all stocks were not equally vulnerable to capture for tagging, actual recovery rates in the AYK region were not known (we assumed that many recoveries were not reported), and post-tagging mortality and tag loss were time dependent. We compared results from tagging experiments to published estimates of stock composition using scale pattern and genetic methods, if available.

Vertical Distribution and Migration Patterns

We analyzed data from 38 previous recoveries of salmon tagged on the high seas with of depth-recording data storage tags (DST) to compare vertical distributions of Chinook salmon to depth distribution of other species. Simple descriptors of depth, such as “average depth”, do not capture some

of the variation in salmon behavior. In summarizing the data, we also used the maximum depth recorded for each day and averaged all of these daily maxima.

We analyzed recovery data from three types of data storage tags (DST) that record depth to describe the vertical distribution of salmon. Two types of tags (LTD) were small circuit boards potted in a clear urethane, manufactured by Lotek Marine Technologies (www.lotek.com). Model LTD_1100-500 is 27 x 16 x 8 mm, weighs 2 g in water, and records date, time, temperature, and pressure (depth). For this model, the pre-set maximum depth from which data could be recorded was 300 m (actually functional to 340 m). A newer version of this tag (Lotek model LAT1400) was used during this project for tagging Chinook salmon during *Wakatake maru* tagging operations in 2008 and 2009 (see R/V *Wakatake maru* Study Area, 2007-2009). Lotek model LAT1400 is 11 x 35 mm, weighs ~1.5 g in water, and records date, time, temperature, and pressure (depth). A third type of tag, Model DST CTD, was housed in a 46- x 17-mm cylindrical ceramic shell, these tags weigh 13 g in water and record date, time, conductivity (salinity), temperature, and depth data. These tags, manufactured by Star-Oddi (www.star-oddi.com), recorded salinity, temperature, and depth data. LTD tags were attached to fish just anterior to the dorsal fin using two 76 or 64 mm nickel pins, with labeled U.S. and Japanese disk tags placed on the pins on the other side of the fish. DST CTD tags were attached in the same location, but were affixed with stainless steel wire, with a small oval plastic plate on the opposite side of the fish. U.S. and Japanese disk tags were placed on the wires either under the tag or over the plate.

Mapping methods used to determine the ocean location of tagged fish after release are described in Results Objective 4.

We used NOAA Fisheries Groundfish Observer Program data (1997-1999) on fishing depth of trawls to describe the vertical distribution of Chinook salmon in the eastern Bering Sea (corrected from Walker et al. 2007 and Myers et al. 2009). Fishing depth was reported in logbooks was used as the depth at which Chinook occurred. Fishing depth in logbooks was recorded in fathoms; however, in previous analyses of these data we erroneously assumed that the logbook-recorded depth was in meters (Walker et al. 2007; Myers et al. 2009). In the corrected analysis reported herein, we converted the logbook-recorded depths from fathoms to meters. Data on depth (meters) of capture were stratified into month and ocean age (number of winters spent at sea) of the fish. Age and depth information were available for 5,246 fish. Most of the data were collected in January–February (48%) and September–October (45%). Myers et al. (2003) and this report (Objective 3) describe methods used to determine the age composition of Chinook salmon from scale samples collected by the Observer Program.

Horizontal Distribution Information From Scale Pattern Analysis

Analysis of scale patterns has been used since the 1950s to estimate the regional stock composition of salmon caught in mixed-stock fisheries on the high seas. We reviewed information in the scientific literature, and collaborated with a Russian scientist in an analysis of scale pattern data to estimate abundance of North American Chinook salmon (including AYK-origin fish) migrating inside the Russian Exclusive Economic Zone in late summer-fall (Bugaev and Myers 2009a). Scale samples collected during Bering-Aleutian Salmon International Survey (BASIS) research were used in this analysis. Detailed methods are published in Bugaev and Myers (2009a).

Horizontal Distribution Information From Genetic Analysis

Primarily, we reviewed information in the scientific literature and processed reports. Researchers have recently determined that sufficient DNA for genotyping can be obtained successfully from salmon scales (e.g., Withler et al. 2004), although some technical problems may be caused by certain types of preservation methods (Moran and Baker 2002). During this project, we collected samples for DNA analysis from Chinook salmon caught during the *Oshoro maru* (July 2007) and *Wakatake maru* research vessel surveys. The SAFS has a large collection of Chinook salmon scales from research and commercial

vessel operations in the Bering Sea and North Pacific Ocean (1956-present). We evaluated whether these scale samples were of sufficient quality (DNA lab tests coordinated with Jim Seeb, ADFG), quantity, and spatial-temporal coverage to fill critical information gaps in ocean distribution maps. However, full implementation of genetic analyses of recent and historical high seas scale collections was beyond the scope of this project.

Conceptual Model of Ocean Distribution and Migration of AYK Chinook Salmon

The GIS maps of recoveries of tagged fish and information from scale pattern and genetic stock identification analyses were used to identify spatial and temporal patterns in AYK Chinook salmon distribution by life-history stage, to develop a new conceptual model(s) of their ocean distribution and migration patterns, and to evaluate when and where inter- and intra- specific interactions with other salmon species and stocks are most likely to occur. A difficulty with successful completion of this objective was the paucity of research vessel data for Chinook salmon compared to other species of salmon. During our synthesis (Objective 9), the results of this objective were used to identify critical gaps in information on the ocean distribution and abundance of AYK Chinook salmon.

Stable Isotope Analysis

Stable isotope analysis was used to validate our conceptual model of seasonal feeding migrations of immature and maturing Chinook salmon in the Bering Sea, as a part of graduate student research for this project (W. Fournier). Naturally occurring stable isotopes ratios ($^{13}\text{C}/^{12}\text{C}$) and ($^{15}\text{N}/^{14}\text{N}$) of consumer (salmon) tissue fluctuate with the isotopic composition of primary producers at the base of the food web. Carbon isotope ratios of primary producers depend on the degree of fractionation during CO_2 and nutrient uptake which differs for terrestrial C_4 plants and marine C_3 plants (Fry 2006), to the degree that littoral and pelagic based food webs are distinguishable (France 1995). This allows for determination of proximity of feeding to shore (in our case, continental shelf versus open-ocean basin) based on the type of primary productivity at the base of the food web. Stable isotope analysis was performed on muscle tissue samples of ages 1.2, 1.3, and 1.4 Chinook salmon collected from the BSAI pollock fishery bycatch and during U.S. BASIS research in the Bering Sea in winter and summer-fall 2009 ($n = 76$ fish). The muscle tissue used for isotope analysis was removed from the fish's dorsal area, immediately posterior to the insertion of the dorsal fin. This is the standard method for collecting tissue from salmon for isotope analysis. The main source of variability in carbon isotopes is due to lipid fractionation, and consistent sampling location decreases the variability of fat content. Tissues were analyzed with an Isotope Ratio Mass Spectrometer at the University of Washington. Isotopic composition of muscle tissue was expressed in the standard delta (δ) notation, defined as parts per thousand (‰) deviations from a standard material (PDB limestone for ^{13}C and atmospheric nitrogen for ^{15}N). A lipid fractionation correction equation was used on the carbon isotope data due to high fat content of Chinook salmon tissue (Post et al. 2007).

Methods Objective 3: Reconstruct Histories of Ocean Age, Growth, and Size-Selective Mortality

Organizations and individuals performing the work: J. Nielsen and G. Ruggerone (AYK SSI Project no. 410: Retrospective analysis of AYK Chinook growth in freshwater and marine habitats, 1964-2004; Ruggerone et al. 2007; 2009a,b) provided an existing time series of age 1.3 and 1.4 adult Yukon (YUK) and Kuskokwim (KUS) River Chinook salmon scale measurement data (1955-2004; scales were measured by the Alaska Department of Fish and Game, ADFG). We updated the Ruggerone et al. (2007; 2009a,b) time series of YUK Chinook with 2005-2009 scales and data provided by L. DuBois, ADFG; a subset of the scale samples (age 1.3 and 1.4 female fish) was measured by R. Walker and J. Armstrong, SAFS/UW. J. Berger, North Pacific Groundfish Observer (OBS) Program, Alaska Fisheries Science Center (AFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), provided scale samples and associated data collected from the Chinook salmon bycatch of U.S. pollock trawl vessels in the eastern Bering Sea in 1997-2008; a subset of the scale

samples (ages 1.2, 1.3, and 1.4 fish) was measured by J. Armstrong, SAFS/UW. M. Fukuwaka, Hokkaido National Fisheries Research Institute, provided 1991-2007 *Wakatake maru* (WAK) Chinook salmon scale samples and associated data; M. Fukuwaka and N. Davis collaborated in aging scale samples; a subset of the scale samples (age 1.2 fish) was measured by R. Walker, SAFS/UW. A. Bugaev provided Russian BASIS samples of Chinook salmon scales and associated biological data from the Russian EEZ; a subset of the scale samples, age 1.1 Chinook salmon, 2003-2005, was measured by J. Armstrong, SAFS/UW, however, the samples were insufficient to develop a scale growth time series. J. Murphy, Auke Bay Laboratories, AFSE, NMFS, NOAA, provided US BASIS scale samples from the eastern Bering Sea; scales were aged by K. Myers; a subset of the scales (age 1.0 Chinook salmon, 2002-2005, 2007) was measured by J. Armstrong SAFS/UW, however, samples were insufficient to develop a scale growth time series. J. Armstrong, R. Walker, and W. Fournier performed the data analyses.

Our working hypothesis was that large, fast-growing Chinook salmon have higher ocean survival than smaller, slower-growing salmon. Many previous studies have demonstrated that somatic growth of salmon is directly related to the spacing of circuli on scales, and provides reliable estimates of growth rates or indices of relative growth between age groups and seasons (e.g., Casselman 1990; Fisher and Percy 1990, 2005; Francis 1990; Ricker 1992; Fukuwaka and Kaeriyama 1997; Moss et al. 2005). We used Chinook salmon scales to reconstruct histories of ocean age and growth and to evaluate several previously developed hypotheses about AYK Chinook salmon growth and size-selective mortality:

1. Annual size and growth of Chinook are dependent on the previous-year's growth for each age and life stage (Ruggerone et al. 2007; 2009a,b).
2. Sexually dimorphic growth of Chinook is evident from an early age (Ruggerone et al. 2007, 2009a).
3. Annual abundance and growth anomalies of AYK Chinook salmon are related to alternating-year abundance patterns of eastern Kamchatka pink salmon (Ruggerone et al. 2007, 2009a). Life cycle and general ocean migration patterns of Bering Sea populations of Russian pink salmon indicate potential overlaps in distribution with AYK Chinook salmon at several key life history stages (e.g., Takagi et al. 1981; Myers et al. 1996; 2007).
4. Size-selective mortality of Chinook salmon occurs during the first winter in the Bering Sea (critical size-critical period hypothesis, Beamish and Mahnken 2001).

We assumed that scale growth patterns of subadult Chinook salmon in ocean samples from the Bering Sea are representative of the ocean growth patterns of AYK Chinook salmon. A problem with this assumption is that we do not know the stock of origin of individual fish in our ocean samples. However, our assumption is partially corroborated by the results of previous tagging experiments, scale pattern analysis, and genetic analysis (e.g., Myers et al. 1987, 1996, 2003; Myers and Rogers 1988; NPFMC 2008, 2009), which indicate that Western Alaska, including AYK, Chinook salmon are the dominant regional stock group in the Bering Sea (see results, Objective 2).

Scale Age, Selection, and Measurement Methods

We determined ages of Chinook salmon in ocean samples using criteria developed by SAFS/UW scientists specifically for Chinook salmon caught in the open ocean (e.g., Myers et al. 1987; Myers and Rogers 1988; Davis et al. 1990). Only scales collected from the International North Pacific Fisheries Commission (INPFC)-preferred body area were used. Scale images were magnified, and annuli (bands of closely spaced, narrow, broken, or resorbed circuli that form once a year) were counted. Age is designated by the European formula (Koo 1962, see methods: Objective 2).

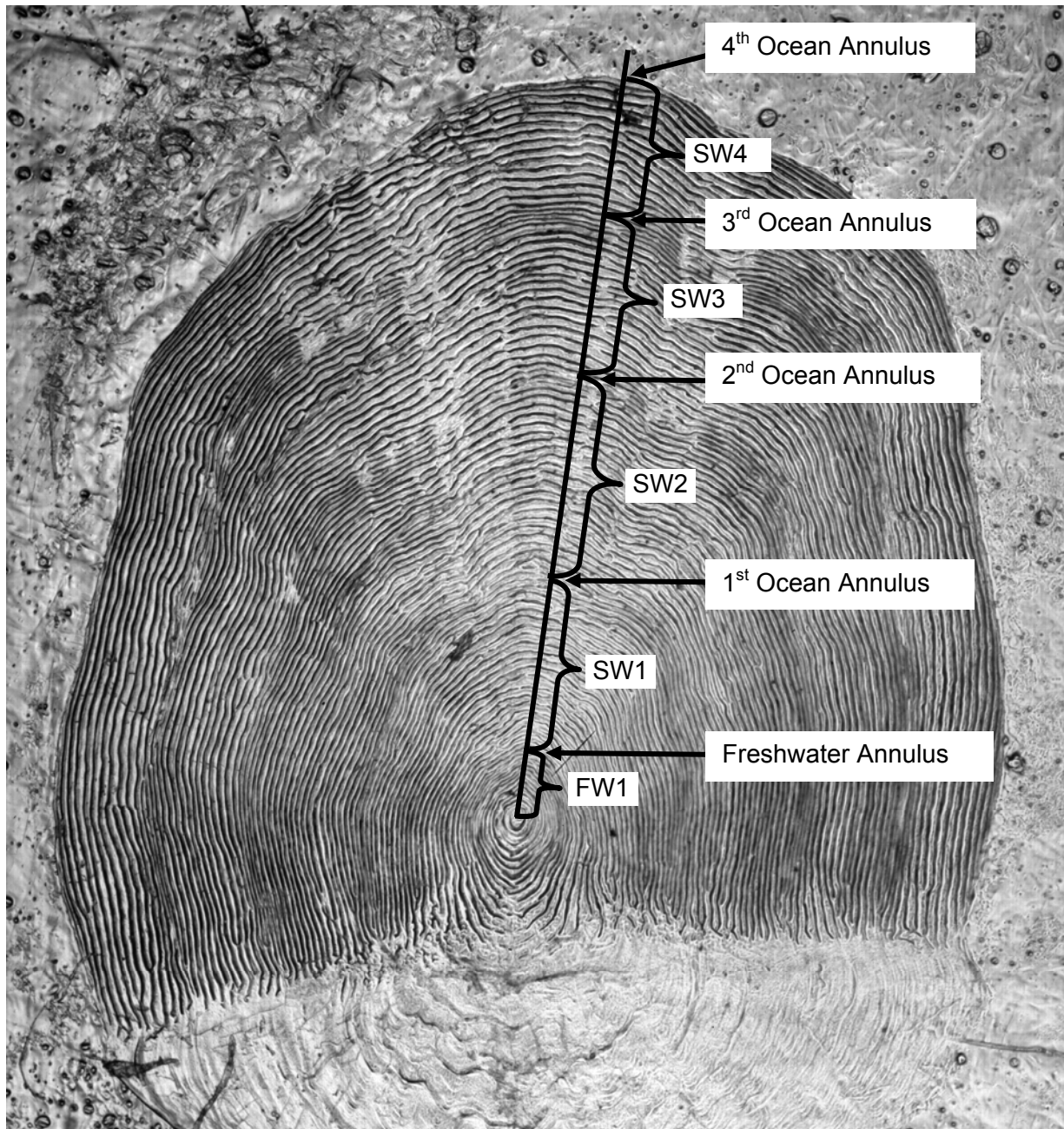


Figure 3- 1. An acetate impression of the scale of an age 1.4 female Chinook salmon (85 cm FL, 7.7 kg) caught in the eastern Bering Sea in winter (2/19/2006) showing the scale measurement axis, location of freshwater and ocean annuli, and scale growth increments: center of focus to edge of freshwater annulus (FW1), first ocean year (SW1), second ocean year (SW2), third ocean year (SW3), and fourth ocean year (SW4). The scale was collected by the NOAA Fisheries Observer (OBS) Program from the salmon bycatch of the winter pollock trawl fishery in the Bering Sea/Aleutian Islands (BSAI) region.

Scales were selected for measurement only when they met three criteria: (1) multiple readers agreed with the age determination, (2) scale shape indicated the scale was removed from the INPFC preferred area (Davis et al. 1990), and (3) circuli and annuli were clearly defined and not affected by scale regeneration or significant resorption along the measurement axis. For YUK female Chinook samples,

one scale per fish from up to 27 fish per year was measured using the same techniques as the Ruggerone et al. (2007; 2009a,b). For ocean samples, one scale per fish from up to 50 fish per year (25 males; 25 females) from each available age group (ages 1.1, 1.2, 1.3, and 1.4) was measured.

Scale growth increments were measured using a high resolution imaging approach developed by Hagen et al. (2001). Briefly, acetate impressions of scales were digitized using a high-resolution microfiche scanner, stored as a high resolution digital file, and then measured with computer imaging software that automatically marks and records circulus growth increments. We used Optimas 6.5 image processing software to collect measurement data using a customized program. The scale image was displayed on a LCD monitor, and the scale measurement axis was defined as the longest axis (anterior-posterior axis) extending from the center of the scale focus to the edge of the scale (Fig. 3-1). Measurements were converted to microns using calibrations of the scanning system.

Measurements in common to all data sets are distance from center of focus to edge of freshwater annulus (FW1), and, if present, size of first ocean year (SW1), second ocean year (SW2), third (SW3), and fourth (SW4) ocean years (Fig. 3-1). Spring freshwater plus growth (FWPL), if present, was included in the first ocean zone (SW1). Circuli in growth at the edge of the scale beyond the last marine annulus were individually measured, and later combined as ocean plus growth (SWPL). No ocean plus growth (SWPL) was seen in the OBS Program scales that were sampled during winter/early spring (January to March) before the next year's growth had commenced. SWPL growth was seen only rarely on adult age 1.3 and 1.4 YUK female Chinook scales in 2005-2009.

Seasonal (summer, winter) growth patterns were measured only on OBS and YUK Chinook scales. Since rate of growth is reflected in spacing of scale circuli, faster summer growth can be discerned from slower winter growth. The increment between the outer edge of the freshwater annulus and the last widely spaced circuli in the first ocean zone (SW1) was measured as Ocean 1 summer (Oc1summer) and the remaining increment of closely spaced circuli within the SW1 increment was measured as Ocean 1 winter (Oc1winter). Subsequent ocean summer and winter increments were measured for summers and winters 2 through 4.

Scales from 1,837 OBS Chinook salmon were measured and digitized (Table 3-1). These were selected for measurement from a larger number of OBS Chinook salmon scales collected during 1997-2008 (Table 3-2; $n = 4994$). Comparison of mean fish body lengths by age, sex and year between the original larger data set ($n = 4994$) and the subset of fish selected for growth measurements (Tables 3-1 and 3-3; $n = 1837$) showed no significant differences (t-test results for age 1.2, 1.3 and 1.4, years 1997 – 2008 were $p = 0.88, 0.78$ and 0.19 respectively, $\alpha = 0.05$). Thus, we have confidence that our sample subset represents the larger mixed-stock Chinook population in the winter bycatch of the pollock trawl fishery in the eastern Bering Sea/Aleutian Islands (BSAI) region (Figure 3-2).

Different methods were used by ocean and freshwater data collection agencies to measure body lengths of Chinook salmon in our samples. OBS, WAK, and BASIS Chinook were measured from tip of snout to fork of tail (SNF), and YUK and KUS Chinook were measured from mid eye to fork of tail (MEFT; Ruggerone et al. 2007). To compare SNF lengths of OBS Chinook (caught in January-March) with MEFT lengths of YUK and KUS fish (caught at river mouths in June-July), we used a length measurement conversion equation (Pahlke 1988).

Graphical and Statistical Analyses of Body Size, Abundance, and Scale Growth Data

As a part of graduate student research (W. Fournier), simple linear regression models that can be used to estimate SNF length from scale radius and body weight from SNF length of Bering Sea Chinook salmon were developed. The analysis included scale data and associated biological data from all ocean age groups of Chinook salmon measured by SAFS/UW (WAK, OBS, US BASIS, and Russia BASIS collections) for this project.

Table 3- 1. Number of NOAA Fisheries Observer (OBS) Chinook salmon scales measured from samples collected during winter pollock fisheries in the eastern Bering Sea/Aleutian Islands region in 1997-2008 by year, age group, and sex. Low sample numbers are highlighted in yellow (n<25 per sample group). F=female, M=male.

Year	Age 1.2		1.2 Total	Age 1.3		1.3 Total	Age 1.4		1.4 Total	Total
	F	M		F	M		F	M		
1997	26	24	50	25	25	50	25	28	53	153
1998	26	25	51	27	27	54	27	26	53	158
1999	26	25	51	26	27	53	25	26	51	155
2000	25	27	52	28	28	56	27	28	55	163
2001	23	28	51	27	28	55	27	25	52	158
2002	27	27	54	26	27	53	25	29	54	161
2003	26	26	52	27	27	54	24	18	42	148
2004	25	26	51	25	27	52	27	26	53	156
2005	25	27	52	28	25	53	26	24	50	155
2006	26	26	52	27	27	54	26	27	53	159
2007	28	27	55	28	22	50	14	10	24	129
2008	16	32	48	28	29	57	29	8	37	142
Grand Total	299	320	619	322	319	641	302	275	577	1837

Table 3- 2. Number of NOAA Fisheries Observer (OBS) Chinook salmon scales in the original database by year and statistical area in the Bering Sea/Aleutian Islands (BSAI). A subset of these samples was selected for analysis.

Year	NOAA Fisheries BSAI areas												Total
	509	513	516	517	518	519	521	523	531	541	542	543	
1997	236	11		454	1	44			3	38	7	1	795
1998	348	2		416		32	3	3	6	7	1		818
1999	215	13	1	382					5	3			619
2000	51	2		99		22	4						178
2001	109	26	10	56		6	24						231
2002	124	2	6	110			2						244
2003	146	24	6	42			24						242
2004	159	39		46		1	12						257
2005	140	14	2	83			24						263
2006	316	35		452		40	5			6	4		858
2007	24	1		108		46	39						218
2008	45	18		169		13	22	4					271
Grand Total	1913	187	25	2417	1	204	159	7	14	54	12	1	4994

Table 3- 3. Number of NOAA Fisheries Observer (OBS) Chinook salmon scales measured by year and statistical area in the Bering Sea/Aleutian Islands (BSAI).

Haul	BSAI areas								Total
Year	509	513	516	517	519	521	523	541	
1997	46			92	14			1	153
1998	64			88	6				158
1999	51			104					155
2000	41	2		96	21	3			163
2001	76	22	7	35	2	16			158
2002	85	1	2	72		1			161
2003	86	14	4	25		18		1	148
2004	100	25		24	1	6			156
2005	79	8		52		16			155
2006	19	6		133		1			159
2007	20	1		63	25	20			129
2008	27	10		93	4	7	1		142
Total	694	89	13	877	73	88	1	2	1837
Proportion	38%			48%					

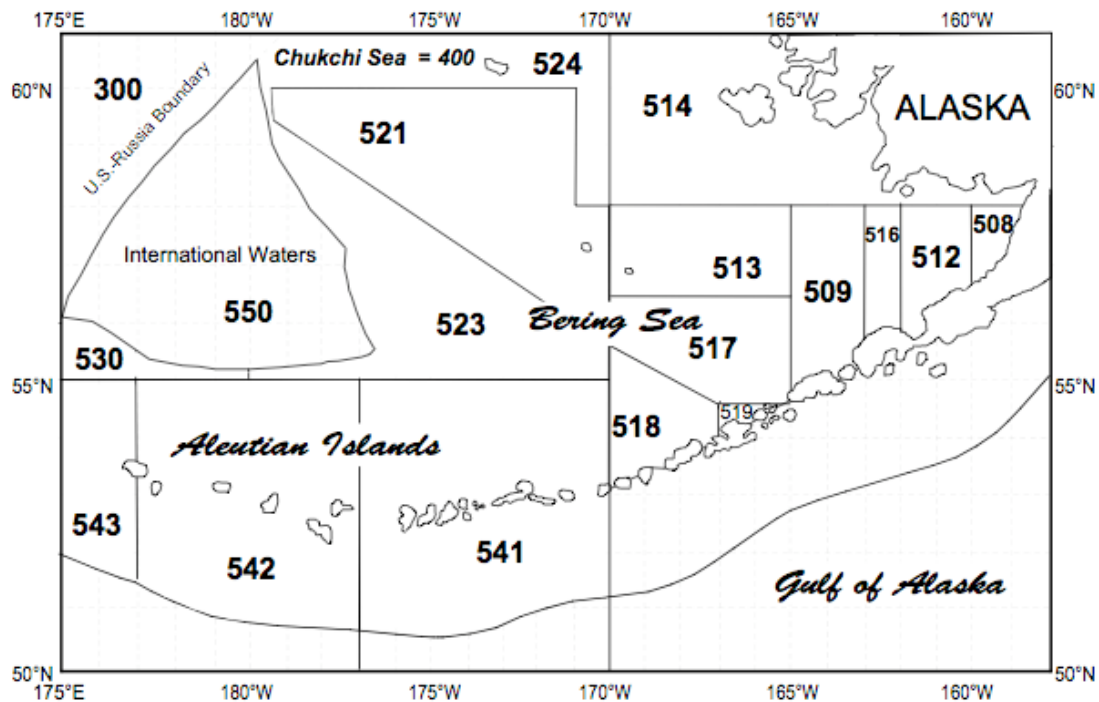


Figure 3- 2. NOAA Fisheries statistical areas for the Bering Sea and Aleutian Islands (BSAI). Source: NOAA Fisheries Alaska Region (<http://www.fakr.noaa.gov/r/figures/fig1.pdf>).

Table 3- 4. *Wakatake maru* (WAK) age 1.2 Chinook salmon sample sizes (n=) by year-sex (1991-2007; F=female, M=male), average and standard deviation (STDev) of fork lengths (mm; average), and results of Shapiro-Wilk tests of normality ($\alpha= 0.05$), F tests of equality of variance ($\alpha= 0.05$), and Welch's t-tests of equality of mean lengths ($\alpha= 0.05$; significant differences highlighted in yellow and orange).

Year-sex	n=	Average	StDev	Shapiro-Wilk p-value	F test p-value	t test p-value (* Welch)
91F	26	517.50	37.30	0.4828		
91M	27	510.96	42.52	0.997	0.515	0.555
92F	19	566.47	39.62	0.8421		
92M	27	567.33	64.64	0.2305	0.03526	0.9558*
93F	15	551.20	30.55	0.6815		
93M	13	554.85	38.60	0.9339	0.4011	0.7825
94F	12	551.50	24.88	0.5507		
94M	8	521.00	34.82	0.05389	0.3068	0.03417
95F	36	516.44	42.71	0.6373		
95M	30	542.63	41.29	0.5587	0.86	0.01431
96F	24	550.21	42.83	0.8903		
96M	20	552.20	43.96	0.5543	0.895	0.8801
97F	20	570.15	40.30	0.1675		
97M	22	563.09	39.53	0.1581	0.9266	0.5701
98F	36	527.69	40.69	0.5724		
98M	32	552.44	50.81	0.4215	0.2034	0.02934
99F	8	525.38	25.70	0.3365		
99M	13	522.85	40.46	0.6048	0.2349	0.8765
00F	35	526.60	40.67	0.4973		
00M	34	514.47	45.84	0.4446	0.4916	0.2488
01F	5	510.40	33.78	0.6754		
01M	7	531.29	25.06	0.952	0.489	0.2449
02F	30	538.47	28.92	0.96		
02M	31	564.23	35.39	0.4469	0.28	0.0029
03F	25	528.92	44.72	0.5199		
03M	25	551.00	40.37	0.5475	0.6208	0.07309
04F	37	587.68	35.29	0.1622		
04M	29	576.52	59.36	0.08994	0.00362	0.3754*
05F	6	571.83	28.77	0.08038		
05M	3	556.00	20.66	0.5145	0.7487	0.4295
06F	9	540.00	22.76	0.23		
06M	2	535.00	12.73	NA	0.8174	0.7766
07F	6	553.83	33.33	0.5915		
07M	8	521.25	65.42	0.7653	0.1568	0.2892

Descriptive statistics of Chinook salmon body length and scale growth increments were calculated for each age, life stage, and collection or growth year for each sex and for both sexes combined. Normalized mean increment growth values were calculated over the collection time periods being evaluated using the following formula:

$$(3-1) \text{ Annual mean growth } Z_i = (X_i - X) / s$$

where X_i is the mean value in year i , X is the grand mean and s is the standard deviation. Normalized growth increments are the number of standard deviations above or below the long-term mean of each data series.

Because sample sizes of WAK Chinook salmon were low, unequal numbers of males and females were collected over the time series with some years having less than five individual per sex (Table 3-4). Preliminary analyses revealed that for both sexes the fork lengths were normally distributed in all years and in all but two years the sexes had equal variances. Results of standard and Welch's t-tests showed significantly different mean fork lengths between the sexes in five years. Normalized fork lengths of males and females had opposite signs in five of the 16 years (Fig. 3-3). In order to utilize all WAK Chinook scale measurements, growth indices were developed that weighted the male and female scale growth during each year (Ruggerone et al. 2007, 2009):

$$(3-2) \text{ Annual Mean Growth} = [n_M(\text{Growth } Z_M) + n_F(\text{Growth } Z_F)] / [n_M + n_F],$$

where n_M and n_F are sample sizes of male and female salmon, and $\text{Growth } Z_M$ and $\text{Growth } Z_F$ are the normalized mean growth of male and female salmon (eqn. 3-1), respectively.

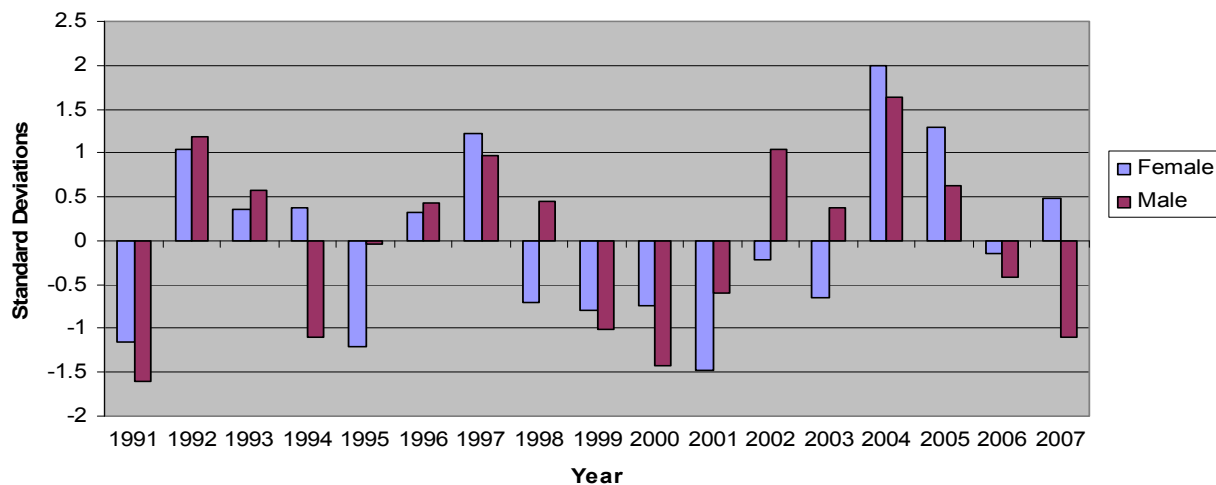


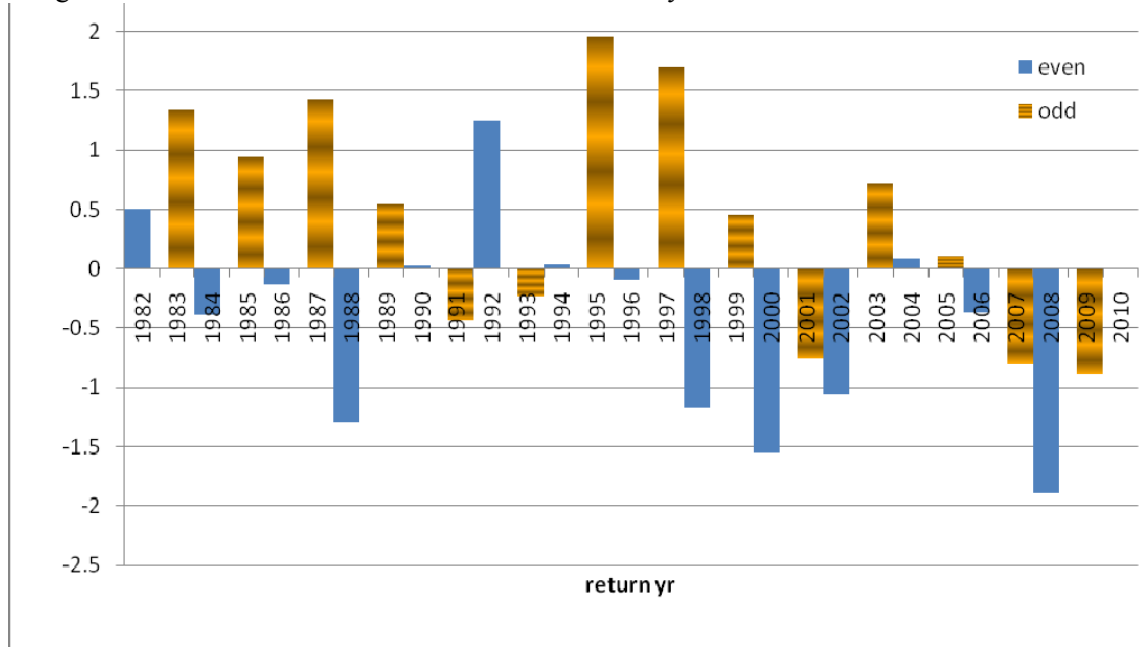
Figure 3- 3. Interannual variation in normalized fork lengths of age 1.2 male and female Chinook salmon in the *Wakatake maru* (WAK) gillnet survey samples from the central Bering Sea basin in July 1991-2007. Normalized lengths are the number of standard deviations above or below the mean of the 1991-2007 data series.

Annual variation in mean body size (fork lengths FL) and scale growth increments by life stage were examined for mixed-stock OBS Chinook salmon and compared to single-stock YUK and KUS Chinook salmon. Trends in annual scale growth by life stage of OBS, YUK, and WAK Chinook salmon were evaluated graphically.

To test for salmon growth dependence on previous years' growth, we used correlation analysis (Pearson correlation, S-Plus) and single-factor analysis of variance (ANOVA; S-Plus; $\alpha=0.05$) of scale growth increments sizes (FW1 and subsequent ocean increments, SW1, SW2, SW3 and SW4) for each age group (males and females combined) by collection year (both unlagged and lagged to growth year).

Similar analyses (correlation and ANOVAs) were run for males and females separately to test for growth differences between sexes at each life phase.

a. Age 1.4 Canadian Yukon Chinook abundance anomaly.



b. Age 1.1 Eastern Kamchatka pink salmon abundance anomaly.

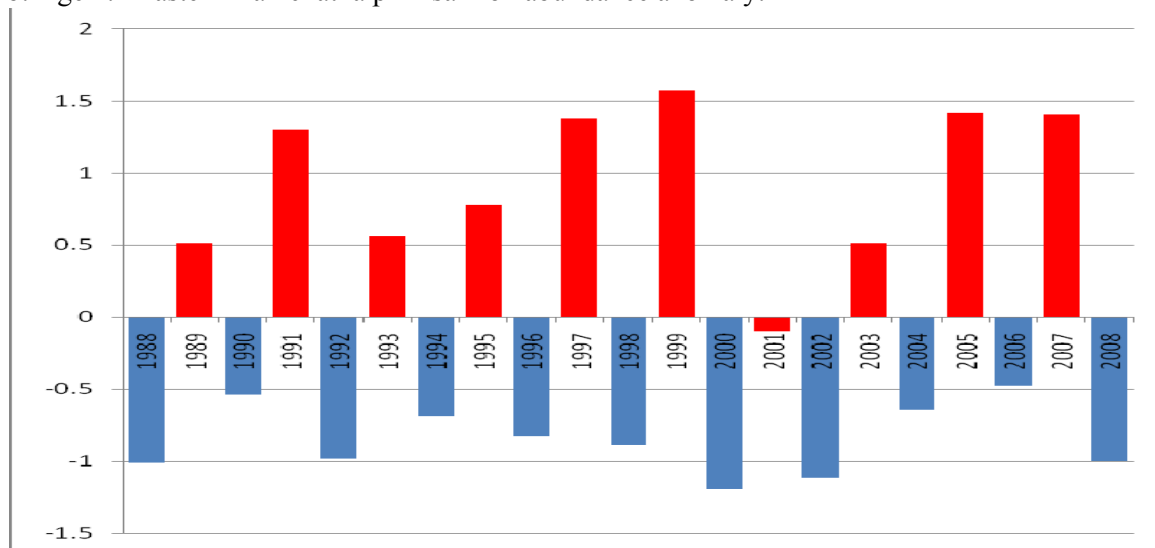


Figure 3- 4. Estimated abundance anomalies of age 1.4 Canadian Yukon Chinook age 1.4 (a., top panel) and age 1.1 Eastern Kamchatka (Russian) pink salmon (b., lower panel). Tan (upper panel) or red (lower panel) bars denote odd/high pink salmon abundance years and blue bars denote even year/low pink salmon abundance and t. Y-axes are standard deviations. Run size data sources: Yukon Chinook data were provided by K. Howard, Alaska Department of Fish and Game, and JTC 2010; run size estimates of

Russian pink salmon were obtained from annual documents submitted by Russia to the North Pacific Anadromous Fish Commission, www.npafc.org).

To further explore whether AYK Chinook salmon may be affected by the dominant odd-year abundance cycle of adult eastern Kamchatka pink salmon (Ruggerone et al. 2007, 2009a), we evaluated correlations between estimated abundance (adult run size) anomalies of age 1.4 Canadian Yukon Chinook and eastern Kamchatka pink salmon (obtained from NPAFC documents) for years 1988 – 2008 (Fig. 3-4). We also graphically compared normalized annual growth anomalies, lagged to ocean growth year, of age 1.2 female WAK Chinook salmon with eastern Kamchatka pink salmon abundance anomalies. To further evaluate life-stage specific growth patterns, we used backward step-wise multi-linear regression, applied to 45 climate, biological and ocean condition and biological indices including eastern Kamchatka pink salmon abundance (Appendix Table 6-1) with normalized annual mean growth of age 1.2 WAK Chinook salmon (males and females) in each life stage as the dependent variable.

Trends in seasonal growth patterns of adult female YUK and sub-adult OBS were evaluated graphically and statistically. Frequency distributions of OBS Chinook summer and winter growth increments were generated for all ocean life stages and compared across years to determine whether size-selective survival was evident, especially during the first to second marine years. For a given OBS mixed-stock brood year, the relationship between Oc1 winter growth and age group was explored using ANOVA tests. An increase in Oc1 winter growth in successively older ocean age groups of the same brood year group was assumed to indicate potential size-selective mortality.

The results of our reconstructions of age and growth histories were used for bioenergetics models (Objectives 6 and 7), age and growth simulations (Objective 8), and to evaluate relationships between various climate indices and scale growth increments at each age and life stage (Objective 9).

Methods Objective 4: Map Climate-Ocean Conditions in Regions Where AYK Salmon Migrate

Organizations and individuals performing the work: R. Walker, J. Armstrong, N. Davis, O. Abdul-Aziz, and N. Mantua (SAFS/UW). M.N. Aita, Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama Institute for Earth Sciences, Yokohama, Japan, provided 3-D NEMURO ecosystem model data. Additional data sources are described in Results Objective 3.

Environmental data sets were collected and mapped to identify distribution and migration routes of AYK salmon from temperature-depth tag data (Objective 2), for use in bioenergetic models (Objectives 6 and 7), and for models and simulations of climate-ocean effects on salmon growth and thermal habitats (Objective 9). A number of climate-oceanographic datasets were evaluated, including but not limited to: (1) surface observations of wind stress and sea level pressure from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS); (2) blended ship, buoy, and satellite SST records from NOAA's Optimally Interpolated SST (OISST) dataset; (3) gridded satellite observations of marine chlorophyll to characterize the space-time patterns of phytoplankton productivity; (4) ice cover data for the Bering Sea from the National Ice Center; and (5) high seas research vessel oceanographic profile data of temperature, salinity, and depth. Existing subsurface data were evaluated to determine their utility for mapping ocean conditions within the approximate known range of vertical distribution of Chinook salmon (0-525 m). Oceanographic data from the western Bering Sea were not readily available. We consulted with our Russian BASIS colleagues at TINRO-Centre on this aspect of our project, and some published summaries of BASIS oceanographic data were provided. Because oceanographic data time series, particularly for the western Bering Sea were both spatially and temporally limited, we also evaluated historical reconstructions of atmospheric, oceanographic, and ecosystem data. In addition, rough maps of LTK related to salmon fishing locations and other environmental observations in the Bering Straits region were drawn during interviews with village experts (J. Raymond-Yakoubian, pers. comm.), however, refinement and digitizing of LTK maps was beyond the scope of this project.

Methods Objective 5: Collect New Seasonal Food Habits Data; Evaluate Variation in Diets

Organizations and individuals performing the work: N. Davis, W. Fournier, J. Armstrong, R. Walker, and K. Myers (SAFS/UW) performed field, laboratory, and data analyses; Cooperating investigators, K. Aydin and J. Berger (NOAA/NMFS/AFSC) administered a special project by the North Pacific Groundfish Observer Program to collect the samples and data. We especially acknowledge the groundfish observers who collected salmon samples and data for this special project. W. Walker, National Marine Mammal Laboratory (AFSC) provided help and advice in identifying squid and fish prey. T. Buckley (REFM) provided information for walleye pollock otolith and subopercle size conversions to pollock length and age. T. Buser, I. Jimenez-Hidalgo, and L. Hauser, SAFS/UW developed and applied genetic techniques to identify species in fish offal from Chinook salmon stomach contents. Sample and data collection students aboard the R/V *Wakatake maru* was coordinated and assisted by Captain Y. Murata (2007-2008), Captain T. Yoshino (2009), and the officers, crew, teachers, and students, M. Fukuwaka, Chief Scientist (2007-2008), Hokkaido National Fisheries Research Institute (HNFRI), Fisheries Research Agency, Kushiro, Japan, and T. Kaga, Chief Scientist (2009), National Salmon Resources Center, Fisheries Research Agency, Sapporo, Japan. Collection of samples and data at processing plants in Dutch Harbor was coordinated and assisted by the U.S. National Marine Fisheries Service (NMFS) Observer Program, Fisheries Monitoring and Analysis (FMA) Division, Alaska Fisheries Science Center, Seattle (M. Loeffled and J. Berger), P. Wilkins, NMFS Observer Program (Dutch Harbor, Alaska), D. Boisseau (Westward Seafoods, Dutch Harbor), D. Goodfellow (Alyeska Seafoods, Dutch Harbor), and D. Graves (Unisea Seafoods, Dutch Harbor). Sample and data collection aboard the NOAA Ship *Oscar Dysan* was coordinated and assisted by officers, crew, and scientists (Chief Scientist, E. Farley, NOAA, Alaska Fisheries Science Center, Auke Bay Laboratories, Juneau). A.V. Volkov, A.Ya. Efimkin, and N.A. Kuznetsova, Pacific Scientific Research Fisheries Center (TINRO-Center), Vladivostok, Russia, and Osamu Sakai, National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Shimizu, Japan, collaborated in a review of BASIS salmon food habits studies.

To complete this objective, new seasonal food habits and Chinook salmon maturity samples were collected by a special project of US observers placed on pollock catcher-processors operating in the Bering Sea throughout the year in 2007 and 2008, as well as by our project staff at processing plants in Dutch Harbor in winter and summer 2009. We collected additional summer samples while on board a Japanese salmon research vessel (*Wakatake maru*) in 2007-2009 and the NOAA ship *Oscar Dysan* in 2009.

US Groundfish Observer Sampling on Pollock Catcher-Processors, 2007-2008

Data collected by US groundfish observers over the past 30 years have made a tremendous contribution to scientific knowledge of the distribution and migration patterns of Chinook salmon in the eastern Bering Sea (NPFMC 2008). While these data indicate the eastern Bering Sea is an important habitat for Chinook salmon, almost nothing is known about the role of Chinook salmon in the Bering Sea ecosystem. Better scientific information on the position of Chinook salmon in eastern Bering Sea food webs is essential to sustainable fishery management of AYK Chinook salmon. US groundfish observer sampling of Chinook salmon bycatch in eastern Bering Sea fisheries provided an unrivaled opportunity to sample large numbers of Chinook salmon throughout the year in areas where no other information source is available. At the start of this project, food habits and maturity data from Chinook in the eastern Bering Sea in winter were almost non-existent because there have been few salmon research vessel surveys at this time of year.

During winter (January–March) and summer (July–August) 2007 and 2008, a special project was assigned to observers placed aboard commercial catcher-processors in the walleye Pollock midwater trawl fishery in the southeast Bering Sea (SEBS). Trawl fishing depth (average gear depth measured by various instrumentation), trawl gear deployment and retrieval time (tow time period) were recorded by observers from bridge data. Observers were requested to sample up to five Chinook salmon each day throughout

their deployments. For each sampled fish, observers measured fork length and body weight of individual Chinook salmon, determined sex and maturity (immature or maturing), and collected scales and stomach samples. A maturing fish would sexually mature in the current calendar year and return to freshwater to spawn. Immature fish would not return to freshwater until a subsequent year. Observers based their maturity assessment on visual examination of color, size (not weight), and texture of the ovaries and testes. Ovaries are pink or red and contain granular eggs that are tiny in immature fish, or large in maturing fish. Immature testes are translucent and threadlike in small fish and appear pinkish and empty in larger immature fish (AFSC 2007). When the male is maturing, the gonads become larger and creamy-white in color. Stomach samples (2007) and stomach and gonad samples (2008) were frozen and returned to our laboratory for analysis.

Sampling and Data Collection on the Japanese Research Vessel *Wakatake maru*, 2007-2009

In 2007-2009 Chinook salmon stomach samples were collected during the research cruises of the Japanese salmon research vessel, *Wakatake maru*, surveying the central Bering Sea basin (CBS) in July. Chinook salmon samples were collected from all Chinook salmon caught in a surface gillnet (research and commercial meshes) and from surface longline mortalities (Fukuwaka et al. 2007a, 2008b; Kaga and Davis 2009). Chinook length, body weight, and gonad weight were measured and scale samples collected. Chinook maturity was determined by the criteria of Ito et al. (1974), which is a combination of gonad weight and time period. Criteria for a maturing male were minimum total weight of the paired gonads in the following time intervals: >10g in May 21-Jun 20; >15g in Jun 21-30, >20g in July 1- 20; and >30g in July 21- Aug 10 (Ito et al. 1974). Criteria for a maturing female were minimum total weight of the paired gonads in the following time intervals: >80g in May 21-Jun 20; and >100g in Jun 21- Aug 10 (Ito et al. 1974).

All stomach samples were analyzed on an individual basis, such that the individual fish's length, weight, sex, gonad weight, and age were associated with the particular fish's food habits. Stomachs were removed and the contents observed while on board the vessel. Stomach samples were weighed to the nearest gram before and after removal of the contents, and the weight of the stomach contents obtained by subtraction. Stomach fullness was categorized into the following five categories: empty, less than $\frac{1}{4}$ full, $\frac{1}{4}$ to $\frac{1}{2}$ full, $\frac{1}{2}$ to $\frac{3}{4}$ full, and $\frac{3}{4}$ full to completely full. The stomach contents were examined using a binocular microscope and separated into the lowest possible taxonomic grouping. Percent volume in each prey category was estimated by eye. Squid and fish prey were counted and the body length of squid (ml; mantle length) and fish (sl; standard length) were measured. Fish and squid are major prey of Chinook salmon, and the identity and size of these organisms may prove to be helpful indicators of ecosystem effects of climate change. D

Sampling and Data Collection in Processing Plants and on the NOAA Ship *Oscar Dyson*, 2009

As a part of graduate student research (W. Fournier) to investigate seasonal variation in diets, energetic condition, and trophic levels, whole immature Chinook salmon from the by-catch of the winter and summer 2009 Bering Sea commercial walleye pollock fishery were collected at processing plants in Dutch Harbor. Chinook salmon sampled aboard the second leg of NOAA's 2009 *Oscar Dyson* survey in the eastern Bering Sea supplemented summer collections at processing plants. Detailed field sampling and data collection methods were described above (*see* Study Areas and Field Research Methods: Processing Plant Sampling – Dutch Harbor, NOAA Ship *Oscar Dyson*).

Laboratory Analysis of Observer Samples

Chinook salmon ocean age (count of annuli in the ocean zone of the scale) was determined from scales (Davis et al. 1990). Frozen stomach and gonad samples returned to our laboratory were analyzed after thawing. Chinook salmon stomach contents were counted, weighed, and identified to the lowest possible taxonomic group. When possible, estimates of prey size were obtained by measuring squid (mantle length), fish (standard length), and pollock otoliths (maximum length). Pollock standard

length and age were estimated based on otolith maximum size, and the pollock subopercle size, from information provided by T. Buckley (Troy.Buckley@noaa.gov, pers. comm.). When observed in stomach contents, fish offal was identified by the presence of distinct, isolated body parts of prey, such as wads of skin, individual fins, sections of vertebral column, or the head from a large-bodied fish. The presence of individual body parts of prey in the stomach was inconsistent with the consumption of whole fish, which is typical for Chinook salmon. The 2007 samples of fish offal were frozen, and samples were later analyzed using genetic techniques to confirm species identification of fish offal (Buser et al. 2009).

The 2008 gonad samples were weighed and categorized as either immature or maturing using the criteria of Ito et al. (1974) for summer samples. For the fall samples, males had a total gonad weight <30g and were all considered immature. For winter samples (i.e., samples collected after Jan 1), maturing males were those with a total gonad weight ≥ 5 g and at least one testis with a maximum width of ≥ 10 mm. In fall samples, females had a total gonad weight <80g and were all considered immature. Maturing females with a total gonad weight >50 g in winter were considered maturing. Stomach content weight was determined by subtraction of full and empty stomach weight. Stomach fullness was determined using the same categories as those used for analysis of *Wakatake maru* samples. Prey items were identified to the lowest taxonomic group possible and the individuals counted and weighed. Body lengths of intact squid (mantle length, ml) and fish (standard length, sl) were measured.

Graphical and Statistical Analysis of Food Habits Data

Our first analysis of food habits data involved only 2007 observer samples (Davis et al. 2009a). In this analysis, prey composition was summarized in two ways. Results were initially summarized at a high level of detail with regard to prey identification. Individual stomach samples were grouped by ocean age and season, and the prey weights in each prey group were summed, then divided by the total prey weight in each stratum. A second approach aggregated data for statistical comparison of winter prey composition of the major prey categories (euphausiids, squid, fish, and fish offal) to fishing depth zones, tow time period, Chinook salmon ocean age, and maturity. For each individual stomach sample containing prey, the weight of each of the four prey categories was divided by the fish's body weight to get a prey index (PI). The PI was compared among strata with the Kruskal Wallis or the Wilcoxon rank sum test. Only the winter samples were statistically analyzed because summer samples were too few in number. Trawl fishing depth was grouped into three categories (< 200 m, 201–400 m, 401–600 m) and tow time period was divided into four six-hour periods of the day (0001–0600 hr, 0601–1200 hr, 1201–1800 hr, and 1801–2400 hr). When a tow was not completed within one time interval, a stomach sample was attributed to the interval when at least 50% of the tow was conducted.

Our second analysis summarized all diet data collected during the project, including Chinook salmon age, maturity composition, and food habits in observer samples from the SEBS (2007-2008) and the *Wakatake maru* samples from the CBS (2007-2009). Stomach fullness, prey composition, and body size of squid and fish prey were compared by location, season, year, and age or size of Chinook salmon. Prey composition for 2007-2009 summer samples was converted from percent by volume to percent by weight by multiplying the volume by the prey weight contained in each stomach. To summarize prey composition, individual stomach samples were grouped by area, year, season, and ocean age and the weight of each prey category was summed and divided by the total prey weight in each stratum.

Energetics, Lipids, and Isotope Analysis

The NOAA Observer program approved removal from Dutch Harbor processing plants of tissue samples from only 40 Chinook salmon in winter 2009. For these samples, whole Chinook salmon were frozen and then homogenized by a meat grinder after being cut with a reciprocating saw. A sub-sample from the homogenate and corresponding gonad tissue samples were analyzed for energetic content by bomb calorimetry. To increase winter sample size (n=100), a multi-linear regression model was constructed with Bioelectrical Impedance Analysis (BIA), biological, and lab calorimetry measurements to estimate energetic content of remaining Chinook sampled at the processing plants. This equation was

derived through backward stepwise linear regression analysis of all measured variables until the lowest p-value, residual error and Akaike Information Criterion (AIC) was achieved. BIA is an accurate tool used to quantify the energetic content and proximate composition of fish (Cox and Hartman 2005; Pothoven et al. 2008). The theory behind BIA states that water has less resistance to electrical current than lipids so that a higher resistance equates to higher lipid content or non-conductive materials such as bone. The second measure, reactance, estimates the volume of cell membrane capacitance. Cell membranes consist of a non-conductive lipid bilayer between two conductive protein layers. BIA analysis uses low voltages and high frequencies to send currents through extra-cellular fluids making cell walls capacitive. This allows reactance and resistance numbers to be sensitive to changes in volume of extra-cellular and cellular material allowing estimates of proximate composition and energetic content. Estimated and observed total energetic content was divided by total mass of each fish to calculate energetic density (kJ/g). Energy allocated to gonads was estimated for the remaining gonads sampled using a second multi-linear regression model that was developed with highly significant validation statistics. The summer 2009 sample collection at Dutch Harbor processing plants was limited to only 40 Chinook salmon, and was processed with established methods, analyzing energetics by laboratory calorimetry. The sampling of whole Chinook salmon during both winter and summer commercial pollock seasons allowed us to observe seasonal changes in somatic and gonad energetic content with respect to sex and age. Stable isotope analysis was described in methods for Objective 2.

Methods Objectives 6: Estimate Consumption and Growth Efficiencies Modeled Under Different Climate Scenarios

Organizations and individuals performing the work: N. Davis, W. Fournier, and D. Beauchamp (SAFS/UW)

We used a bioenergetics modeling approach (the Wisconsin Model, Hanson et al. 1997) with field-derived input data on prey composition and growth to estimate Chinook salmon prey consumption and growth conversion efficiencies (conversion efficiency=growth/consumption) under different climate scenarios. The climate scenarios used for this analysis were the five-year period before (1972-76) and after (1977-82) the major 1977 regime shift. These periods were selected to represent two different climate scenarios that were clearly different from one another and separated by the 1977 regime shift. The 1977 regime was characterized major changes in the oceanographic and ecological relationships in the North Pacific Ocean and Bering Sea, when the Pacific Decadal Oscillation (PDO) shifted from the negative (cool) to positive (warm) phase (Mantua et al. 1997; Hare and Mantua 2000; Hollowed et al. 2001). The changes in sea surface temperature before and after the 1997 regime shift are of the same order as the average warming of the Bering Sea warming anticipated in the next 100 years (e.g., IPCC 2007; Stabeno et al. 2007; Wang et al. 2010), and provide a case study in the changes that might be expected with likely future warming scenarios. Growth increments based on back-calculations from Yukon Chinook salmon scales collected during the 5-year periods before- and after-1977 regime shift (Objective 3) were used to calculate field-based estimates of fish growth that date to the targeted time periods. Back-calculation procedures are described in Methods Objective 8. Analyses focused on the growth of fast growing (mature at age 1.3) and slow growing (mature at age 1.4) female Yukon Chinook salmon, because the growth trajectories of females are different from males, and female fecundity is fundamental to stock production.

Bering Sea Habitats

We used our conceptual model of AYK Chinook salmon distribution (Objective 2) and environmental fields developed in Objective 4 to obtain spatiotemporally explicit sea surface temperatures for bioenergetics models (Fig. 6-1). In our model, juvenile Chinook salmon enter the shallow northeastern shelf (NEBS Shelf <30m) off the Yukon River in summer (Jun-Aug) and move westerly to the deeper northeastern shelf (NEBS Shelf > 30m) in fall (Sep-Oct). Both of these areas are located between 60°N

and 65° N where AYK Chinook salmon are most commonly distributed on the eastern Bering Sea shelf Farley et al. (2009). The two areas are divided at 168°W at the approximate location of the 30-m isobath. From Nov- May (juveniles) and Oct-May (immatures) Chinook salmon are located in the southeastern shelf break (SEBS Shelf break) for over-wintering (NPFMC 2008). Immature Chinook salmon alternate between the Aleutian Basin in the central Bering Sea (CBS Basin) in summer (Jun-Sep) and the southeastern shelf break in winter (Oct-May; Myers et al 2009). After their final winter at sea maturing Chinook salmon return to the shallow NEBS Shelf (<30 m) in early summer (Jun) before entry to the Yukon River for spawning. The number of days delineated in the model that are spent in each of these habitats is listed on Table 6-1.

Sea Surface Temperature Scenarios Before and After Regime Shift

The five years before (1972-76) and after (1977-81) the 1977 regime shift in the North Pacific was selected as the time period on which to portray radically different, yet reasonable sea surface temperatures (SST). Monthly sea surface temperatures for the four habitat areas were obtained from the NOAA/OAR/ESRL NCEP Reanalysis Derived Data (<http://www.esrl.noaa.gov>; Kalnay et al. 1996; see Results Objective 4). Monthly values were assumed to represent the temperature on the 15th day of the month. The monthly value was averaged among the five years in each period to determine the temperature scenario for each five-year period. Temperature on the first day of the month was determined by linear interpolation between the adjacent monthly values for each period (Fig. 6-2).

The 1972-76 period before the 1977 regime shift was cooler than the 1977-81 period throughout the year in all habitats (Fig. 6-2). The temperatures in winter in the SEBS shelf break were substantially cooler (~2.6°C) in the earlier period. During the earlier, colder period, the monthly mean SST fell to -1.04°C. However, based on recovery of data-recording temperature tags from overwintering Chinook salmon in the Bering Sea (Walker and Myers 2009), we think it is unlikely that Chinook salmon would be exposed to such low surface temperatures for many days, so we adjusted the single mean value to 0.10°C.

Diet Composition and Prey Energy Density

Diet composition data was matched as closely as possible to the habitat, season, and life stage of Chinook salmon used in the bioenergetics models (Table 6-1). There are no food habits data for juvenile Chinook salmon available for fish immediately upon entry into the marine waters of the shallow NEBS shelf (<30m). Therefore, diet composition for this habitat and life stage was obtained from studies of juvenile Chinook salmon diets in the coastal zone of Karaginskii Bay in the western Bering Sea in July (Karpenko 1982). Diet composition data for the deeper NEBS shelf (>30m) was obtained from BASIS cruises in that area and season summarized by Volkov et al. (2007). Winter diet data for specific ocean ages of juvenile and immature Chinook salmon for the SEBS shelf break habitat was obtained from analysis of samples collected by US groundfish observers for this research project. Age- and maturity-specific diet data for Chinook salmon in the CBS basin were available from samples collected during cooperative Japan-US salmon research cruises onboard the *Wakatake maru* for this project. There were no food habits data for maturing Chinook salmon in the NEBS <30 m in June, so information from large Chinook salmon consuming Pacific herring (*Clupea pallasii*) in the coastal areas of Southeast Alaska (Healey 1991) was assumed to represent conditions in the marine areas adjacent to the Yukon River. The same diet composition was assumed for periods before and after the regime shift.

Prey energy densities (J/g) were obtained from literature values by matching the prey species, location, and month to Chinook salmon diet composition (Table 6-1). Some energy densities changed from one habitat area to another, or for Chinook salmon age group, while other energy densities did not change. For example, the energy density for crab larvae (crab megalopa; Mazur et al. 2007), euphausiids (*Thysanoessa spinifera*; Mazur et al. 2007), copepods (calanoids; Mazur et al. 2007), and shrimp (*Hymendora frontalis*; Davis 2003) remained the same for all age-maturity and habitat models. For the model of juveniles in the NEBS <30 m, the value used for insects was the mean for Diptera after converting from dry to wet weight (Higgs et al. 1995). The size and species composition of fish and squid changed from one habitat and Chinook age-maturity group to another. For juvenile Chinook

salmon in their first winter at sea (model run 1), the fish energy density for juvenile *Millosus villosus* (capelin; Mazur et al. 2007) was used. For immature Chinook salmon in the CBS basin in summer the density value used for fish prey was young *Pleurogrammus monopterygius* (Atka mackerel 44 mm SL [standard length]; Davis 2003). The fish prey energy density value used for immature Chinook salmon in the SEBS shelf break in winter was the mean value for *Stenobrachius leucopsarus* (lanternfish 44-112 mm SL, Davis et al. 1998 and Davis 2003). The fish prey energy density value used for maturing Chinook salmon in the shallow NEBS <30 m in June was Pacific herring (*C. pallasii* 97-104 mm SL, Davis et al. 1998). The prey energy density of the squid changed from one age-maturity group and habitat, as well. For juveniles and ocean age-1 Chinook salmon through their first summer at sea, the energy density value for squids was the mean value for small squids 13-22 mm ML [mantle length] from Davis (2003). The energy density for *Berryteuthis magister* (202-867 g body weight; Perez 1994) was used in models of consumption by older Chinook salmon in the CBS basin and SEBS shelf break habitats. The same prey energy densities were assumed for the period before and after the regime shift.

Chinook Salmon Growth Increment and Energy Density

To estimate prey consumption the bioenergetics model requires initial body weight for the first day and final body weight for the last day in the model (Table 6-2). Growth increments were estimated by back-calculation of fish body length based on scale data time series of Ruggerone et al. (2007; 2009a,b) for female Chinook salmon returning to the Yukon River during the periods before (1972-76) and after (1977-81) the 1977 regime shift. Back-calculated mid-eye-to-fork-of-tail (MEFT, mm) lengths were converted to tip-of-snout-to-fork-of-tail lengths (SNF, mm) using a published conversion equation for ocean-caught Chinook salmon (Pahlke 1988). Back-calculated (Francis 1990; Ricker 1992) SNF lengths of juveniles were converted to weights using a published weight-length regression for juvenile Chinook salmon in the northern (N of 60°N latitude) BASIS study area (Farley et al. 2005a). For older age groups, SNF lengths were converted to weights using a weight-length regression for Chinook salmon sampled by Bering Sea Aleutian Island (BSAI) groundfish observers in January. Body weight for each age group includes scales on which there was both plus growth and no plus growth (growth at the edge of the scale after the winter annulus). Start weights for all groups at age 1.0 includes freshwater plus growth. Body weight increments were calculated for fast-growing female Chinook salmon that mature early and return to freshwater at ocean age-3 and slow-growing fish that mature later and return to freshwater at ocean age-4. Growth increments of maturing fish during the final month (June in NEBS shelf <30m) were estimated from the size of plus growth at the edge of the scale.

Chinook salmon energy density was estimated to be 4000 J/g for fish throughout their first year at sea (Hansen et al. 1977, Trudel et al. 2005; Table 6-2). Energy densities for older fish estimated from the equations of Stewart and Ibarra (1991) and linearly interpolated between initial and final body weight. The same Chinook salmon energy densities were assumed for the period before and after the regime shift.

Results of preliminary model simulations indicated that models for immature ocean age-2, -3, -4 and maturing ocean age-3 and -4 fish were not able to model enough prey consumption to achieve the determined growth increment. As these age-maturity groups weigh more than 2.5 kg, it is possible there is a different relationship between body weight and the capacity for prey consumption in larger Chinook salmon. By using the same modeling approach used previously for chum salmon prey consumption (Davis et al. 1998), we increased the y-intercept for weight dependence of consumption from 0.303 (Stewart and Ibarra 1991) to 0.424 (1.4 times) for model runs 3 to 6 in order to increase the prey consumption parameter.

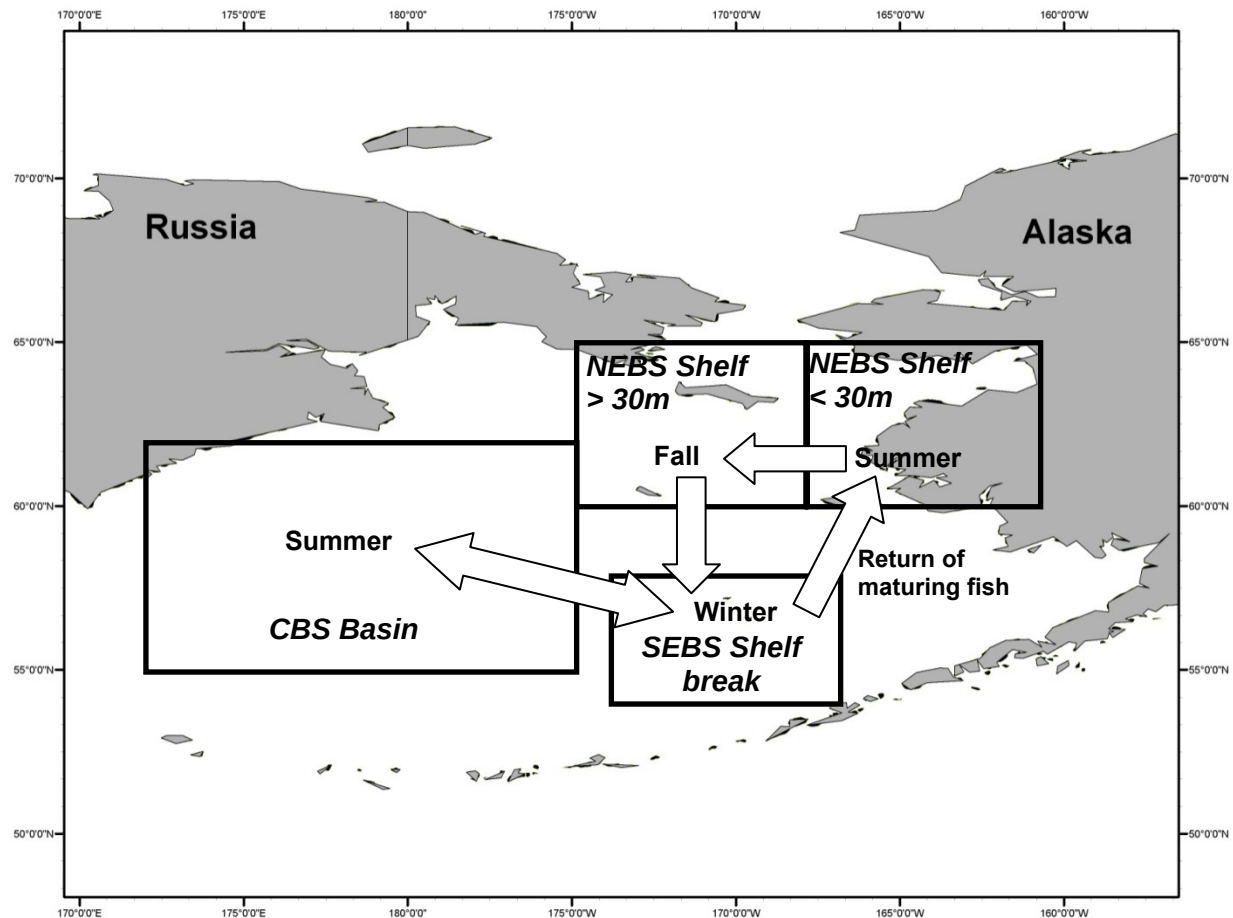


Figure 6- 1. Seasonal habitats in the Bering Sea used to characterize environmental and feeding conditions of female Yukon River Chinook salmon for bioenergetics modeling. Juveniles enter the shallow northeastern shelf (NEBS Shelf <30m) off the Yukon River in summer (Jun-Aug) and move westerly to the deeper northeastern shelf (NEBS Shelf > 30m) by fall (Sep-Oct). In November - May (juveniles) and October - May (immatures) Chinook salmon have moved to the southeastern shelf break (SEBS Shelf break) for over-wintering. Immature Chinook salmon alternate between the central Bering Sea basin (CBS Basin) in summer (June-September) and the southeastern shelf break in winter (October - May). After their final winter at sea maturing Chinook salmon return to the shallow NEBS Shelf (<30 m) in early summer (June) before entry to the Yukon River for spawning. Scenario of seasonal and maturity-specific distribution of western Alaska Chinook salmon based on Chinook salmon tag returns, scale pattern analysis, and genetic stock identification (see Results Objective 2).

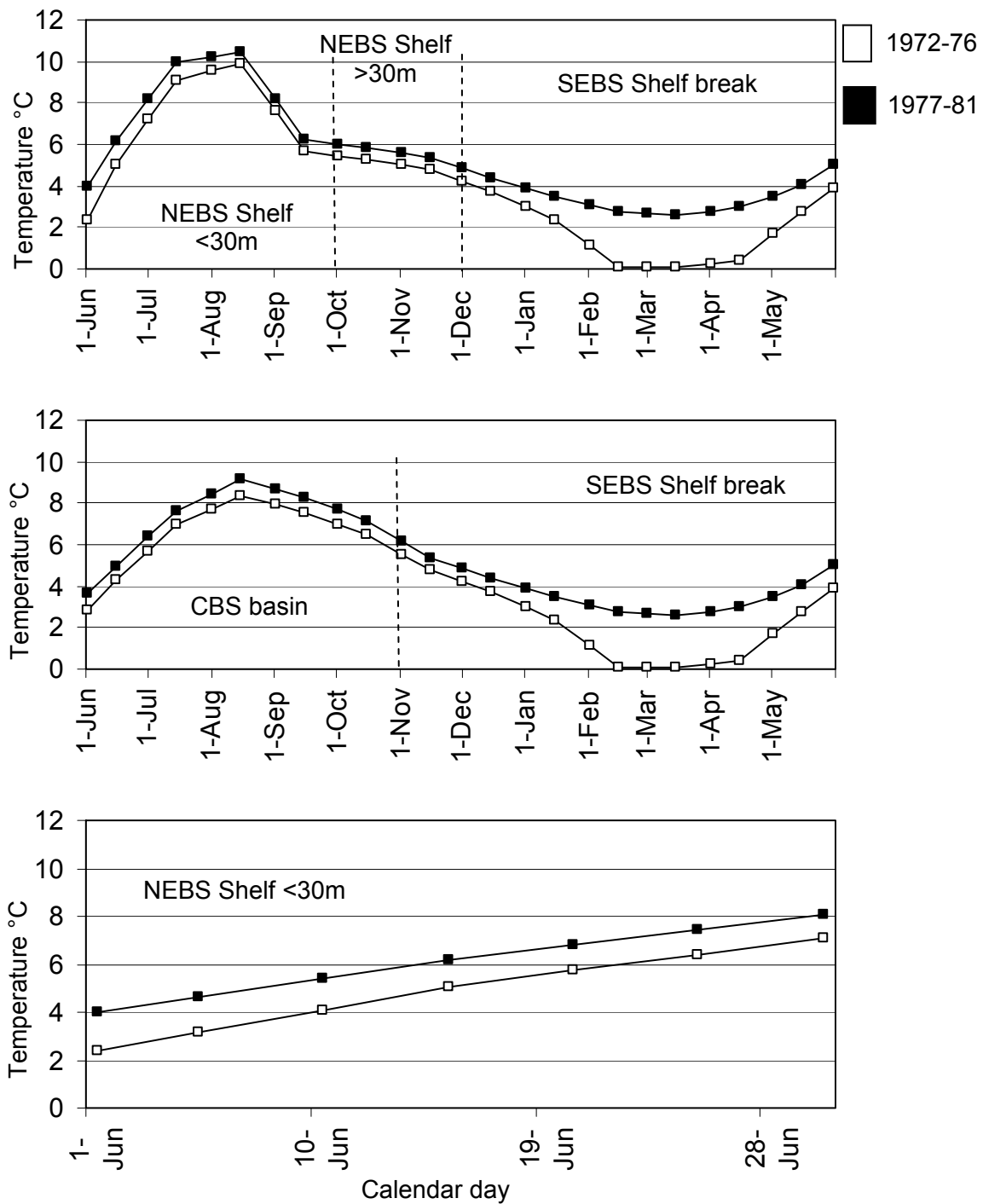


Figure 6- 2. Monthly sea surface temperatures (°C) averaged for the five year period (1972-76, open squares, and 1977-81, closed squares) before and after the 1977 regime shift used to model habitat conditions for female Yukon River Chinook salmon in the Bering Sea. Monthly sea surface temperatures for the areas defined in Fig. 6-1 were obtained from NOAA/OAR/ESRL NCEP Reanalysis Derived Data <http://www.esrl.noaa.gov>. Daily values linearly interpolated between average monthly means

Table 6- 1. Female Chinook salmon ocean age and maturity, habitat areas, time period, diet composition (proportion), and prey energy density (J/g wet weight) used as input values in bioenergetics models to simulate feeding conditions in the Bering Sea. Total prey energy density is weighted by prey composition and represents the gross energy content of the daily diet of fish in the respective habitat and season. Number of days is the number of daily time steps used in the model run. Maturity groups include juv=juvenile, imm=immature, mat=maturing fish.

Mod- el run	No. of days	Ocean age	Ma- turity	Area	Time period	Prey category	Prey composition		Prey energy density (J/g wet weight)	
							Propor- tion	Data source	Value	Data source
1	365	0 to 1	juv to imm	NEBS Shelf < 30m	Jun 1- Aug 31	fish	0.95		3760	Mazur et al. 2007
						insects	0.05		3859	Higgs et al. 1995
						total	1.00	Karpenko 1982	3765	
				NEBS Shelf > 30m	Sep 1- Oct 31	crab larvae	0.11		4458	Mazur et al. 2007
						fish	0.86		3760	Mazur et al. 2007
						squid	0.03		3962	Davis 2003
						total	1.00	Volkov et al. 2007	3843	
				SEBS Shelf break	Nov 1- May 31	euphausiids	0.30		5577	Mazur et al. 2007
						fish	0.09		3760	Mazur et al. 2007
						squid	0.61		3962	Davis 2003
						total	1.00	this study	4428	
2	365	1 to 2	imm	CBS basin	Jun 1- Sep 30	amphipods	0.01		3833	Davis 2003
						copepods	0.01		5319	Mazur et al. 2007
						crab larvae	0.01		4458	Mazur et al. 2007
						euphausiids	0.10		5577	Mazur et al. 2007
						fish	0.49		5188	Davis 2003
						squid	0.38		3962	Davis 2003
						total	1.00	this study	4741	
				SEBS Shelf break	Oct 1- May 31	euphausiids	0.05		5577	Mazur et al. 2007
						fish	0.04		9205	Davis et al. 1998, Davis 2003
						shrimp	0.01		5736	Davis 2003
						squid	0.90		5523	Perez 1994
						total	1.00	this study	5675	

Table 6-1. Continued.

Mod- el run	No. of days	Ocean age	Ma- turity	Area	Time period	Prey category	Prey composition		Prey energy density (J/g wet weight)	
							Propor- tion	Data source	Value	Data source
3	365	2 to 3	imm	CBS basin	Jun 1- Sep 30	euphausiids	0.19	this study	5577	Mazur et al. 2007
						fish	0.13		5188	Davis 2003
						squid	0.68		5523	Perez 1994
						total	1.00		5490	
				SEBS Shelf break	Oct 1- May 31	euphausiids	0.09	this study	5577	Mazur et al. 2007
						fish	0.07		9205	Davis et al. 1998, Davis 2003
						squid	0.84		5523	
						total	1.00		5786	
4	365	3 to 4	imm	CBS basin	Jun 1- Sep 30	euphausiids	0.05	this study	5577	Mazur et al. 2007
						fish	0.05		5188	Davis 2003
						squid	0.90		5523	Perez 1994
						total	1.00		5509	
				SEBS Shelf break	Oct 1- May 31	euphausiids	0.04	this study	5577	Mazur et al. 2007
						fish	0.07		9205	Davis et al. 1998, Davis 2003
						squid	0.89		5523	
						total	1.00		5783	
5	30	3	mat	NEBS Shelf < 30m	Jun 1- Jun 30	fish	1.00	Healey 1991	8008	Davis et al. 1998
						total	1.00		8008	
6	30	4	mat	NEBS Shelf < 30m	Jun 1- Jun 30	fish	1.00	Healey 1991	8008	Davis et al. 1998
						total	1.00		8008	

Table 6- 2. Female Chinook salmon body weight (g) and energy density (J/g) used for initial and final conditions for bioenergetics models of their prey consumption in the Bering Sea. Time period is the 5-year period before (1972-76) and after (1977-81) the 1977 regime shift. Chinook salmon body size determined from back-calculation of scale data from a time series for these years for Yukon River fish (Ruggerone et. al. 2007; 2009a,b; average for each five-year period) with fish lengths converted to weight data. Fast-growth rate is the weight increment of fish that mature and return to freshwater at ocean age-3. Slow-growth rate is the weight increment of fish maturing later at ocean age-4. Chinook salmon energy density estimated to be 4000 J/g wet weight for fish through their first year at sea (Hansen et al. 1977, Trudel et al. 2005). Energy densities for older fish estimated from the equations* of Stewart and Ibarra (1991) and linearly interpolated between initial and final body weight.

Model no.	Ocean age	Maturity	Time period	Growth rate	Initial conditions		Final conditions	
					Body weight (g)	Energy density (J/g)	Body weight (g)	Energy density (J/g)
		juvenile to immature						
1	0 to 1		1972-76	fast	40	4000	762	4000
				slow	21	4000	583	4000
			1977-81	fast	22	4000	744	4000
				slow	20	4000	611	4000
2	1 to 2		1972-76	fast	762	6515	2837	8562
				slow	583	6339	2089	7824
			1977-81	fast	744	6498	2936	8659
				slow	611	6367	2101	7836
3	2 to 3		1972-76	fast	2837	8562	8053	11843
				slow	2089	8702	5385	10438
			1977-81	fast	2936	9148	7482	11542
				slow	2101	8708	5572	10536
4	3 to 4		1972-76	slow	5385	10438	10308	13030
			1977-81	slow	5572	10536	10496	13129
5	3	maturing	1972-76	fast	7777	11697	8831	12252
			1977-81	fast	6946	11260	8434	12043
6	4	maturing	1972-76	slow	9031	12358	10640	13205
			1977-81	slow	10059	12899	11810	13821

*for Chinook salmon ≤ 4000 g body weight (W); energy density (J/g) = $5764 + 0.9962W$;
for Chinook salmon >4000 g body weight; energy density = $7602 + 0.5266W$ (Stewart and Ibarra 1991).

Methods Objective 7: Map Spatial and Temporal Variability in Ocean Growth Potential

Organizations and individuals performing the work: N. Davis, W. Fournier, and D. Beauchamp (SAFS)

We used a life history approach to bioenergetics modeling to develop prey consumption and conversion estimates for AYK Chinook by accounting for movement of juvenile, immature, and maturing Chinook to different habitats in the Bering Sea throughout the year (Objectives 2 and 6; Fig. 6-1). Field-based observations of Bering Sea Chinook salmon diet (Objective 5; Table 6-1) were stratified by age and habitat location. We explore critical habitat (temperature and feeding) conditions for growth for particular Chinook salmon life stages to determine age-structured growth response to different feeding rates and differing prey energy density over a range of temperatures.

The methodology of Beauchamp (2009) was used to estimate specific growth rate (g/g/day) over a range of temperatures from 1 to 25°C for Chinook salmon of different life stages and body weights. Body weights typical for juvenile ocean age-0 (50 g), immature ocean age-1 (1 kg), age-2 (2.5 kg), age-3 (6 kg), age-4 (10 kg), and maturing ocean age-3 (8.5 kg) and age-4 (12 kg) Chinook salmon were used. Two diet scenarios were selected. A diet with a value of 5,500 J/g (all energy densities are in terms of wet weight) and an enhanced diet of 9,500 J/g were used to compare the effect from different quality diets on growth at a range of temperatures. Feeding rate was set to 25%, 50%, 75% and 100% of C_{max} , which is the theoretical maximum daily consumption rate based on the body mass and temperature on the day of the simulation (Hansen et al. 1997). The results can be used as a tool to map age-specific ocean growth potential with respect to sea temperatures and diet quality in the Bering Sea.

Methods Objective 8: Simulate Climate Effects on Age and Growth

Organizations and individuals performing the work: K. Myers (SAFS); G. Ruggerone, B. Agler, and J. Nielson provided Yukon River Chinook salmon scale measurement data for the analysis. K. Howard, Alaska Department of Fish and Game, provided Yukon River run reconstruction data.

We hypothesized that climate forcing results in changes in the ocean growth rates of Chinook salmon, which in turn affects their age and body size at maturity. Morita et al. (2005) found that recent decadal-scale trends in decreasing body size and increasing age at maturity of Japanese chum salmon could be attributed to an adaptive phenotypic response to reduced growth rates. They identified a simple rule of fish age and size at maturity, i.e., slow growing fish mature at a larger size and older age than fast growing fish. Then, they used a size-structured model with age- and size-specific maturation rates to simulate response to changes in growth rates. We used methods similar to those of Morita et al. (2005) to simulate the response of Chinook salmon to climate-induced changes in ocean growth rates.

For this analysis, we obtained age, sex, length, run size, and scale measurement data for adult Chinook salmon returning to the Yukon River (64°00'N; 164°14' W) during 1997-2004. Scale measurement data were those of Ruggerone et al. (2007; 2009a,b), and consisted of a time series of annual growth measurements of scales from ages 1.3 and 1.4 fish captured with set gillnets (21.6 cm stretched mesh) in test fisheries located in the lower Yukon River (river km 20–30). We analyzed data only for female Chinook salmon, because the gillnet test fishery samples used by Ruggerone et al. (2007; 2009a,b) were not representative of males that dominate younger age groups (ages 1.1 and 1.2) returning to the river. The 1997-2004 data included seven cohorts (brood years 1992-1998). We reconstructed the lengths of immature fish at each age using the Fraser-Lee back-calculation method with a biological intercept (Francis 1990; Ricker 1992), as follows:

(8-1) $L_i = c + (L_c - c)(S_i/S_c)$, where L_c is fish mid-eye-to-fork-of-tail (MEFT) length at capture, S_c is total scale radius at capture, L_i and S_i are the corresponding measurements at the time of formation of the i th scale annulus, for $i=1,2,\dots,n$, and c is a constant equal to the length of the fish at the time of scale

formation (44 mm) for Chinook salmon, Welander 1940). All fish used in the analysis were immature at age 1.2 and matured at either age 1.3 or age 1.4. Therefore, we calculated the probability of maturing at age 1.3.

To calculate the probability of maturing, age and size frequency distributions of immature and maturing females were estimated.

The number of maturing fish of size class i at age t or $n_{i,t}$ is:

$$(8-2) \ n_{i,t} = R \cdot f_t \cdot p_i$$

where R is the reconstructed annual run size of Chinook salmon returning to the Yukon river in 1997-2004 (JTC 2009; Table 8-1), f_t is the observed annual proportion of females of age group t in the run (Table 8-2), and p_i is the back-calculated size probability distribution in 5-mm increments.

Table 8- 1. Reconstructions of the total run (total number of fish in catch + spawning escapement) of Yukon River Chinook salmon, 1997-2004. Estimates based on assumption that 50% of the total run is Canadian-origin fish. Data Source: K. Howard, Alaska Department of Fish and Game, Anchorage, based on estimates of Canadian-origin run reconstructions in Appendix Table A10, JTC (2010).

Year	Total Run
1997	323,401
1998	176,566
1999	220,893
2000	105,687
2001	171,970
2002	163,492
2003	300,304
2004	235,078

Table 8- 2. Proportion of ages 1.3 and 1.4 adult female Chinook salmon, 1997-2004, computed from lower Yukon River test fishery samples from fishing district Y1 (Big Eddy, 8.5" set gillnet, May-July). Data source: Alaska Dept. Fish and Game.

Year	Age 1.3	Age 1.4
1997	0.04	0.45
1998	0.19	0.27
1999	0.03	0.59
2000	0.05	0.42
2001	0.02	0.43
2002	0.03	0.31
2003	0.03	0.44
2004	0.03	0.55

The number of immature fish of size class i at age $t-a$ that mature at age t , denoted by $n_{i,t-a}$ is:

$$(8-3) n_{i,t-a} = \sum_i n_{i,t} e^{-M a} q_{i,t-a,t}$$

where M is the instantaneous mortality rate and $q_{i,t-a,t}$ is the back-calculated size probability distribution at age $t-a$ from fish that mature at age t .

We are not aware of any direct estimates for natural ocean mortality of Yukon River Chinook salmon. Ricker (1976) suggested that $M = 0.20/\text{year}$ is a reasonable value for the annual rate of ocean mortality during the final years of salmon at sea. Major (1984) noted that annual mortality rates used for other Chinook stocks have ranged from 0.1 to 0.69. Bradford (1995) found large interspecific differences in marine survival of Pacific salmon and speculated that Chinook salmon have much higher marine mortality rates than other freshwater-rearing salmon species. Initially, the baseline mortality was set at $M = 0.20$ a, and to account for the large amount of uncertainty, mortality rates of $M = 0.445$ and $M = 0.69$ were used.

Logistic regression analysis (S-PLUS 8.0 for Windows) was used to determine the threshold size at maturity for age 1.3 Chinook salmon, i.e., the size at which 50% of the individuals are mature (Morita et al. 2005):

$$(8-4) \text{logit}(P) = \log(P/1-P) = c_0 + c_1 l$$

where P is the probability of maturing, c_0 is constant, and c_1 is the coefficient for l (MEFT length). We analyzed the probability of maturing per 5-cm size class. To evaluate the statistical significance of the individual coefficients using the t-values in S-PLUS software output, the square of the t-values was treated as asymptotically chi-squared with 1 df.

Following the methods of Morita et al. (2005), we used a general life history model for fish (Roff 1984) to estimate the optimal age at maturity (t^*) maximizing fitness of Chinook salmon:

$$(8-5) t^* = (1/k) \ln((3k+M)/M), \text{ where } M \text{ is the instantaneous ocean mortality.}$$

The optimal size at maturity (l^*) was estimated by substituting (t^*) into a simplified von Bertalanffy growth equation:

$$(8-6) l^* = l_\infty ((3k+M)/M)$$

The asymptotic MEFT length (l_∞) was set at 110 cm, which was near the maximum MEFT length of female Chinook salmon in the Ruggerone et al. (2007; 2009a,b) data series (1964-2004).

In addition, optimal growth rates (k^*) of ages 1.3 and 1.4 female Yukon River Chinook salmon (BY1992-1998) were estimated from back-calculated size at age data using a linear regression approach to von Bertalanffy growth, i.e., fish length at age t (FAO, VONBIT Software, <http://www.fao.org/fishery/topic/16078/en>; Stamatopoulos and Caddy 1989). The advantage to this approach is that it allows independent and near optimal solutions for estimation of the main parameters, k (rate of growth towards asymptotic length) and l_∞ (asymptotic maximum length reached when age increases infinitely).

For a given value of k , size is expressed linearly as:

$$(8-7) l_t = a_0 + a_1 x_t, \text{ where}$$

$$(8-8) a_0 = l_\infty, a_1 = -l_\infty e^{kt_0}, \text{ and } x_t = e^{-kt} \text{ or}$$

$$(8-9) a_0 = l_0, a_1 = l_0 - l_\infty, \text{ and } x_t = e^{-kt} - 1,$$

where l_0 is a theoretical length at zero age and t_0 is the age at which length is zero. In this approach, trial values of k each generate a regression line with an associated coefficient of determination, R^2 . The optimum k is the value when R^2 is closest to 1. Secondary parameters l_∞ , t_0 , and l_0 are calculated directly using the optimum k , any two estimated sizes l_i and l_j , and equations $x_t = e^{-kt}$ or $x_t = e^{-kt} - 1$.

To explore how growth rates might affect average size and age at maturity of female Yukon River Chinook salmon, we developed a simple size-structured model to simulate the size distribution of maturing age 1.3 fish in January of the year of their return to the river. The number of maturing fish of size class i at age 1.3, denoted in matrix form, is $\mathbf{R}_i = \mathbf{P}_i \mathbf{N}_i$, where $\mathbf{P}_i$ is the matrix of size class i specific probabilities of maturing according to the logistic regression equation (4) and $\mathbf{N}_i$ is the matrix of number of fish of size class i . In the simulation, we set the minimum size at 30 cm and the maximum size at 110 cm, with a size class interval of 1 cm. The initial size distribution was calculated from a normal distribution, with mean = $110 \times (1 - e^{-kx^3})$ and SD = 4.7 (observed value). Estimates were generated for four different growth rates ($k = 0.2, 0.3, 0.4$, and 0.5). Simulated results were compared to observed mean sizes of maturing age 1.3 female Yukon River Chinook salmon in January (back-calculated from scale data) for different climate-regimes (before and after the winter 1976-77 regime shift and a period, 1997-2004, that included the strong 1997-1999 ENSO). Simulated results were also compared to winter (January) mixed-stock samples from the commercial groundfish fishery bycatch in the Bering Sea during three different periods. The lengths of salmon sampled from the groundfish fishery bycatch were measured from the tip of the snout to the fork of the tail (SNF). SNF lengths (mm) were converted to mid-eye-to-fork-of-tail lengths (MEFT; mm) using a linear regression equation developed from measurements of ocean-caught Chinook salmon (Pahlke 1988):

$$(8-10) \text{ MEFT} = 0.900(\text{SNF}) + 20.321$$

Methods Objective 9: Synthesize Information on the Ocean Life History and Climate-Ocean Effects on Chinook salmon

Organizations and individuals performing the work: K. Myers, R. Walker, N. Davis, J. Armstrong, W. Fournier, O. Abdul-Aziz, and N. Mantua (SAFS/UW), and J. Raymond-Yakoubian (Kawerak, Inc.),

The final objective of our project was to provide a synthesis and review of information on ocean life history and climate-ocean effects on AYK Chinook salmon. We use LTK collected during this project to develop hypotheses for future research, discuss information gaps, and suggest future research directions. As part of our synthesis, we reviewed published information on the marine life history of Chinook salmon and associated climate-ocean effects. Our data compilations, assessments, analyses, simulations, and modeling of Chinook salmon life history information were accomplished as a part of Objectives 1-8.

Long-Term Trends and Shifts in Size of Immature Chinook Salmon in the Bering Sea

Other studies have reported apparent long-term, regime-scale climate or ecosystem effects on body size and growth of AYK Chinook salmon (e.g., Ruggerone et al. 2007; 2009a,b). The longest continuous time series of body size data in our historical database (see Objective 1) was fork length measurements of immature age 1.2 Chinook salmon caught by Japanese salmon research vessels in the Bering Sea in July 1974-2008. A preliminary graphical analysis of long-term trends in these data indicated similar regime-scale shifts in both male and female Chinook salmon (see Fig. 3-23). To statistically detect when significant shifts may have occurred, we used a sequential t -test analysis of regime shifts (STARS, $\alpha=0.05$; Rodionov 2004, 2005; <http://www.beringclimate.noaa.gov/regimes/index.html>).

Correlations Between Annual Scale Growth Increments and Climate Indices

We further evaluated the hypothesis that high frequency (interannual) variation in growth of Chinook salmon is related to climate events (e.g., the 1997-1999 ENSO event), as well as other large-, meso-, and

local-scale climate-ocean conditions (Appendix Table 6-1). Exploratory mapping of differences in climate and ocean conditions over the periods evaluated was done using a website of the Earth Science Research Lab of NOAA (<http://www.esrl.noaa.gov/psd/cgi-bin/data/getpage.pl>; monthly/seasonal composites at <http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl>; see Results Objective 4). Variables examined included sea level pressure, sea surface temperature, and zonal and meridional winds. To characterize Chinook salmon growth by age and life stage, we used annual scale-growth increment data from both mixed-stock (OBS and WAK) Bering Sea and adult female Yukon (YUK) Chinook salmon samples (see Objective 3). Sizes of annual growth, lagged to years in which the growth occurred, were analyzed for correlations with climate and biological indices for those years. Initial statistical analysis consisted of calculating correlations (Pearson r) and single factor ANOVAs between growth measures and climate-ocean indices. Those indices with higher correlations (greater than 0.45) for several of the growth measures were further evaluated by regression models of individual growth measures with individual indices. Stepwise multiple regression models were constructed for a combination of four or five high correlation indices and individual marine growth years for age 1.3 and 1.4 females. Multiple regressions were run to relate annual scale growth with climate indices. The four or five indices which showed the highest correlations were used for the initial backwards stepwise regression in S-Plus. Some indices with good correlations were not used as they were related to or variations of others that were being used. The final variables used for YUK Chinook salmon were related to temperature (May SST and Fairbanks air temperatures), ice cover, wind stress along the Alaska Peninsula, and a few larger scale climate indices (ALPI, MEIa, PDO, Bering Sea winter air pressure, and Siberian Index).

Potential Climate Change Impacts on Open Ocean Thermal Habitats of Chinook Salmon

We collaborated with another project funded by a grant through the National Center for Ecological Analysis and Synthesis (NCEAS), University of California, Santa Barbara, to estimate potential future climate change impacts on high seas (open ocean) thermal (SST) habitats of Chinook salmon in the North Pacific and adjacent seas (O. Abdul-Aziz, N. Mantua, and K. Myers, SAFS/JISAO/UW). The following results were extracted from a manuscript submitted to a peer-reviewed scientific journal (Abdul-Aziz, O.I., N.J. Mantua, and K.W. Myers. Potential climate change impacts of thermal habitats of Pacific salmon in the North Pacific Ocean and adjacent seas. Submitted to the Canadian Journal of Fisheries and Aquatic Sciences, November 3, 2010).

The historical sea surface temperature (SST) reference period for this analysis was the 30-year average centered on the 1980s (i.e., 1970-1999). Three 30-year average periods centered on the 2020s (2010-2039), 2040s (2030-2059), and 2080s (2070-2099) were used to evaluate projected changes in sea surface temperatures (SSTs) and reference thermal habitats. The Pacific Decadal Oscillation (PDO) (Mantua et al. 1997) warm and cool phase-eras of 1925-1946 (1925s; warm), 1946-1976 (1947s; cool), and 1977-1997 (1977s; warm) were also used to assess the effects of natural, inter-decadal climate variability on historical, thermally-defined high-seas habitat areas of Chinook salmon in the 20th century. Sources of SST data used for mapping were described previously (see Methods Objective 4). Simulated SSTs (mean monthly skin temperature data) for the ‘climate of the 20th century experiment (20c3m)’, as well as for three warming scenarios of lower (SRES B1), medium (SRES A1B), and higher (SRES A2) greenhouse gas emissions, were obtained from the world wide web site of the Program for Climate Model Diagnosis and Intercomparison (PCMDI) (<http://www-pcmdi.llnl.gov/>). Further details on the greenhouse gas emissions scenarios can be found in Nakicenovic et al. (2000). Eighteen global climate models (GCMs) were used. Four GCMs did not provide SSTs for the A2 emissions scenario, and, therefore, only 14 models contributed to the A2 scenario multi-model average. Skin temperature is defined as the SST for ‘open ocean’ in PCMDI’s “IPCC standard output from coupled ocean-atmosphere GCMs” (available at http://www-pcmdi.llnl.gov/ipcc/standard_output.html). Spatial resolution of the global, historical SST

field was 2°x2°, while model resolutions for the ‘surface skin temperature’ simulations varied approximately from 1.4°x1.4° to 4°x5° (latitude by longitude), which is an appropriate scale given the coarse resolution of the historical SST field and the ‘open ocean’ focus of our analysis. The historical data resolution was defined as the reference resolution, the time-averaged mean monthly SSTs of 2020s, 2040s, and 2080s were regridded to the reference grids to achieve compatibility with those of the historical 1980s period. The regridded model SSTs were corrected for biases (the differences between model simulations and historical observations for the 30-year average centered on the 1980s) of all individual GCMs. Because each GCM has unique biases in simulated SST fields, we used a simple delta method to compute model-specific changes in SSTs relative to each model’s own reference climatology for the simulated 1980s (1970-99) as obtained from their respective 20c3m experiments. Then, the multi-model average changes of monthly SSTs in different future periods relative to the 1980s were obtained by the ensemble averages of changes from 14 models for A2 scenario and 18 models for both B1 and A1B scenarios. The final bias-corrected mean monthly SST projections for each of the different periods and scenarios were constructed by adding the respective ensemble-average changes in mean monthly SSTs with the observed, historical mean monthly SSTs of 1980s. High seas salmon survey data collected over the last 50 years were used to identify reference thermal limits for Chinook salmon. Lower and upper limits, respectively, refer to the coldest (northern) and warmest (southern) thermal limits. We subjectively selected a set of ‘frequently observed’ thermal ranges as reference ranges for mapping and analyses. The selected reference spring-summer-fall and winter ranges were, respectively, 1.0-10°C and 1.5-12°C. These ranges were not definitive boundaries for high-seas Chinook salmon habitat, but instead were selected to investigate sensitivity of Chinook salmon thermal habitat areas to historical and future climate scenarios. Reference thermal habitats in different seasons and periods were determined by applying these reference limits to the different SST fields (historical versus future scenarios). The observed, historical reference SST climatology of the 1980s was calculated by averaging SST time-series at each grid cell for each calendar month within the 1970-1999 period. Likewise, historical mean monthly SSTs were calculated for the 1925s, 1947s, and 1977s. The sensitivity of the habitat areas to the specified thermal boundaries for Chinook salmon was determined by the changes in the 1980s July and December habitat areas due to a 1°C increase and decrease in the respective isotherm of the warmest or coldest limit while keeping the other limit unchanged. The ratios of the corresponding percent changes in the habitat areas and reference limits were defined as the sensitivity coefficients (Abdul-Aziz et al. 2010), which are non-dimensional and show both the magnitude and direction of the sensitivity rates. Since both 1°C increase and decrease resulted in similar estimates of sensitivity coefficients, we only reported sensitivity results obtained with the case of 1°C increase in the thermal limits as examples. Multi-model average monthly SST projections for the 2020s, 2040s, and 2080s were calculated for each of the three emission scenarios (B1, A1B, and A2) after regridding and correcting projected SSTs for model biases.

Objective 9 also includes ongoing work towards completion of a graduate student (Master of Science) thesis (W. Fournier, expected completion date December 15, 2010), and one or more manuscripts for peer-review publication, as warranted by the results.

IV. RESULTS

Results: Research Vessel Surveys and Fish Processing Plant Sampling

Wakatake maru

In 2007-2009, continuation of the unique *Wakatake maru* time series of salmon survey data (1991-2010) from the central North Pacific Ocean and Bering Sea contributed significantly to our investigation. Chinook salmon are infrequently encountered in offshore fishing operations because of their low abundance relative to other salmon species. As a result, ocean data on Chinook salmon accumulates slowly over many years. The *Wakatake maru* survey provided up-to-date biological, ecological, and

environmental information on immature Chinook salmon near the center of their ocean distribution in the Bering Sea in summer. Primarily, we used the *Wakatake maru* time-series data on Chinook salmon to evaluate seasonal and interannual variation in scale growth patterns (Objective 3), to characterize summer food habits for diet analyses (Objective 5) and bioenergetics models (Objectives 6 and 7), and to develop statistical models of the relationships between Bering Sea Chinook salmon growth and climate-ocean conditions (Objective 9).

The results of the surveys were reported to the NPAFC in documents that can be downloaded from the Commission's website (Fukuwaka et al. 2007a; [http://www.npafc.org/new/publications/Documents/PDF%202007/1046\(Japan\).pdf](http://www.npafc.org/new/publications/Documents/PDF%202007/1046(Japan).pdf)), Fukuwaka et al. 2008b (<http://www.npafc.org/new/publications/Documents/PDF%202008/1115%28Japan%29.pdf>), and Kaga and Davis 2009 (<http://www.npafc.org/new/publications/Documents/PDF%202009/1194%28Japan%29.pdf>).

This project also supported tagging (aboard the *Wakatake maru*) of all viable Chinook salmon with external disk tags and Lotek temperature-depth data-storage tags in 2008 (19 fish tagged) and 2009 (6 fish tagged). To date, one tagged fish was recovered and reported (see Methods and Results Objective 2). Analyses of Chinook salmon scale growth and food habits data collected during the *Wakatake maru* surveys are discussed in methods and results of Objectives 3, 5, 6, and 9.

***Oshoro maru*, 2007**

K. Myers, M. Kaeriyama, and H. Herter boarded the T/S *Oshoro maru* in Dutch Harbor, Alaska, on July 24, 2007, for survey Leg 2 (Fig. 4). At the end of Leg 2, the vessel made a port call in Nome, Alaska (August 3-5, 2007), where H. Herter disembarked. K. Myers and M. Kaeriyama remained on board for Leg 3, and A.C. Odden boarded the vessel in Nome on August 5 for Leg 3 (Fig. 5). At the end of Leg 3 the vessel made a port call in Nome (August 15-16, 2007), where K. Myers, M. Kaeriyama, and A.C. Odden disembarked. AYK SSI/SSSF project funds covered travel and shipboard per diem costs for K. Myers, H. Herter, and A.C. Odden. Shipboard activities of AYK SSI-funded participants included research observation, cooperation, coordination, and sample and data exchanges with an international team of experts on climate, oceanography, fish, and other marine biota of the Bering Sea.

During Leg 2, sampling operations focused on three regions: the southeastern shelf of the Bering Sea, St. Lawrence Island Polynya (SLIP), and the mouth of Yukon River (Fig. 4). During Leg 3, sampling operations focused on the northern Bering Straits and Chukchi Sea. (Fig. 5).

M. Kaeriyama reported the results of salmon sampling during Leg 2 (Bering Sea; Appendix 1) and Leg 3 (Chukchi Sea; Appendix 2). A total of 101 salmon (80 chum salmon, 2 pink salmon, 8 sockeye salmon, 15 coho salmon, and 2 Chinook salmon) were caught during Leg 2 in the Bering Sea, and no salmon were caught during Leg 3 in the Chukchi Sea. Chinook salmon (2 immature fish) were caught at only one station during the survey (longline station B40 in the St. Lawrence Island Polynya; Fig. 4). Low salmon catches were primarily due to limited fishing effort and inefficiency of fishing gear used to catch salmon (longlines, bottom trawl, angling). Nevertheless, the survey provided a wealth of new data on climate and ocean conditions in the Bering Sea and Chukchi Sea.

The *Oshoro maru* made two port calls in Nome, Alaska, which facilitated our public outreach activities in the AYK region. S. Saitoh, K. Myers, and M. Kaeriyama with local assistance from R. Fosdick (Kawerak, Inc.), H. Herter, and A.C. Odden organized a 1-day public mini-symposium, "Marine Ecosystem Responses to Global Climate Change in the Bering and Chukchi Seas" to mark the 2007 IPY cruise of the T/S *Oshoro maru*. The symposium, held at Old St. Joseph's Hall in Nome on August 4, 2007, and was attended by *Oshoro maru* scientists and students, project investigators, and some members of the public. K. Myers, M. Kaeriyama, R. Fosdick, H. Herter, and A.C. Odden made oral presentations at the symposium (Attachment 3). In addition, H. Herter, provided an internet journal of shipboard activities during Leg 2 (<http://seagrant.uaf.edu/marine-ed/news/ipy-cruise-2007.html#salmon>), and AYK SSI featured information about the cruise and mini-symposium on the "Spotlight" page of their website (http://www.aykssi.org/temporary/High_Seas_Salmon.htm).

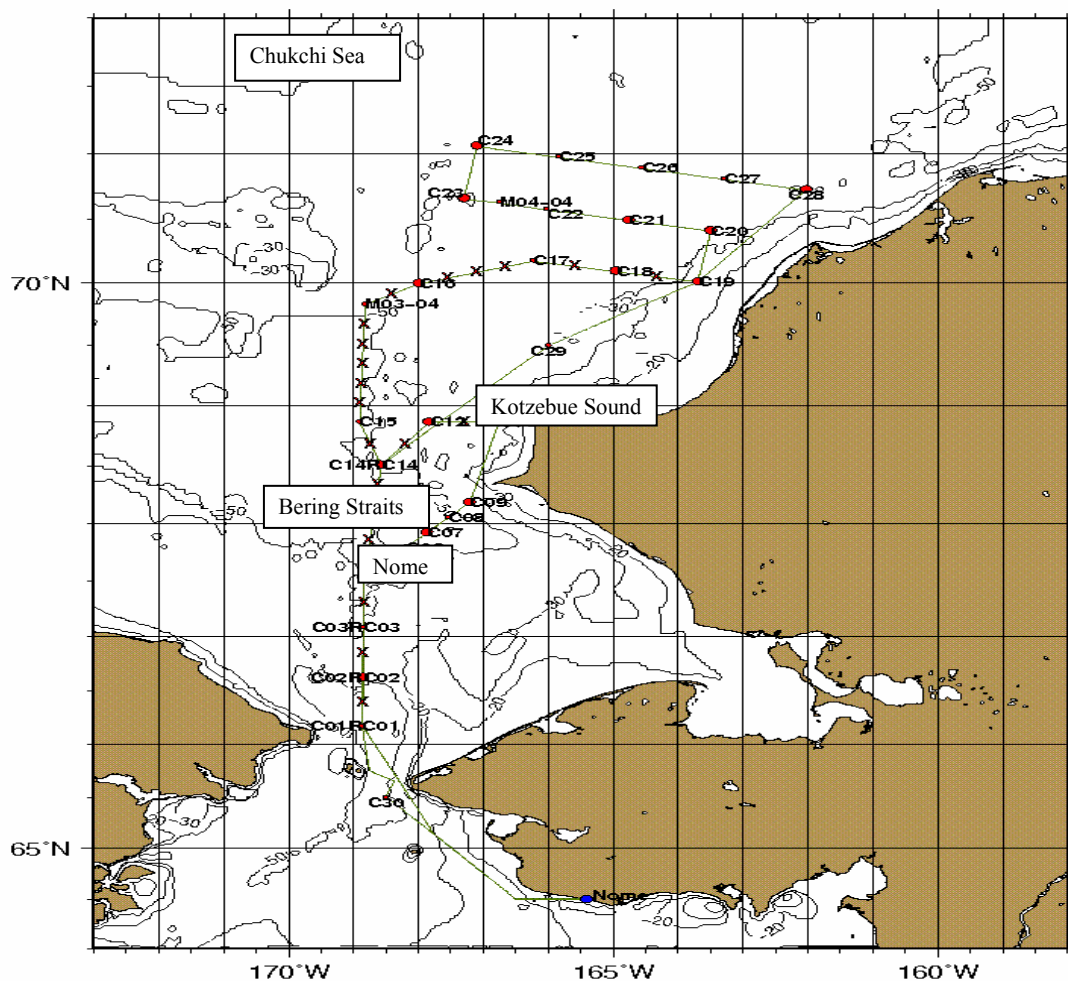


Figure 7. Stations sampled during Leg 3 of the T/S *Oshoro maru* IPY survey (indicated by red dots), August 5, 2007 (Nome, Alaska) to August 12, 2007 (Nome, Alaska).

The number of operations by each sampling gear during Legs 2 and 3 of the survey were as follows:

CTD/water sampling: 35 (Leg 2) and 32 (Leg 3) casts
 XCTD: 15 (Leg 2) and 22 (Leg 3) casts (XCTD=expendable CTD)
 Primary production: 9 (Leg 2) and 8 (Leg 3)
 Plankton net: Twin NORPAC net 35 (Leg 2) and 32 (Leg 3) casts, Closing NORPAC net 13 (Leg 2) and 6 (Leg 3) casts
 Bongo net: 19 (Leg 2) and 13 (Leg 3) casts
 Beam Trawl: 16 (Leg 3 only) casts
 Remote Operated Vehicle (ROV) operations: 6 (Leg 2) and 7 (Leg 3) casts
 Frame trawling: 20 (Leg 2 only) casts
 Bottom trawling: 7 (Leg 2) and 9 (Leg 3) casts
 Longline: 4 (Leg 2) and 3 (Leg 3) casts
 Angling operations: 35 (Leg 2) and 8 (Leg 3)

NOAA Ship Oscar Dysan

During the 1-mo survey (9/1-9/30) of the *Oscar Dysan*, 50 surface (Fig.3) and 31 mid-water stations were sampled in the southeastern Bering Sea (161°W to 173°W). During the 2nd cruise leg, only 7 immature Chinook salmon were caught and sampled. One additional sample was obtained from an immature Chinook salmon caught during the 9/5-9/15/2009 cruise leg of the Alaska Fisheries Science Center-chartered F/V *Epic Explorer* in the northeastern Bering Sea.

Fish Processing Plant Sampling

A total of 125 Chinook salmon were sampled at Dutch Harbor seafood processing plants from the bycatch of the commercial pollock fishery during winter (A season, n=94 fish) and summer (B season, n=31 fish) 2009 with permission from NOAA's Groundfish Observer Program.

Results Objective 1: Develop a Comprehensive High Seas Chinook Salmon Database

Historical High Seas Research Database

We assembled a comprehensive database of historical high seas research data (1954-2009) The contents of the high seas research database are shown in Table 1-1. The high seas research database includes five broad categories of data: (1) catch, fishing effort, and associated environmental data, (2) specimen data, (3) tag data, (4) food habits data, and (5) scale measurement data. The database and associated metadata were provided on Universal Serial Bus (USB) flash drive to AYK SSI as a final product.

Summary of Local Traditional Knowledge (LTK) Interview Database

The LTK data consist of a series of digitally recorded interviews conducted in the participating communities (Brevig Mission, Golovin and Unalakleet). These interviews were stored on archival quality CDs in the Eskimo Heritage Program archives housed at the offices of Kawerak, Inc. in Nome, Alaska. The archives are accessible to the public and researchers for educational purposes. Copies of interviews can be obtained by contacting the Eskimo Heritage Program at: Colleen Reynolds, Program Director, Eskimo Heritage Program, Kawerak, Inc., PO Box 948, Nome, AK 99762, Phone: (907) 443-4386, Fax: (907) 443-4458, Email: creynolds@kawerak.org. Results of the LTK interviews are summarized below.

LTK: Chinook salmon

The majority of the information on Chinook salmon comes from Unalakleet. The Unalakleet River has experienced the greatest declines in Chinook returns, and of the three communities involved in this study Unalakleet has utilized Chinook at a much higher level, followed by Golovin and then Brevig Mission (Ahmasuk et al. 2008). Local residents primarily use the term “kings” to refer to Chinook salmon, and the two terms are used interchangeably below.

Health of Chinook salmon: “...but the king salmon – there’s lotta jack kings mostly, I think. Compared to the big ones we used to get. But we smoke them anyway.” -Unalakleet fisherwoman

Residents of *Unalakleet* noted that Chinook salmon they are catching today are much smaller than in previous decades (1960s to early 1990s). Formerly there was variation in the size of Chinook salmon that would be seen and harvested, but the kings now seem to be almost uniformly small. Individuals noted that they catch and see many more “jack kings” than previously. Jack kings are smaller, sexually mature male Chinook. Residents estimate that the average size of Chinook caught in recent years has been 15-40 pounds, whereas previously people regularly caught kings as large as 60-80 pounds. Also related to overall size of the fish, one Unalakleet resident noted that the Chinook, “used to be real thick, like footballs, just massive.” This resident, and others, noted that the Chinook appear to be a lot skinnier than they previously were.

Table 1- 1. Contents of historical (1955-2009) high seas Chinook salmon research database for AYK SSI and AKSSF.

Data category	Filename	No. of records	Contents
Catch Data	Canada_DFO_SalmonRVCatch1956-1995	1,879	Canadian research vessel salmon catch data collected from 1956-1995 by scientists of Fisheries and Ocean Canada, Pacific Biological Station, Nanaimo, BC, Canada (Fisheries Research Board of Canada and Department of Fisheries and Oceans (DFO) for International North Pacific Fisheries Commission and North Pacific Anadromous Fish Commission research in the Gulf of Alaska.
Catch Data	Japan_FAJ_SalmonRVCatch1972-2008	160,817	Japanese research vessel salmon catch data collected from 1971-2008 by scientists of the Fisheries Agency of Japan for International North Pacific Fisheries Commission and North Pacific Anadromous Fish Commission research in the North Pacific Ocean and Bering Sea.
Catch Data	Japan_FAJ_SquidRVCatchEffort1984_1989	6,415	Fish catch data (including Chinook salmon) and associated oceanographic data from 22 Japanese flying squid research cruises in the North Pacific for 6 years: 1984-1989.
Catch Data	Japan_FAJ_LandbasedFisherySalmonCatch1962-86	1,434	Japanese Landbased commercial high seas salmon driftnet fishery catch data during two periods: 1962-1967 and 1972-1986.
Catch Data	Japan_FAJ_MothershipFisherySalmonCatch1952-1984	3,472	Japanese Mothership commercial high seas salmon driftnet fishery catch data for 1952-1977.

Table 1-1 (continued)

Data category		Filename	No. of records	Contents
Catch Data		Russia_BASIS_SalmonRVCatch2002-2006	7,191	Catch and fishing effort data for all species of fish and invertebrates caught during Russian Bering-Aleutian Salmon International Survey (BASIS) research by TINRO-centre, Vladivostok, Russia in 2002-2006.
Catch Data		USA_BCF_SalmonRVCatch1955-1972	3,450	Salmon, steelhead, and non-salmonid fish catch data collected by the US Bureau of Commercial Fisheries (BCF), Seattle, Washington, in 1955-1972 for International North Pacific Fisheries Commission (INPFC) related research (see INPFC Annual Report series, Bulletin Series, and Document series).
Catch Data		USA_BCF_DeepGillnetSalmonRVCatch1965-1969	655	US Bureau of Commercial Fisheries salmon gillnet experimental data to evaluate inter- and intra-specific and seasonal variation in vertical distribution of salmon (e.g., see French et al. 1971, INPFC Annual Report 1969:99-100).
Catch Data		USA_FRI_SalmonRVCatch_1956-1991	4,765	Salmon catch data collected during high seas salmon tagging research by the Fisheries Research Institute (FRI), University of Washington, Seattle in 1956-1978, 1980, and 1982 and during cooperative US-USSR (TINRO-centre, Vladivostok) salmon tagging research in 1983-1991.

Table 1-1 (continued)

Data category	Filename	No. of records	Contents
Specimen Data	Japan_FAJ_SalmonRVChinookSpecimen1972-2008	101,380	Japanese salmon research vessel and commercial mothership salmon driftnet fishery Chinook salmon biological specimen data collected from 1972-2008 by scientists of the Fisheries Agency of Japan for International North Pacific Fisheries Commission and North Pacific Anadromous Fish Commission research in the North Pacific Ocean and Bering Sea.
Specimen Data	Japan_MothershipFisheryChinookSpecimen1975-1981	21,936	Chinook salmon biological data from the Japanese mothership commercial salmon driftnet fishery in the Bering Sea and North Pacific Ocean in 1975-1981. Please note that this file contains some records not included in the file of Japanese salmon research vessel biological data 1971-2008.
Specimen Data	Russia_BASISChinookSpecimen2002-2006	1,882	Specimen data for Chinook salmon caught during Russian Bering-Aleutian Salmon International Survey (BASIS) research by TINRO-centre, Vladivostok, Russia in 2002-2006.
Specimen Data	USA_BASIS_Chinook_Specimen2001-2008	2,491	Chinook salmon biological data collected in the eastern Bering Sea in late summer-fall by the US NMFS, Auke Bay Laboratories (ABL), Juneau, Alaska in 2001-2008 for North Pacific Anadromous Fish Commission (NPAFC) related research as the USA contribution to Bering Aleutian Salmon International Survey (BASIS).

Table 1-1 (continued)

Data category	Filename	No. of records	Contents
Specimen Data	USA_BCF_ChinookSpecimen1955-1972	684	Chinook salmon biological data collected by the US Bureau of Commercial Fisheries (BCF) in 1955-1972 for International North Pacific Fisheries Commission (INPFC) related research (see INPFC Annual Reports, Documents, and Bulletins).
Specimen Data	USA_FRI_ChinookSpecimen1956-1991	986	Biological data on Chinook salmon specimens collected during high seas salmon tagging research by the Fisheries Research Institute (FRI), University of Washington, Seattle in 1956-1978, 1980, and 1982 and during cooperative US-USSR (TINRO-centre, Vladivostok) salmon tagging research in 1983-1991.
Specimen Data	USA_NMFS_DomesticTrawlFisheryChinookSpecimen1997-1999	5,386	Chinook salmon scale specimen data for fish collected by US National Marine Fisheries Service observers on USA (domestic) commercial groundfish trawl fishery vessels in the Bering Sea/Aleutian Islands regions of the US EEZ in 1997-1999.
Specimen Data	USA_NMFS_ForeignTrawlFisheryChinookSpecimen1977-1982	9,381	Chinook salmon scale specimen data and catch location data collected by US National Marine Fisheries Service observers on foreign and joint venture trawl vessels in the Bering Sea/Aleutian Islands, Gulf of Alaska, and US West Coast regions of the US EEZ in 1977-1982

Table 1-1 (continued)

Data category	Filename	No. of records	Contents
Tag Data	USA_FRI_HighSeaChinookTagRelease1956-1991	2,246	Data on Chinook salmon tagged and released during high seas salmon tagging operations by the Fisheries Research Institute (FRI), University of Washington, Seattle in 1956-1978, 1980, and 1982 and during cooperative US-USSR (TINRO-centre, Vladivostok) salmon tagging research in 1983-1991.
Tag Data	USA_NMFS_YukonChinookCWTRecoveries1992-2009	24	Release and recovery data for coded-wire tagged Yukon River (Whitehorse Hatchery, Yukon Territory) Chinook salmon recovered by US observers aboard commercial groundfish trawlers in the eastern Bering Sea and Aleutian Islands and by NMFS scientists during US Bering-Aleutian Salmon International Survey (BASIS) research, 1999-2009.
Tag Data	HighSeasTagRecsAYK_Chinook1956-2009	15	Release and recovery data for Chinook salmon tagged with external tags on the high seas and recovered in the Arctic-Yukon-Kuskokwim (AYK) region of Alaska.
Tag Data	Tag601TempDepthWAlaskaChinook_2008-2009	45,056	Time, temperature, and depth data recorded by an archival tag placed on a Chinook salmon in June 2008 and recovered along the Alaska Peninsula in July 2009.

Table 1-1 (continued)

Data category	Filename	No. of records	Contents
Tag Data	Tag1401TempDepthYukonChinook_2002-2004	16,249	Time, temperature, and depth data recorded by an archival tag placed on a Chinook salmon in July 2002 and recovered in the Yukon River in June 2004.
Tag Data	Tag1899TempDepthSalinityYukonChinook_2006	4,012	Time, temperature, depth, and salinity data recorded by an archival tag placed on a Chinook salmon in the Bering Sea in June 2006 and recovered in the Yukon River in June 2006.
Food Habits Data	Japan_USA_WakatakeChinookFoodHabits1991-2009	1,108	Chinook salmon food habits analysis of fish caught during the research cruises of the <i>Wakatake maru</i> in 1991-2009, by the Fisheries Agency of Japan (FAJ), and Japan Fisheries Research Agency (FRA).
Food Habits Data	USA_ObserverSpecProjChinookFoodhabits2007-2008	670	Food habits data for Chinook salmon caught as bycatch during the walleye pollock (<i>Theragra chalcogramma</i>) fishery by the U.S catcher-processor fleet in the eastern Bering Sea in 2007 and 2008.
Food Habits Data	USA_BeringSeaChinookDietEnergeticsIsotopeBIA2009	133	Chinook salmon diet and associated energetics, isotope, and bioelectrical impedance analysis (BIA) data from salmon bycatch during the Bering Sea pollock fishery in winter and summer 2009 and during NOAA's BASIS research Oscar Dyson RV and FV Epic Explorer surveys in summer 2009.

Table 1-1 (continued)

Data category		Filename	No. of records	Contents
Scale Measurement Data		Japan_WakatakeChinookScaleData1991-2007	573	Scale measurement and biological data from age 1.2 (4-year-old) Chinook salmon caught in the Bering Sea by the research vessel Wakatake maru from 1991 to 2007.
Scale Measurement Data		Russia_BASISChinookScaleData2002-2005	1,650	Scale measurement data and biological data from immature Chinook salmon caught during Russian Bering-Aleutian Salmon International Survey (BASIS) research in the western Bering Sea (Russian Exclusive Economic Zone) in 2002 to 2005.
Scale Measurement Data		USA_BASISJuvenileChinookScale2002-2007	152	NPAFC (North Pacific Anadromous Fish Commission) preferred-body-area scale measurement and biological data from 152 age 1.0 juvenile Chinook salmon caught in the Bering Sea by the US National Marine Fisheries Service (NMFS) Bering-Aleutian Salmon International Survey (BASIS), 2002-2007.
Scale Measurement Data		USA_DomesticTrawlFisheryChinookScale1997-2008	1,833	Chinook salmon age information and seasonal scale growth measurements of Chinook salmon caught as bycatch onboard various pollock fishing vessels in the Bering Sea, 1997-2008.
Scale Measurement Data		YukonChinookFemaleScaleData2005-2009	267	Preferred body area scale measurement and biological data from 267 ages 1.3 and 1.4 adult female Chinook salmon caught in Alaska Department of Fish and Game gillnet test fisheries in the lower Yukon River in 2005-2009.

In addition to the size of Chinook declining, their overall health appears to have deteriorated as well. Some Unalakleet residents regularly check the contents of the stomachs of fish that they harvest –out of curiosity and a general concern over the health of the fish they are harvesting for consumption. One fisher noted that when she has checked the stomachs of king salmon over the past few years that, “their stomachs are just empty, nothing in them. Just kind of a yellowish liquid.” [Authors note: bile is a yellowish liquid, and when observed in salmon stomachs is an indicator of starvation.] In previous years, this same woman had often caught kings with shrimp in their digestive systems, sometimes even hanging out of the mouth of the fish. Other Unalakleet residents have seen other changes in Chinook health, such as changes in the meat itself. Fishers have noticed “funny” looking meat that is either very pale or very dark in color, in multiple salmon species, sometimes accompanied by a foul smell. Some residents have noted an increase in parasites like tapeworms in the Chinook, but other residents are of the opinion that such worms have not increased in number. This may be because some people are not bothered by worms, and therefore notice them less or find them less comment-worthy. Additionally, some residents believe that they have seen an increase in abnormalities such as cysts, sores and scabs on the skin of all salmon, including Chinook. These changes seem to have all occurred over the past 10 years.

Declines in Chinook Salmon: “I want to see numbers like I saw when I was growing up, on the kings. It was amazing. I think back on those times and I think, man, it’s unbelievable, because those times are gone. It’s like, was it real? But I seen it with my own eyes. Massive, massive amounts of king salmon. Big ones. B-i-i-i-g, bright, beautiful kings.” -Unalakleet fisherman

One of the reasons this research project was undertaken is because of the variation in Chinook population numbers, sometimes drastic in particular fishing districts. Unalakleet residents interviewed for this project unanimously agree that Chinook populations have significantly declined in their lifetimes. One resident summarized it thusly, “The kings, they’re the biggest concern of ours – I think the whole town, the whole region, Norton Sound, that the kings are just not coming back like they should be.” This has also been acknowledged by the Alaska Department of Fish and Game (ADFG), which has put strict limitations on Chinook fishing in place in several districts across the Bering Strait region. The information presented here can be supplemented by examination of both subsistence and commercial harvest records for the region documented in ADFG harvest reports (which can be found at http://www.adfg.state.ak.us/pubs/dept_publications.php) as well as in Ahmasuk et al. 2008 and other similar reports.

The seriousness of the decline in Chinook salmon has been observed by Unalakleet residents as occurring over the past 3-25 years, since the late 1980s and early 1990s, with the more drastic declines becoming noticeable in the 1990s. This period was followed by a closure of commercial fishing for Chinook in 2001, with commercial fishing only occurring once (2005) since, with additional subsistence restrictions also being put in place during this same period. The former commercial king salmon fishermen interviewed do not believe that there will ever be a commercial king harvest again. One Unalakleet resident noted that when he was younger (1950s - 1960s) his family used to catch as many kings as they wanted. While he does not remember the exact number, it was not more than a few hundred. Another fisher noted that his family would put away several hundred kings each year, during the same period. Unalakleet fishers interviewed for this project said that they typically harvest less than 50 Chinook each season in recent years, and that this is a drastic decrease from their former harvests. Fishers also often have difficulty obtaining even that small harvest of Chinook. Some Unalakleet area fishers have changed their fishing locations in order either to attempt to obtain more fish, or to get them in a shorter amount of time. One woman noted that the summer of 2008 was the first time that her family had ever subsistence fished for Chinook in the ocean, as opposed to in the Unalakleet River; “...we had to go out into the ocean to get fish we couldn’t get in the river.” Despite this change in harvest strategy, her family was still only able to get 20-25 Chinook, and her husband believes that many other families have made the same change to ocean fishing. The primary reason for the change is that subsistence fishing for Chinook in ocean waters is typically not subject to the same timing and duration closures imposed by the Alaska Department of Fish and Game on the Unalakleet River. Traditionally most people have

subsistence fished in the river, because they prefer the characteristics of river kings as opposed to ocean kings. However, there are currently fewer restrictions on ocean fishing, which increases the chances of obtaining more fish. The family described above, as well as others, noted that it also sometimes takes longer to obtain the same amount fish than it did in the past. For example, one woman noted that in the late 1970s her family would only have to set their net maybe three times to get all the king salmon they needed, but more recently they have only been able to catch three or four king salmon a day, which is a big change for them. Similarly, another Unalakleet fisherman noted that he used to be able to get thirty kings in three hours, but now it could take him ten days to get twenty eight. Yet another said that subsistence fishers used to be able to set a 20-foot net in the river overnight and get about 90 kings, but that now it can take several days to get just ten kings.

Due to concerns over the decline of Chinook salmon returns, some Unalakleet residents have made conscious decision not to target them at all, or only to harvest a very small number. One individual noted that he just wants a few kings each season, and only fishes for kings until he has obtained that small number, just so his family can have the fish to “taste” and to share. He has changed his family’s harvest strategy for kings over concern for the health and sustainability of the population. The community of Unalakleet, on several occasions and with high compliance, has asked all their residents to voluntarily not fish for Chinook because of the same concerns. No specific numbers are available as to how many Unalakleet residents have voluntarily stopped or curtailed their fishing for Chinook in recent years, but it is generally acknowledged that many people have.

One final note on Unalakleet area king salmon has to do with the timing of salmon runs. A resident fisher has been keeping track of when the first king salmon is caught by someone in Unalakleet. Her observations indicated that the first king was typically caught in the middle of May, but more recently, no kings were caught until June.

Golovin residents primarily target species of salmon other than Chinook for their subsistence harvests. Those interviewed for this project did not agree on the changes in king salmon populations over time, though they did agree that catches of Chinook were primarily incidental by Golovin fishers. Golovin residents primarily fish for salmon in front of the village (set nets) or north of Golovin at Katchavik River (seining) and kings are primarily caught in set nets in front of the village. One elder fisherman, who no longer fishes for kings, said that he believes the Golovin area king runs are healthy, though small, and did not note a decline over his lifetime. This same elder described how when he was younger (1940s–1950s) his family’s harvest of king salmon was primarily an incidental catch when targeting other species, which still seems to be the case today. One elder fisher in her 80s recalled catching her first king salmon as a young woman and not knowing what to do with it because “it was so big!” One fisherman noted the 2009 fishing season as his second best for Chinook, and said that he had harvested around 50 fish. He is the only Golovin resident interviewed who was making an effort to target kings in his fishing, and he believes that there has been an increase in Chinook in the Golovin area over the past 10 years.

Brevig Mission interviewees for this project indicated that they do not target king salmon when subsistence fishing. One resident noted that the village had not historically targeted king salmon because they are “too fatty.” This practice may be an expression of a local preference for less oily salmon that are easier to dry (a reason also expressed by some Unalakleet residents to explain their preference for river kings as opposed to ocean kings). Brevig interviewees seemed to have less information on the migration routes and habits of Chinook salmon than for other salmon species, particularly sockeye salmon, which is a highly targeted species for residents. One fisher believed that king salmon “bypass” the fishing locations that Brevig people use in front of the village on the north side of Port Clarence. Brevig Mission residents primarily fish for salmon in Port Clarence and Grantley Harbor and small creeks and rivers that feed into them, but also fish along the Kuzitrin River, Agiapuk River and in the Imaruk Basin area.

A memorable harvest of king salmon for one Brevig resident was seven or eight fish, and another Brevig fisherman noted that, “sometimes you’re lucky to get maybe at least half a dozen of those kings when they come around and they vary in sizes.” It is notable that Brevig residents were able to remember specific harvests of king salmon (“...we were only able to get three.” “Pauline and Leonard said they got

fifteen...,” and see above). As the interviewees expressed, their harvest of king salmon is far less common than the harvest of other salmon species.

LTK: General comments regarding salmon

Information in this section relates to all or multiple species of salmon. Residents from all three communities expressed concern about boat traffic disturbing the spawning grounds for salmon. People are concerned that jet boats, as well as regular outboard motors, may be disturbing the eggs and “blowing [them] out of their riverbed.” Additionally, many interviewees detailed negative changes in the health of salmon that they have observed. The majority of the comments detailed stories of people finding more worms in the meat of salmon that they harvested, more open sores and scarring on the skin, more deformities (including internal organs being “fused” together), and more discolorations of the skin and meat. Any changes specific to a particular species are noted elsewhere in the report. Elders from *Golovin* noted that silvers, humpbacks and dog salmon have all been increasing in number in Cheenik Creek, next to the village. Though some species have been increasing in this particular creek, Golovin interviewees noted a general decline in salmon numbers, particularly since the advent of commercial fishing in the area, but seem to agree that there is usually enough to meet subsistence needs.

LTK: Other salmon species

Sockeye salmon (O. nerka, red salmon)

In *Brevig Mission* two interviewees noted that they have observed a change in the migration of red salmon near his village. They believe that the fish are taking something of a “short cut” from Point Jackson, across Port Clarence, to Teller at the point where they enter Grantley Harbor – rather than going along the coastline in front of Brevig. Not all Brevig area fishers harvest salmon in Port Clarence, some traditionally harvest further inland. In terms of the size of red salmon, one of the same interviewees noted that there are still some large red salmon but that she has been catching small red salmon and that they are a “little different species that we never used to [have].” She also has observed red salmon that appear to be ready to spawn in July – earlier than previously, possibly because of warmer water. This same interviewee has also seen an increase (compared to the 1970s and 1980s) in worms and a “milky substance” in the meat of the red salmon she is processing and more abnormalities on their skin, like round purplish scars [Authors note: these are likely lamprey scars].

One *Golovin* resident said that red salmon were uncommonly caught when he was growing up (1940s -1950s) and that his family primarily targeted pink and chum salmon. Over the past two years he did report observing an increase in red salmon based on what children in the community were catching via rod and reel in Cheenik Creek. He said that kids were bringing him and others what they thought were small king salmon, but were actually red salmon. He was surprised to find that red salmon were becoming common in this creek.

Two *Unalakleet* fishers have noticed an increase in red salmon in their region, while several others said that they are still unusual to catch. One fisherman who processed the few reds he caught in 2008 found some kind of abscess in several of them and called the meat, “just a big puss-y gooey mess.”

Coho salmon (O. kisutch, silver salmon)

Unalakleet residents interviewed for this project had comments on the status of silver salmon in their region. Several residents who are, or have formerly been, involved in commercial fishing for silver salmon expressed concern over the long-term viability of local stocks and commented that they believe there are too many permit holders for the amount of fish available. One fisherman stated that silvers are now the most abundant salmon species due to the declines in others and that silver salmon runs seem to be starting earlier than in previous decades. Though declines in silvers have not been observed by interviewees, there is general concern over their status. Several interviewees also commented on the health of silver salmon and noted that they have encountered more fish with “scabs” and sores on the skin as well as silvers with deformed snouts, such as where the upper part is smaller than the bottom.

A *Golovin* resident discussed silver salmon that she and other fishers had caught in 2008 that had unusual bumps on their skin. People were not comfortable keeping them for human consumption, but the Alaska Department of Fish and Game told her that they were safe to eat. Silver salmon were noted as appearing in Cheenik Creek in the early 1990s.

Pink salmon (O. gorbuscha, humpback salmon)

One *Brevig Mission* fisher has observed that pink salmon are much smaller than they used to be, while another noted that they seem to be in more streams and creeks than formerly. Interviewees in *Unalakleet* did not agree as to the status of pink salmon in their region. Three *Golovin* interviewees commented that pink salmon numbers had increased or were stable in their region, with one also noting that the fish seemed to be smaller in size, and another noting that the runs seemed to be starting later. One fisher observed, approximately 4 years ago, many pink salmon with deformed bodies (“like cheeks puffed out”), very pale flesh, and with many worms. She noted that they never used to see such things when she was younger.

Chum Salmon (O. keta, dog salmon)

One change relating to chum salmon in the *Brevig Mission* area is that they have begun to spawn in a creek behind the village since about 2000. A *Golovin* fisherman noted that chum decreased significantly in their area during commercial fishing (through the 1970s), but that chum returns seem to be healthy right now. Another fisher, however, also noted that chum returns to the *Golovin* area had substantially decreased since commercial fishing, but that they have not recovered. One fisher has observed that the stomachs of chum she catches are usually empty. Two *Unalakleet* fishermen who formerly fished commercially for chum described them as drastically decreased since the mid 1990s. They understood these declines as being a result of the False Pass fishery (which has had a high amount of chum bycatch) in the 1980s and 1990s, how hard the chum had been fished locally during periods of commercial fishing, and that they believe trout are eating chum eggs and fry (as noted below).

LTK: Other (non-salmonid) fish and jellyfish

Trout: *“I think now the trout feed quite a bit on king salmon eggs... When I was growing up we didn’t have a problem with trout because everybody had dog teams to feed. They rely on the trout. ...[There used to be] thirty to forty dog teams in town, [but] now there is only about three or four teams in town. Because of that, the trout has really multiplied because people aren’t seining for them. ...When I was growing up people would seine maybe three thousand pounds of trout for their dog teams. ...When my wife and I go fishing we’d catch trout through the ice. We would get curious what they were eating so we would open up their stomach, you know, and we would find little fry, like salmon fries and sardines... The trouts have multiplied and every time the chums or kings spawn they would mill around and eat the eggs that are coming out of the females.” -Unalakleet fisherman*

The term “trout” was used in a general sense by interviewees and they did not differentiate between different species. The most comments received about fish other than salmon were related to trout, and were provided by interviewees from *Unalakleet*. Regarding the health of trout, one fisherwoman said she has noticed that trout livers seem to be yellowish, and are not very good to eat anymore. Overall, several *Unalakleet* interviewees expressed concern about perceived impacts of trout on Chinook salmon populations in particular, but all salmon in general.

Several *Unalakleet* and *Golovin* residents interviewed for this project have also observed what they identified as salmon eggs and fry in the stomachs of trout they had caught. While the *Unalakleet* fisherman quoted above noted an increase in trout, a *Golovin* fisher who has observed salmon eggs and fry in trout stomachs stated that she did not think trout populations were increasing in her area. She also has observed trout in Cheenik Creek, next to the village, and that more fish in general have been seen in that creek than in the past (see Other salmon species section, also). Additionally, the researcher has had

multiple informal conversations, outside the bounds of interviews for this project, where sentiments similar to those of Unalakleet fishers about the impact of trout on salmon have been expressed by residents of the region.

Tomcod (Microgadus proximus, Pacific tomcod)

One Brevig Mission fisherman said that it has been harder to catch tomcod in Grantley Harbor, perhaps because of late freeze up. Three Golovin interviewees have noticed a decrease in tomcod and another caught a tomcod with skin lesions. Similarly, in Unalakleet one fisherwoman has caught, over the past two to three years, tomcods with “big, purplish” markings on their skin.

Jellyfish: *“But the last two years we been seeing humongous, humongous jelly fish like a foot long in diameter, in some colors we never seen before. Blue, pink, orange, which we never seen before and I think that is because the water temperatures been warmer and the production is higher because the warmer weather...” -Unalakleet fisherman*

Several Unalakleet fishers noted that over the past few years there has been a dramatic increase in the number of jellyfish in area ocean waters. These jellyfish are a big nuisance to fishing as they are caught in fishnets (and beluga nets) and weigh them down, and make them visible to the species being targeted. In the summer of 2008 one interviewee had to go shake his net every fifteen minutes to keep the jellyfish off it. Another resident thought that these dense swarms of jellyfish might be keeping the salmon away, as well.

LTK: Environmental changes

This section presents information provided by interviewees on their observations regarding changes to the environment they have observed over the course of their lives. This information in this section is presented by village, rather than by change observed. This is because the three villages that contributed to this report are widely spread across the Bering Strait/Norton Sound region and observations from one community may not be applicable to the other two, or the region as a whole. Summarizing comments are provided in the conclusion of this section.

Brevig Mission: *“...we used to pick those greens. There’s no more bank where they grow, it erode where we pick berries. That whole thing was uncovered, we could see just ice underneath. ... Yeah, the bank was washed away and that’s where I used to go pick akpik [salmonberries]... That’s where the greens hardly grow anymore because it’s just all mud where they used to grow.” -Brevig Mission resident*

Melting permafrost and ice lenses, which several interviewees have seen, are posited as possible reasons for some of the erosion, as are storms and wind, and ice movement during breakup (see Changes in Weather section, below). One interviewee has noted an increase in deposition in front of one part of the village where the beach has raised in height by “a couple feet.”

Four of the five Brevig Mission residents interviewed mentioned increased erosion as a big environmental change in their lifetimes. Erosion was noted as happening along both the ocean shoreline and riverbanks. Interviewees have observed increases in the frequency of erosion events and the extent of erosion. One resident described a new “channel” that formed near spring seal hunting camps in the vicinity of Port Clarence, where there used to be only one. Erosion is impacting various area camps as well, and cabins have fallen into the water in several locations. Similarly, the locations where some Brevig residents go to pick berries and greens have also eroded away.

In addition to the loss of some berry and green picking areas, Brevig residents interviewed have also noted other changes in plant life. For example, interviewees have noticed an increase in algae and “weeds” in Grantley Harbor, Kuzitrin River, and other area waters. The local Community Development Quota organization, Norton Sound Economic Development Corporation (NSEDCC), has conducted lake fertilization activities intermittently since the early 1990s at Salmon Lake in the upper reaches of the Brevig Mission area watershed. Multiple residents (within and outside the context of interviews for this

project) identified these fertilization activities as the potential source of the increase in both algae and waterweeds.

Several residents also commented on willows, saying that they were much larger than they formerly had been in their youths, and that they were growing in areas where they had not previously. Additionally, some Brevig interviewees have also observed tundra ponds or small creeks that have dried, or have begun to dry up; “All over it’s just like the land is getting dry back there. Where there used to be lakes there’s just nothing. Just clumps of mud.” Similarly, one resident has seen sinkholes near Fish River and Agiapuk River and another has noted lower water levels in area rivers.

Golovin residents have also observed a variety of changes to their environment. Similar to the Brevig participants in this study, Golovin residents have noticed an increase in algae in rivers near their community (fertilization activities do not occur in this area). One Golovin couple noted that when seining they have encountered algae as deep as one foot at the bottom of a river, and that it is stringy and is initially green but later turns black. Another Golovin fisherman identified the algae in Golovnin Bay (as opposed to the rivers) as “red algae” and noted an increase in sea grasses. The red algae, at least, seems to appear intermittently and unpredictably.

One elder fisherwoman who has been fishing at Katchavik since she moved to Golovin in 1960 noted that there used to be “seining trails” along the banks of the river in deep areas that were created by generations of people walking with their nets while seining. She had formerly used these trails but they have mostly eroded into the rivers now.

In terms of other plant life, several Golovin residents say that willows are growing in new locations where there were formerly none, and in one case where people used to pick blueberries. Erosion has also been notable and, like near Brevig, areas where plants and berries were regularly picked have been eroded away. Possibly related, the character of Golovnin Bay has changed in several locations where shallow areas have become deep and deep areas have become shallow and in the upper reaches of the Katchavik River the water has become too shallow to travel by boat. Additionally, small lakes near Katchavik River have also dried up, and some greens that grew along their shores are gone. Some residents have also noted that spruce trees are growing closer to Golovin (other than willows, no tree species grow within several miles of the village).

One experienced seal hunter has seen fewer seals on the ice in Golovnin Bay over the past several years and less old, thick ice in the bay.

Similar to Brevig and Golovin interviewees, *Unalakleet* residents interviewed for this project have also seen multiple changes to their environment. There was no consensus, however, regarding changes to plants. Unalakleet residents reported increases and decreases, as well as no changes, in both willows and in berry bushes.

Unalakleet residents did agree that erosion is a growing problem, however. Erosion is occurring on the shores of the ocean as well as along area rivers, including the Unalakleet River, which seems to be growing wider and perhaps shallower. Much of this erosion is attributed to melting permafrost, storms and high winds with concurrent lack of shore ice to protect the beaches (see Changes in Weather section, below). One resident expressed his belief that ocean water levels have risen since the 1970s and that they are causing some of the erosion being seen.

Summary. Erosion is a growing issue in all three communities, and is affecting structures as well as plant life. Interviewees from two communities, Brevig and Golovin discussed both an increase in algae and water grasses, which are impacting fishing activities, and the drying up of water bodies around their communities.

LTK : Changes in weather: *“Now everything is so unpredictable. Weather can change in just an instant, especially when you’re way out there.” -Brevig Mission resident*

This section includes observations regarding changes in weather patterns observed over the course of resident’s lives, and are presented by village, rather than by type of change observed. This is because the three villages that contributed to this report are widely spread across the Bering Strait/Norton Sound

region and observations from one community may not be applicable to the other two, or the region as a whole.

Brevig Mission residents interviewed for this project agree that the weather in general is much less predictable than it was earlier in their lives. Weather changes are also believed to happen much more quickly and without warning. All other changes can be seen as deriving from this unpredictability.

Changes in the wind, including increase in strength, increase in duration, changes in direction and seasonality were all also commented on by *Brevig* interviewees. Wind was described as affecting the ways that ice forms in front of the village (including the timing of freeze up), whether or not it gets blown away from shore, and thus how protected the shoreline is from storms. In general, *Brevig* residents noted that they also used to experience many more calm days, which were used to pursue subsistence activities.

In general, winter freeze up is occurring later in the year than it did several decades ago, and spring break up is occurring earlier. *Brevig* interviewees varied on exactly how much of a difference there was in the timing of these events, with ranges from a few weeks to over one month. Some other changes noted by residents were generally cooler summers with more rain, and rain during the months of December and January.

Golovin residents have also experienced later freeze up (November) than what it was several decades ago (October), with *Golovin* Bay still being open water into December. Freezing and then thawing of bay ice is also more common in recent years, as is ice being blown out by the wind. Ice in the bay has also been observed to be much thinner, frequently with areas of open water. One resident noted that there is less ice to auger through now when fishing for tomcod during the winter months than was present when he was younger, and another noted that ice on the east side of the bay is not stable and frequently breaks up and moves out. One elder remembered stories from her elders about people walking from Cape Darby to Rocky Point, across the frozen bay, to have potlucks, dancing and trading during long ago winters. No one would consider walking across the bay now because of the conditions described above.

Breakup was noted as remaining fairly consistent and happening in May. Two *Golovin* residents remembered ice piling up on the beach very high during breakup, when the ice would move back and forth, which hasn't happened for about five years. Breakup was formerly a big event and people would make a fire on the beach and stand around to watch the ice go out.

Golovin interviewees have also noticed changes in the wind, including strength and duration, though one interviewee said that he has not noticed any changes. One couple has seen an increase in "whirlwinds" in the area (it is not clear if these were 'waterspouts' over open water or 'dust devils' over dry land). One elder interviewee commented on how quick the weather seems to change, as opposed to when she was younger: *"When we were growing up we would see clouds coming, say 'Well, it's going to storm.' Maybe a day or a couple of days after it would storm. But now, all of a sudden it storms. It comes so fast. We used to go across the bay to berry pick, when they didn't even have motors. They would pick all day and then come back – real calm."* A different interviewee said that he believes weather is mostly predictable, citing the frequent use of radio and television to get weather forecasts, though he noted that the weather does change quickly some days and people are caught in storms. Two residents noted that they believe the *Golovin* area is having more storms that cause flooding. Much of the village is very close to sea level and several severe floods have occurred in the last few decades.

Unalakleet residents, like those in *Golovin* and *Brevig*, have experienced changes that have led them to characterize current weather patterns as "unpredictable."

"You can't predict the weather. You don't know what's going to happen next." -*Unalakleet* resident

"It seems warmer, but there are still real cold spells each winter. It's not like it used to be – consistent. Now it seems like: warm spell, cold spell, back and forth, back and forth. A winter used to be a winter." -*Unalakleet* resident

Unalakleet has always been a windy place, but residents have noted more consistent, sustained winds over the past approximately 10 years. They have also noticed changes in the direction of wind. One resident noted that because of change in wind direction, Unalakleet area beaches are getting much less driftwood from the south. This same resident has also noticed changes in the migratory patterns of cranes, which he attributes to changes in wind direction; cranes now take a “short cut” directly over the hills behind Unalakleet, as opposed to flying along the coast on their way south in the fall. Cooler summers with more rain have been typical of recent years, and more thunder and lightning was noted by one resident. Several interviewees mentioned more severe winter storms, but less snow in general.

Unalakleet interviewees have experienced later freeze up and earlier break up, as well. Freeze up in the vicinity of the village was typically late October in the 1960s and 1970s, but more recently is happening at the end of November, or even as late as December. Several residents noted that ocean used to be frozen “as far as you can see.” Oftentimes now the ice does not extend out into the Sound very far. Residents interviewed say that this is in part due to the wind pushing thin ice out to sea and not allowing stronger, thicker ice to form. The ice that does remain is thinner and often unsafe for travel. One resident noted that he used to drive out to Besboro Island on a snow machine in the spring for bird hunting, and another remembered being able to go “straight across” Norton Sound by dog team. Both said that the ice does not get thick enough to do either activity anymore. The character of break up, in particular, was commented on by several residents who noted that it used to be as if the water was “boiling” because the break up was so violent, whereas now, “it’s just like, little at a time.”

Summary: There are quite a few commonalities in the changes to weather patterns discussed by residents of Brevig Mission, Golovin and Unalakleet. All three communities noted later freeze up than was the case several decades ago. All have noticed changes to local wind patterns. In addition, every person who made a statement about the weather in general said that weather patterns have become less predictable, with many saying that change happens very quickly.

LTK: Cultural impacts of the decline in salmon

One of the reasons that Chinook salmon were chosen as the focus of this project is because they have been identified by Alaska Native residents of Western Alaska as an important subsistence food. Chinook, and other salmon, also have importance beyond the realm of “food,” however. Some of the economic and cultural impacts of decreased salmon abundance that were discussed by interviewees for this project are presented below.

The decrease in size of salmon is important to note in terms of overall subsistence harvest. While some individuals in some communities may be catching approximately the same amount of fish as they did 10 or 20 years ago, those fish were much larger and had more meat overall (i.e. the total body weights of 20 fish today and 20 fish 30 years ago are not equal). In addition, if you are catching smaller numbers of fish, the decreased size of the salmon even further decreases the overall amount available for consumption.

The combination of decreases and resultant State of Alaska-imposed harvest regulations, have initiated changes to harvest and processing strategies. Unalakleet fishers interviewed for this project talked about changing their salmon fishing location from the Unalakleet River to the adjacent marine waters. This is primarily because marine waters are accessible for fishing for longer periods, due to regulations, and because people have had difficulty meeting their subsistence harvest needs in river waters. This is clearly not a solution for all Unalakleet area subsistence fishers, however. One reason is that many people do not have the necessary boats or other gear to fish in marine waters and such a change would also likely have impacts on the availability of salmon. In terms of processing, king salmon strips are a highly valued and sought after product of subsistence fishing. Fishers have noted that with decreases in availability of Chinook, they have begun to, or are considering, trying to make strips from silver salmon. This is an accepted substitute, but less than ideal. Other species of salmon are also being targeted more intensively to make up for the decrease of Chinook available for subsistence harvest.

Time spent fishing is also impacted by the decreases in salmon abundance. Interviewees noted that it oftentimes takes much longer than previously to obtain the same amount of salmon. Additionally, the necessity of spending more time fishing potentially requires more fuel and/or time away from any wage-based employment, all of which have financial and other repercussions for families.

Salmon is a critically important food item for many individuals and families in communities across Western Alaska. For many families, salmon harvest is necessary for their yearly economic survival. It is a nutritional input that people expect and need to have. However, even for families that are able financially to survive without a large input of subsistence-harvested salmon, it can still be stressful to have less than you were formerly able to harvest and less than you would ideally want. One wife and mother from Unalakleet stated, “It’s stressful to figure out how often you can have a taste of this, trying to make it last all winter until we can get some the next year.” Salmon is a culturally important food that people frequently talk about wanting to have a “taste” of, and that reminds them of their heritage and important cultural values.

In addition to its importance for the economic survival of individuals and families, the importance of customary barter and trade, particularly of fish, has also been documented for the Bering Strait region (Magdanz et al. 2007). One very important impact resulting from a decreased availability of salmon is that individuals have less salmon available for barter and trade and sharing. A fisherwoman from Unalakleet talked about being distressed over having to tell friends from other communities that she did not have enough dry fish (salmon) to participate in their annual exchange; she typically barter with dry salmon for sea mammal products.

A final synthesis of LTK results is presented in the results and discussion of Objective 9.

Results Objective 2: Map Ocean Distribution and Migration Routes of AYK Chinook Salmon

Horizontal Distribution From Tagging Experiments

In this section we review information on the spatial and temporal distribution of AYK Chinook salmon and other species of AYK salmon from recoveries of two different types of tags (high seas tags, coded-wire tags (CWT). The results presented herein were published in Myers et al. (2009).

Figure 2-1 shows the high seas tagging study area and distribution of releases of all species of tagged salmon by ocean region, 1954-2005. Salmon tagging effort in the Bering Sea was low compared to other regions in the North Pacific Ocean.

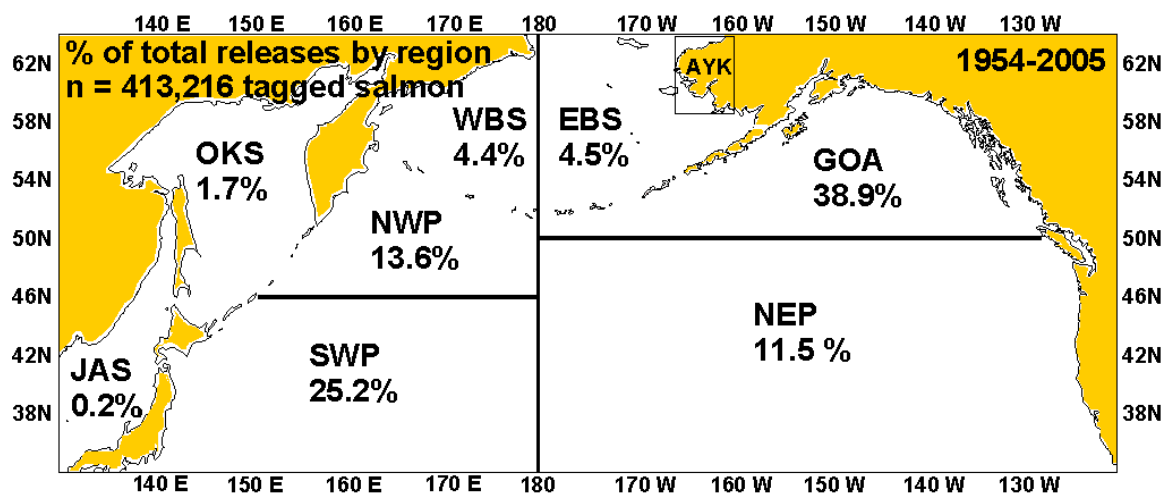


Figure 2- 1. Map of the high seas tagging study area showing, distribution of releases of all species of tagged salmon (% of total releases, n=413,216 salmon) by region, 1954-2005.

WBS = Western Bering Sea, EBS = Eastern Bering Sea, GOA=Gulf of Alaska, NEP = Northeast Pacific, NWP= Western North Pacific (north of 46°N), SWP= Western North Pacific (south of 46°N), JAS = Japan Sea, OKS = Okhotsk Sea.

AYK Chinook salmon tag recoveries

AYK Chinook salmon typically migrate to the ocean in their second year (freshwater age-1), and spend two, three, four, or five winters at sea, before returning to spawn at ages 1.2, 1.3, 1.4, or 1.5. During the 1954-2006 period, the reported recoveries of tagged AYK Chinook salmon were from high seas releases of both immature (n=13 fish) and maturing (n = 1) fish (Fig. 2-2). Recoveries were reported from the Yukon (12 fish) and Kuskokwim (2 fish) rivers. The release data for these fish showed

that immature Yukon and Kuskokwim Chinook salmon were distributed in offshore waters of the Eastern Bering Sea (EBS) and Western Bering Sea (WBS) in summer (Fig. 2-2), and that their distribution shifts to the northwest from June to July, extending well into the Russian EEZ. There have been no reported recoveries of high-seas tagged Chinook salmon in the AYK region since 2006.

During 1992-2006, 20 high-seas recoveries occurred of CWT fish released from the Whitehorse Rapids Hatchery in the upper Yukon River (Canadian Yukon Territory; Fig. 2-3). These recoveries indicated that juvenile and immature AYK Chinook salmon are distributed in the EBS in fall and winter (October-March, Fig. 2-3). Most of the CWT hatchery fish were recovered by NOAA fishery observers on US groundfish vessels operating inside of the US EEZ. Hence, recoveries distributed along the eastern Bering Sea shelf break (200-m depth contour) northwestward from Unimak Pass terminate at the international boundary (Fig. 2-3). One recovery of a CWT Chinook salmon on the eastern Bering Sea shelf in June was probably a maturing fish, which suggests that at least some maturing Yukon River fish approach the river mouth from the south (Fig. 2-3, June panel). This observation was substantiated by a more recent (2006) recovery of another maturing Yukon River fish that was tagged in June in the southern EBS (Fig. 2-2, top panel). Although freshwater ages differed between hatchery CWT fish (age-0) and wild high seas tagged fish (age-1), we assume that immature and maturing hatchery and wild Yukon River salmon have similar ocean distribution and migration patterns. During the period of this project (2007-2009), only one new recovery of a CWT Canadian Yukon hatchery Chinook salmon by NOAA fishery observers on US groundfish vessels was reported (recovered in February 2009 in the eastern Bering Sea at 168°W, 56°N; Fig. 2-4). Murphy et al. (2009) summarized the results of recoveries of CWT juvenile (age-0) Chinook salmon released by the Whitehorse Rapids Fish Hatchery and recovered during U.S. BASIS research trawl fishing operations, which included three previously unreported recoveries in September 2007 just south of the Bering Straits at 168.1°W, 65.2°N (Fig. 2-5).

No reported recoveries of AYK Chinook salmon have occurred from releases of tagged fish in the North Pacific Ocean or from recoveries of CWT fish in the North Pacific Ocean (Figs. 2-2 and 2-3). While some AYK Chinook salmon might migrate to open ocean areas south of the Aleutian Islands and perhaps to the Gulf of Alaska, the majority of AYK Chinook salmon probably remain in the Bering Sea throughout their ocean life-history phase. The overall pattern of recoveries of tagged AYK Chinook salmon suggests seasonal movements of immature fish between summer feeding grounds in the central and northwestern Bering Sea and wintering areas in the southeastern Bering Sea.

AYK chum salmon tag recoveries

AYK chum salmon migrate to the ocean in their first year, and spent two, three, four, or five winters at sea, before returning to spawn at ages 0.2, 0.3, 0.4, or 0.5. The reported recoveries of tagged AYK chum salmon were from high seas releases of both immature (n=22 fish; Fig. 2-6) and maturing (n = 256 fish; Figs. 2-7–2-9) fish. Recoveries were reported from Norton Sound (25 fish), Yukon (189 fish), and Kuskokwim (64 fish). The high seas release locations of immature AYK chum salmon indicated that they were distributed primarily in the GOA, although one older (ocean age 0.4, 622 mm FL at release) immature fish released in the EBS in July 1991 was recovered approximately one year later (June 1992) in the Kuskokwim (Fig. 2-6). From spring to summer, the distribution of immature chum salmon shifts to west or northwest, with older age groups (0.3 and 0.4) moving in advance of younger age groups (0.1 and 0.2).

Maturing AYK chum salmon were distributed in the NEP and GOA in April (Figs. 2-7–2-9). In May, their distribution shifts westward in the GOA, and by June distribution has shifted farther to the north and west, extending into the Bering Sea. In July, maturing Yukon summer chum salmon have already returned to coastal areas and spawning streams, and maturing Yukon fall chum salmon were distributed across a broad front in the western GOA, Aleutians, EBS, and WBS (Fig. 2-9).

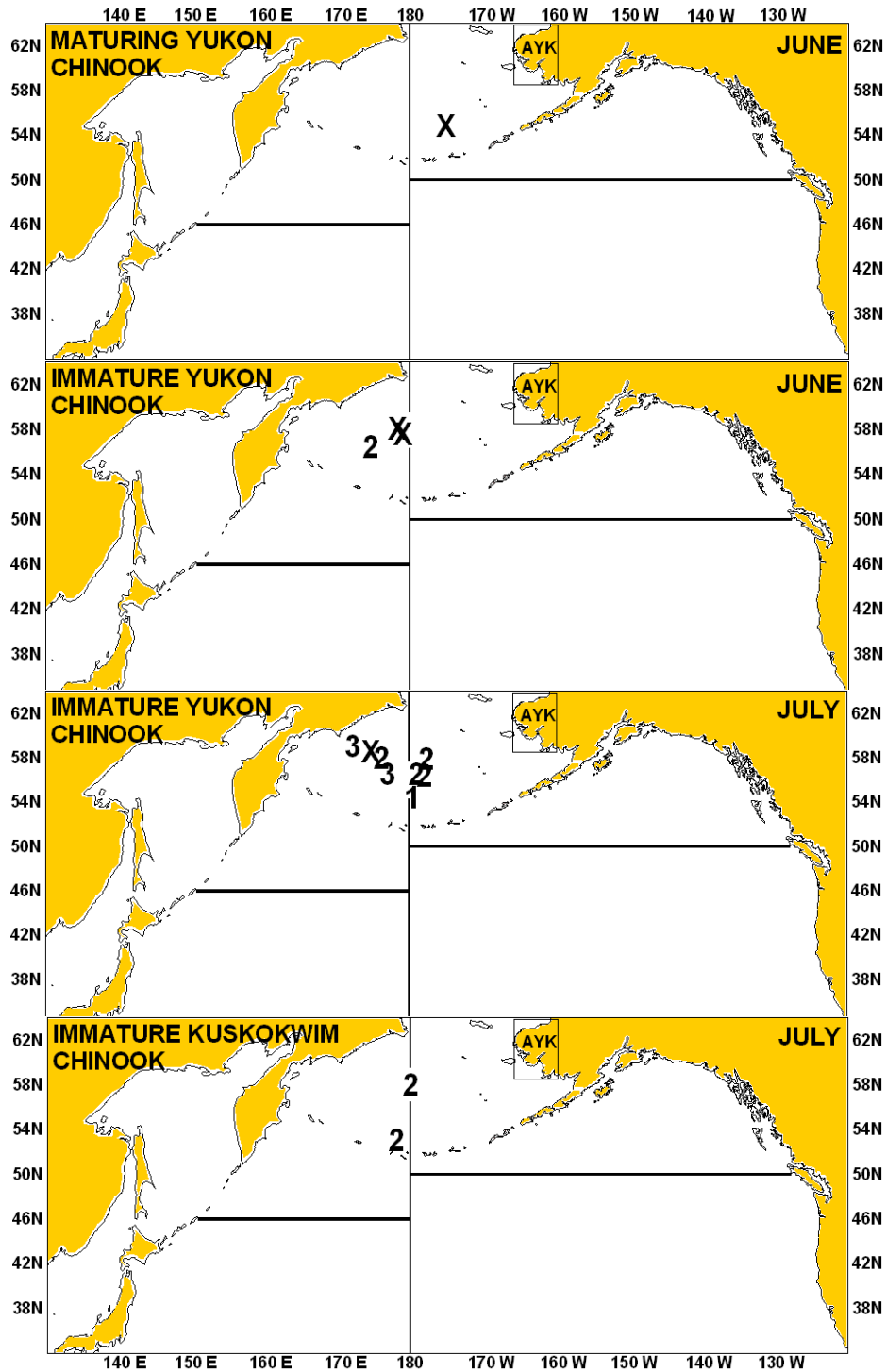


Figure 2- 2. The known ocean distribution of maturing (top panel) and immature Yukon and Kuskokwim Chinook salmon by month, as indicated by high seas tag experiments, 1954-2006.

The numbers indicate the high seas location and ocean age at release. X=ocean age unknown. Number of recoveries by month of release: June = 4 (1 maturing and 3 immature Yukon fish), July=10 immature fish

(8 Yukon, 2 Kuskokwim). Reported dates of recovery of adult fish in the AYK region ranged from June 2 to July 24. Reference lines indicate ocean regions shown in Fig. 2-1.

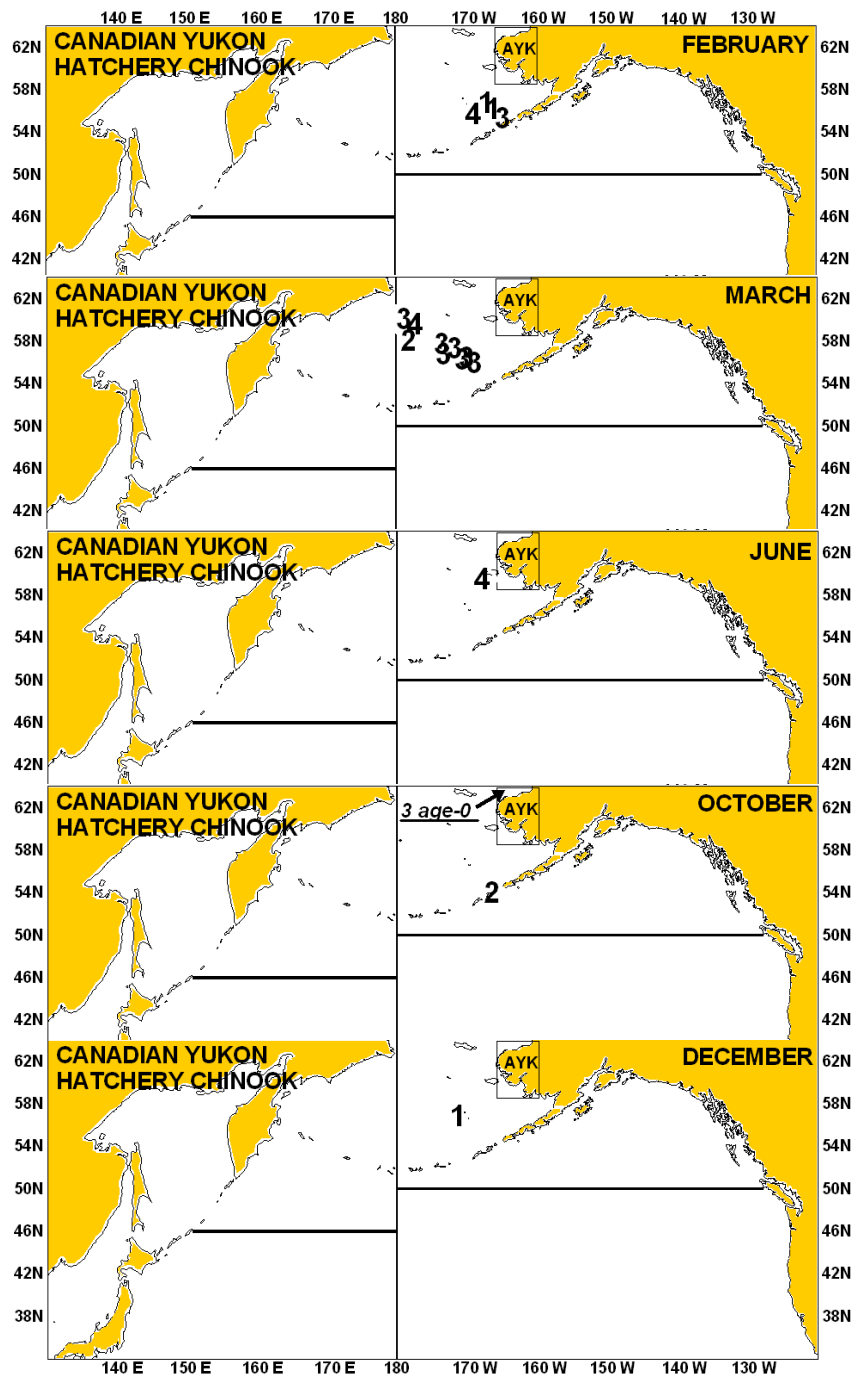


Figure 2- 3. The known ocean distribution of Canadian Yukon hatchery Chinook salmon by month, as indicated by high-seas recoveries of coded-wire tagged fish, 1992-2006.

Numbers indicate the location and ocean age at recovery. In October, labeled arrow (underline, italics) pointing at AYK region box indicates 3 juveniles (brood year 2001; age 0.0) released from Whitehorse Rapids Fish Hatchery in June 2002 and recovered in Norton Sound in October 2002. Number of ocean recoveries by month: February = 4 fish, March = 10, June = 1, October = 4, and December = 1.

Reference lines indicate ocean regions shown in Fig. 2-1. See Figure 2-5 for detailed locations of the three juvenile (age-0) fish recovered in October.



Figure 2- 4. Location of one new recovery (open diamond) of a coded-wire tagged Chinook salmon released by the Whitehorse Rapids Fish Hatchery located near Whitehorse, Yukon, in February 2009. Previous recoveries from salmon bycatch of the commercial pollock trawl fishery are indicated by closed circles (Source: Celewycz et al. 2009).

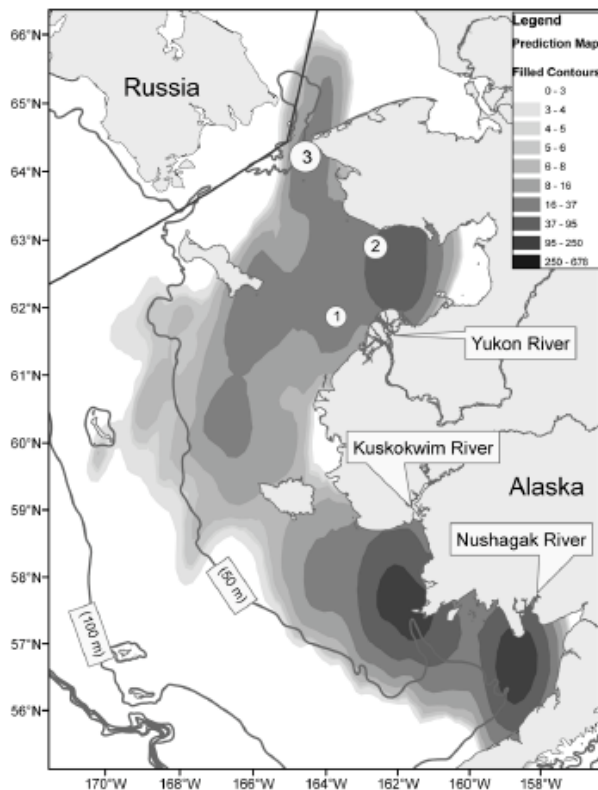


Figure 2- 5. U.S. BASIS surface trawl recovery locations (white circles with number of fish recovered at each location) of six juvenile (age 0.0) coded-wire tagged Whitehorse Rapids Fish Hatchery, Yukon, Chinook salmon from mid August to early October, 2002-2007. (Source: Murphy et al. 2009; the shading

represents estimated catch per unit effort of juvenile Chinook salmon on the eastern Bering Sea shelf during the survey period.)

AYK pink salmon tag recoveries

Data from tagging experiments provide the only stock-specific information on the high seas distribution, biology, and ecology of maturing AYK pink salmon. No stock-identification methods have been used to estimate proportions of AYK pink salmon in mixed-stock high seas catches. AYK pink salmon migrate to the ocean in their first year (freshwater age-0), and spend only one winter at sea, returning to spawn at age 0.1. The few reported recoveries of tagged AYK pink salmon were all from high seas releases of maturing fish ($n = 24$ fish; Fig. 2-10). The sexes of most tagged pink salmon recovered in the AYK region were not reported by fishermen (21 unknown, 2 males, 1 female). The AYK recoveries were dominated by fish that returned to spawn in odd-numbered years (71% of total). The high seas release location of one recovery (Yukon, male, 365 mm FL at release) indicated that by April at least some maturing (age 0.1) AYK pink salmon have migrated far to the southeast in the NEP (Fig. 2-10, top panel). No data exists on the high seas distribution of AYK pink salmon in May. We assumed that in May AYK pink salmon were distributed primarily in the NEP and GOA. Most of the reported recoveries were from fish tagged in June (Fig. 2-10, middle panel), when the distribution of maturing AYK pink salmon has shifted to the west in the NEP and to the north and west in the western GOA, central and eastern Aleutians and EBS. The June recoveries included fish from all three AYK regions (14 Norton Sound, 3 Yukon, 4 Kuskokwim; mean size at release = 450 mm FL), indicating that AYK region populations of pink salmon shared common high seas feeding grounds. One Norton Sound pink salmon tagged in the WBS in June is the westernmost release location for a pink salmon recovered in North America ($n=3,668$ total recoveries, 1956-2006). One Kuskokwim pink salmon tagged in the NEP in June was located farther to the southwest than any other tagged pink salmon recovered in North America. These two recoveries suggested that the high seas distribution of AYK pink salmon extends farther to the west in the Bering Sea and to the southwest in North Pacific Ocean than any other regional stock of North American pink salmon. By July, many maturing AYK pink salmon have returned to coastal areas and spawning streams. However, two recoveries in July indicated that the migration routes of maturing pink salmon returning to the AYK region extended across a broad front in the Bering Sea (Fig. 2-10, bottom panel). Based on these few recoveries, we speculate that future genetic stock identification studies likely will show a much broader distribution of maturing AYK pink salmon, particularly to the west and northwest in the WBS, than indicated by the results of high seas tagging experiments.

AYK coho salmon

AYK coho salmon (*O. kisutch*) migrate to the ocean after one, two, or three winters in freshwater, and spend only one winter at sea, returning to spawn at ocean age-1. The few reported recoveries of tagged AYK coho salmon were all from high seas releases of maturing fish ($n = 18$ fish; Fig. 2-11). Recoveries were made in Norton Sound (2 fish), Yukon (4 fish), Kuskokwim (12 fish). Release locations of tagged fish indicated that in May and June AYK coho salmon (mean size: 481 mm FL, $n = 5$) were distributed in the NEP (Fig. 2-11, top and middle panels). In July, the distribution of maturing AYK coho salmon (mean size: 561 mm FL, $n = 13$) shifted to the west in the NEP and to the north and west in the GOA (Fig. 2-11, bottom panel). By August, maturing AYK coho salmon returned to coastal areas or spawning streams. In general, tag recovery data indicated that the high seas distribution and migration patterns of AYK coho salmon were similar to those of AYK pink salmon, except that the timing of high seas movements and return to coastal areas of coho salmon was about one month later than pink salmon.

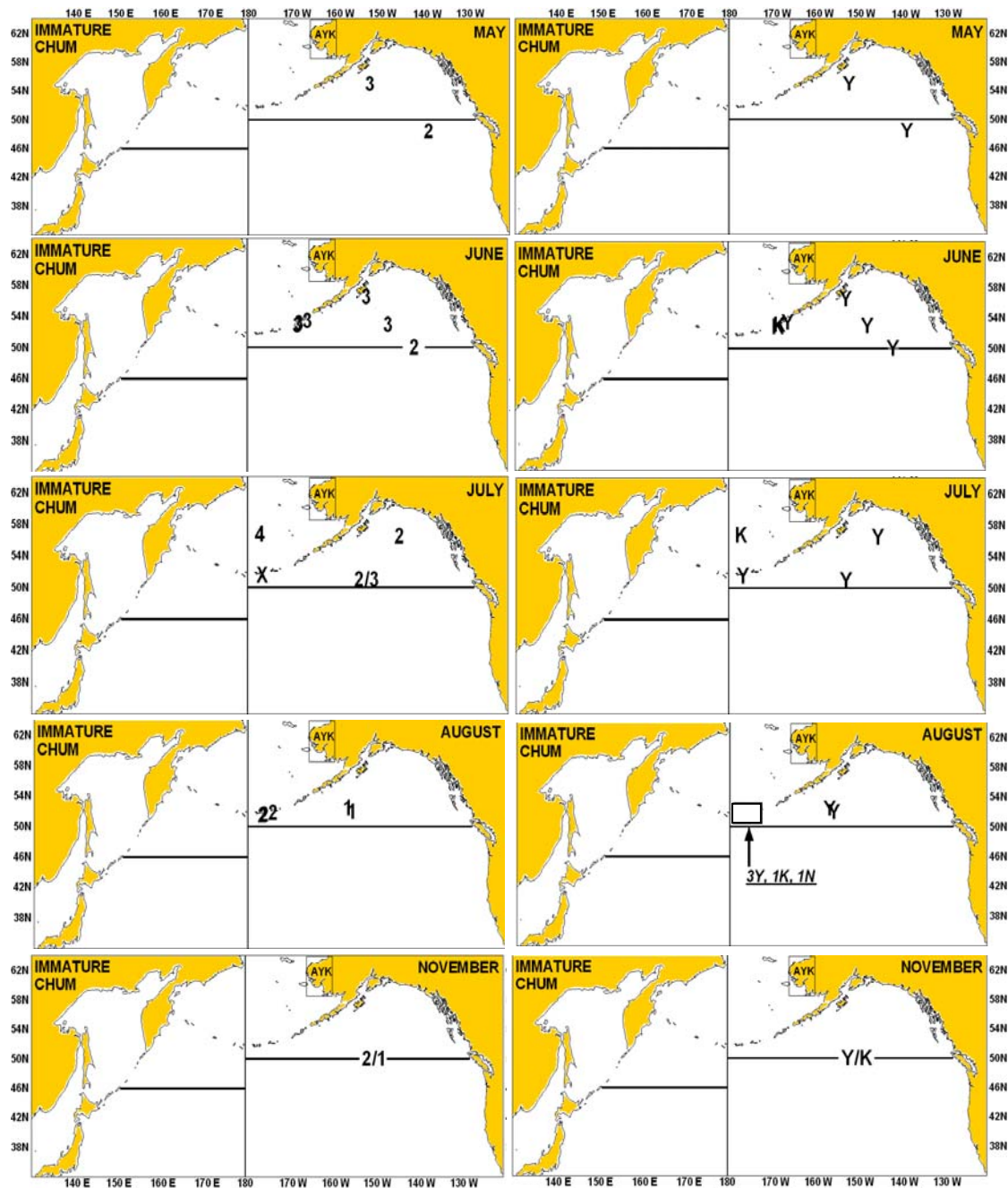


Figure 2- 6. The known ocean distribution of immature Norton Sound (N), Yukon (Y), and Kuskokwim (K) chum salmon by month, ocean age group (left panels), and stock (right panels), as indicated by high seas tag experiments 1954-2006. Numbers in left panels are ocean age at release; X = ocean age unknown; forward slash between two numbers indicates recoveries from two age groups released at or near the same ocean location. In August (right panel), labeled arrow (underline, italics) pointing at multiple recoveries (inside box) shows number of recoveries per stock. Number of recoveries by month of release: May = 2 fish, June = 6, July = 5, August = 7, November = 2. Reported dates of recovery of adult fish in the AYK region ranged from June 16 to September 24. Reference lines indicate ocean regions shown in Fig. 2-1.

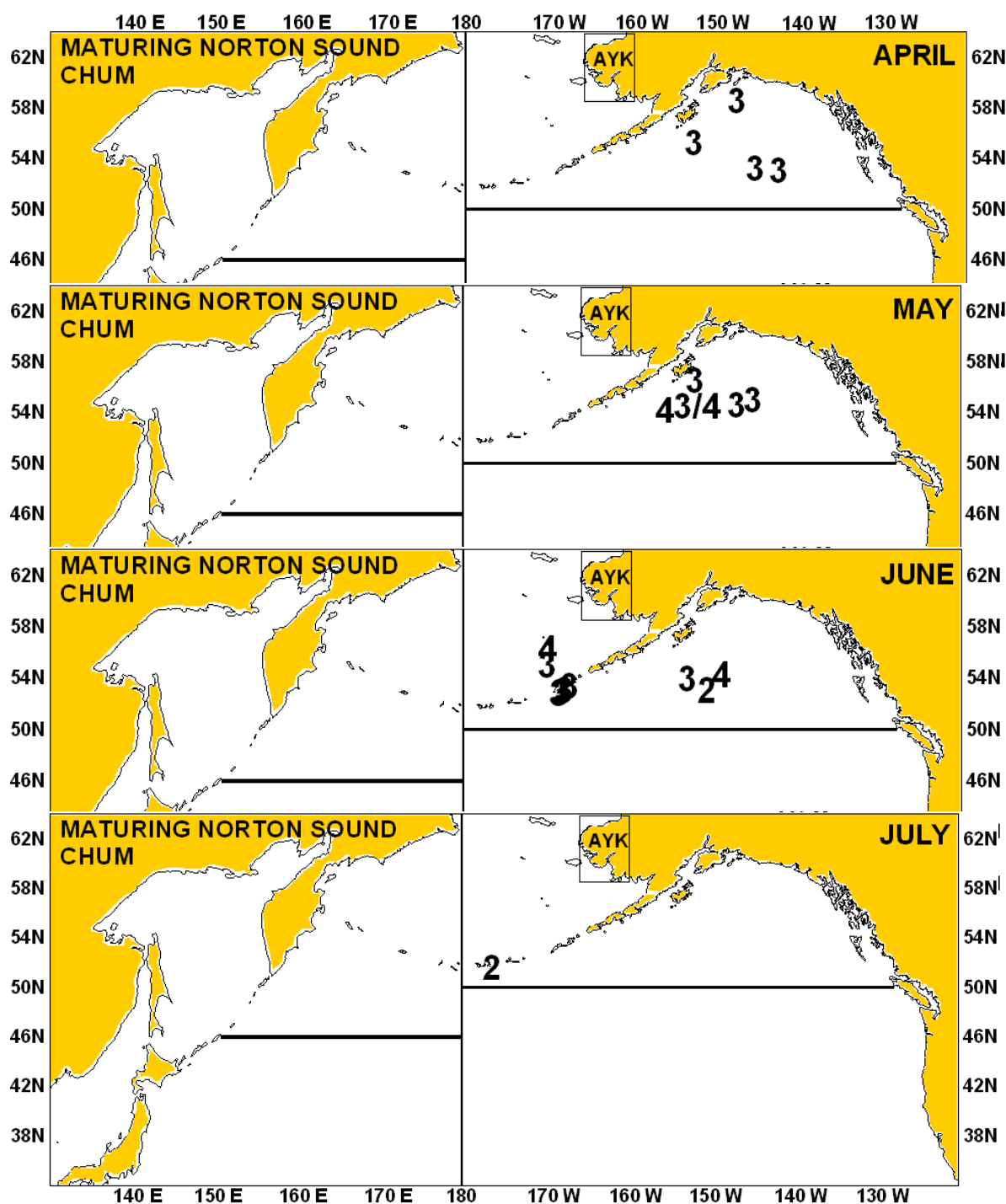


Figure 2- 7. The known ocean distribution of maturing Norton Sound chum salmon by ocean age group and month, as indicated by high seas tag experiments, 1954-2006. Numbers indicate the high seas location and ocean age at release. A forward slash between numbers indicates data for two fish released at the same ocean location. Number of recoveries by month of release: April = 4 fish, May = 6, June = 13, July = 1. Reported dates of recovery of adult fish in the AYK region ranged from June 29 to August 22. Reference lines indicate ocean regions shown in Fig. 2-1.

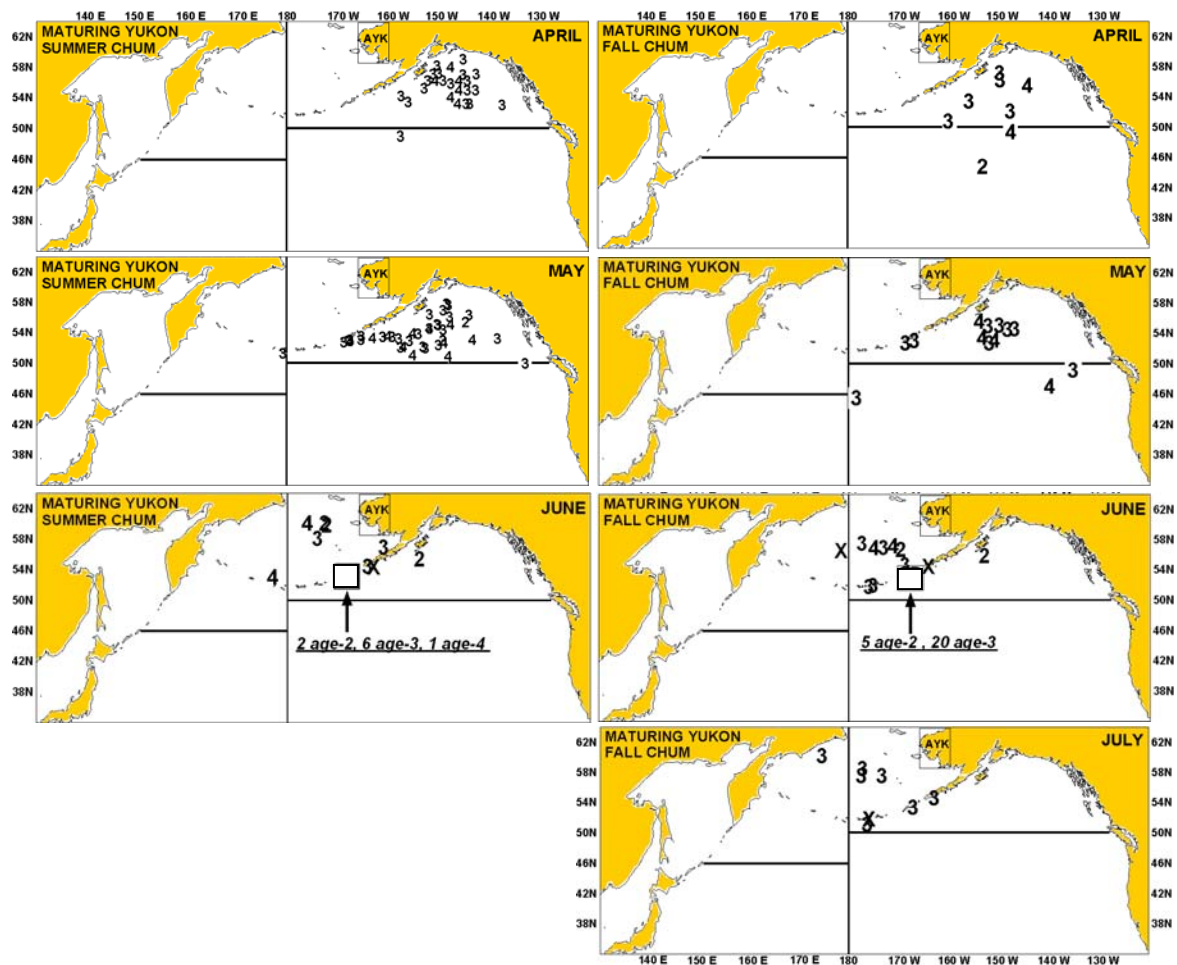


Figure 2- 8. The known ocean distribution of maturing Yukon River summer (left panels) and fall (right panels) chum salmon by ocean age group and month, as indicated by high seas tag experiments 1954-2006. Numbers indicate the high seas location and ocean age at release. X = ocean age unknown. Multiple recoveries from a single age group of fish released at the same ocean location are not indicated. In June, labeled arrows (underline, italics) pointing at multiple recoveries (inside boxes) show number of recoveries by age group. Number of recoveries by month of release for summer chum: April = 32 fish, May = 50 fish, June = 18. Number of recoveries by month of release for fall chum: April = 8 fish, May = 13, June = 36, July = 8. Seasonal race was determined by the reported date of recovery of adult fish in the AYK region; summer chum recovery dates ranged from June 5 to July 14; fall chum recovery dates ranged from July 15 to October 1. Reference lines indicate ocean regions shown in Fig. 2-1.

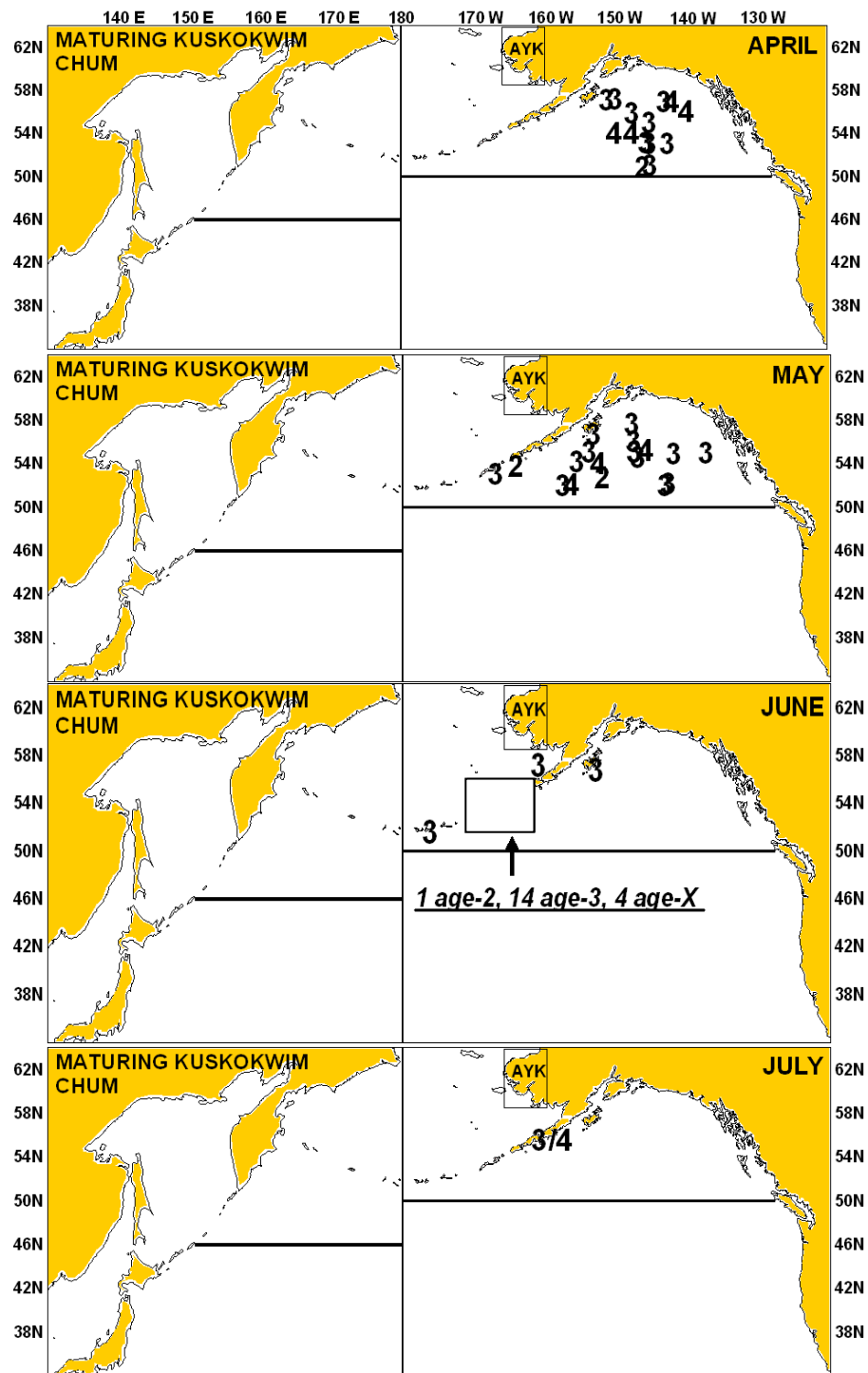


Figure 2- 9. The known ocean distribution of maturing Kuskokwim River chum salmon by ocean age group and month, as indicated by high seas tag experiments, 1954-2006. Numbers indicate the high seas location and ocean age at release. X = ocean age unknown. In June, labeled arrow (underline, italics) pointing at multiple recoveries (inside box) shows number of recoveries per age group. Forward slash between numbers indicates data for two fish released at the same ocean location. Number of recoveries by month of release: April = 14 fish, May = 19, June = 24, July = 2. Reported dates of recovery of adult

fish in the AYK region ranged from June 8 to August 12. Reference lines indicate ocean regions shown in Fig. 2-1.

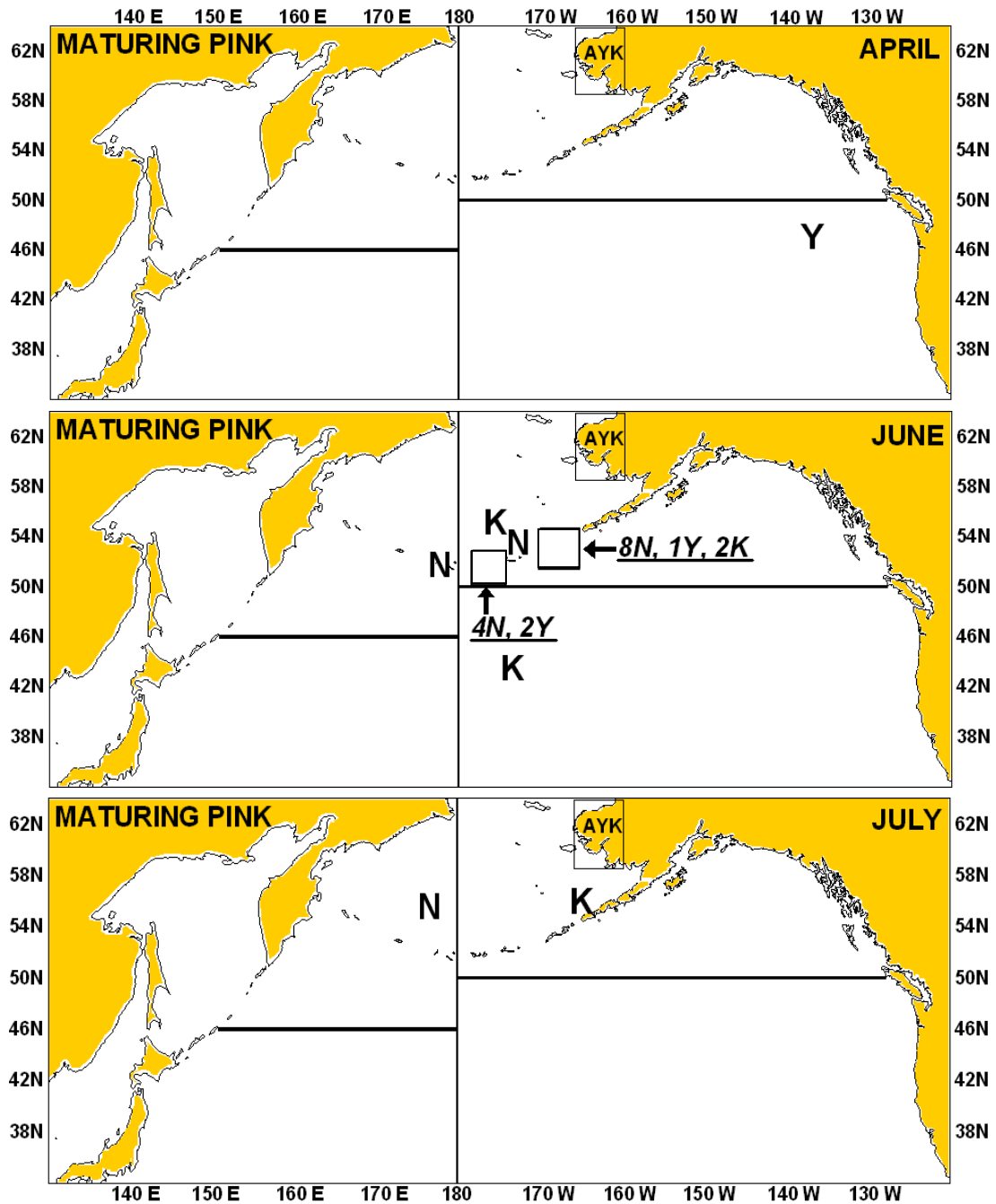


Figure 2- 10. The known ocean distribution of maturing AYK pink salmon by month, as indicated by high seas tag experiments, 1954-2006. The letters indicate high seas release location and stock of origin: N=Norton Sound, Y=Yukon, and K=Kuskokwim. All fish were age 0.1 at release. In June (center panel), labeled arrows (underline, italics) pointing at multiple recoveries (inside boxes) show number of recoveries per stock. Number of recoveries by month of release: April = 1 fish, June = 21, July = 2.

Reported dates of recovery of adult fish in the AYK region ranged from July 18 to August 6. Reference lines indicate ocean regions shown in Fig. 2-1

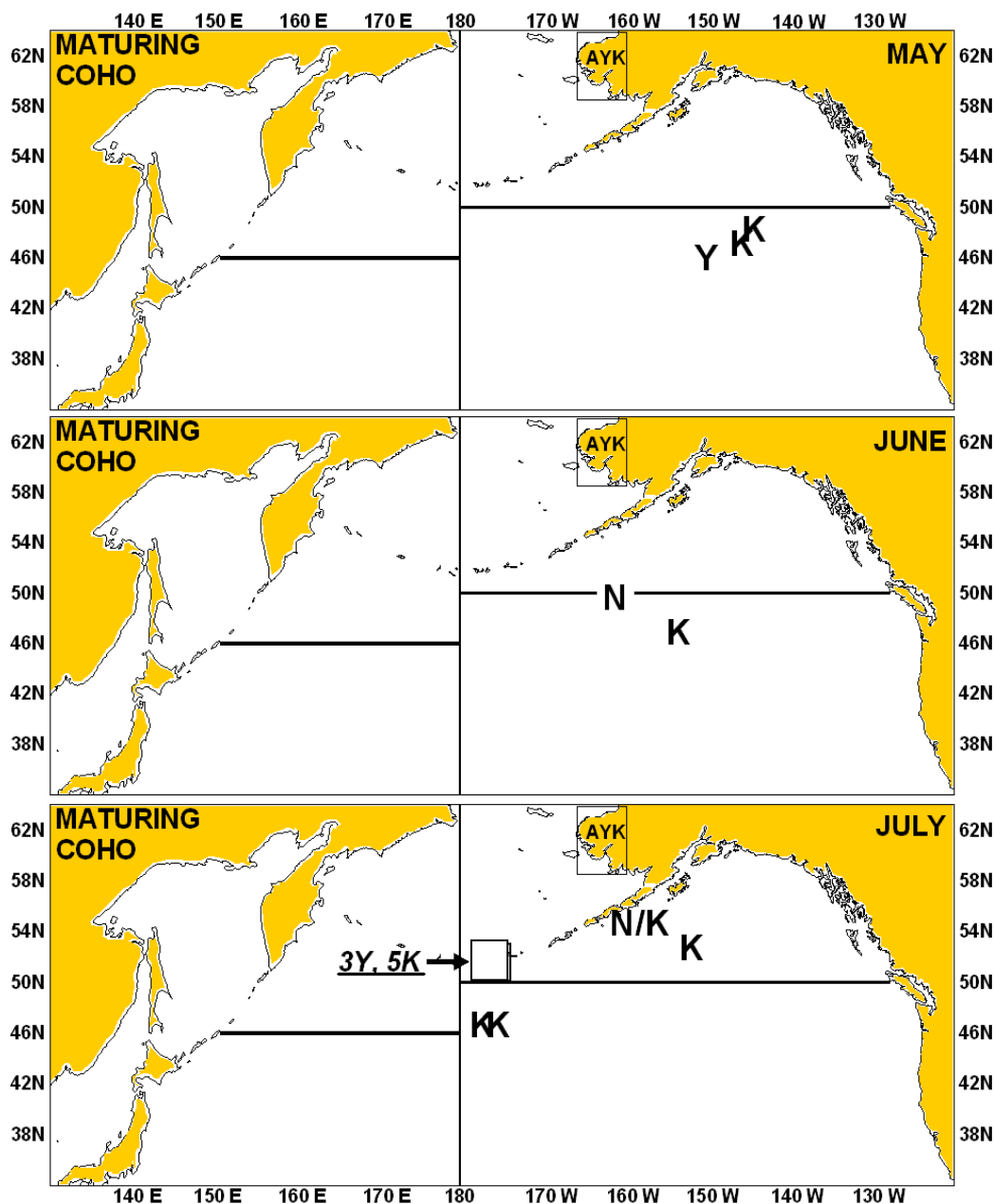


Figure 2- 11. The known ocean distribution of maturing AYK coho salmon by month, as indicated by high seas tag experiments, 1954-2006. The letters indicate high seas release location and stock of origin: N=Norton Sound, Y=Yukon, and K=Kuskokwim. All fish were ocean age-1 at release. In July (bottom panel), labeled arrow (underline, italics) pointing at multiple recoveries (inside box) shows number of recoveries per stock. Forward slash between numbers or letters indicates data for two fish released at the same location. Number of recoveries by month of release: May = 3 fish, June = 2, July = 13. Reported dates of recovery of adult fish in the AYK region ranged from August 10 to September 28. Reference lines indicate ocean regions shown in Fig. 2-1.

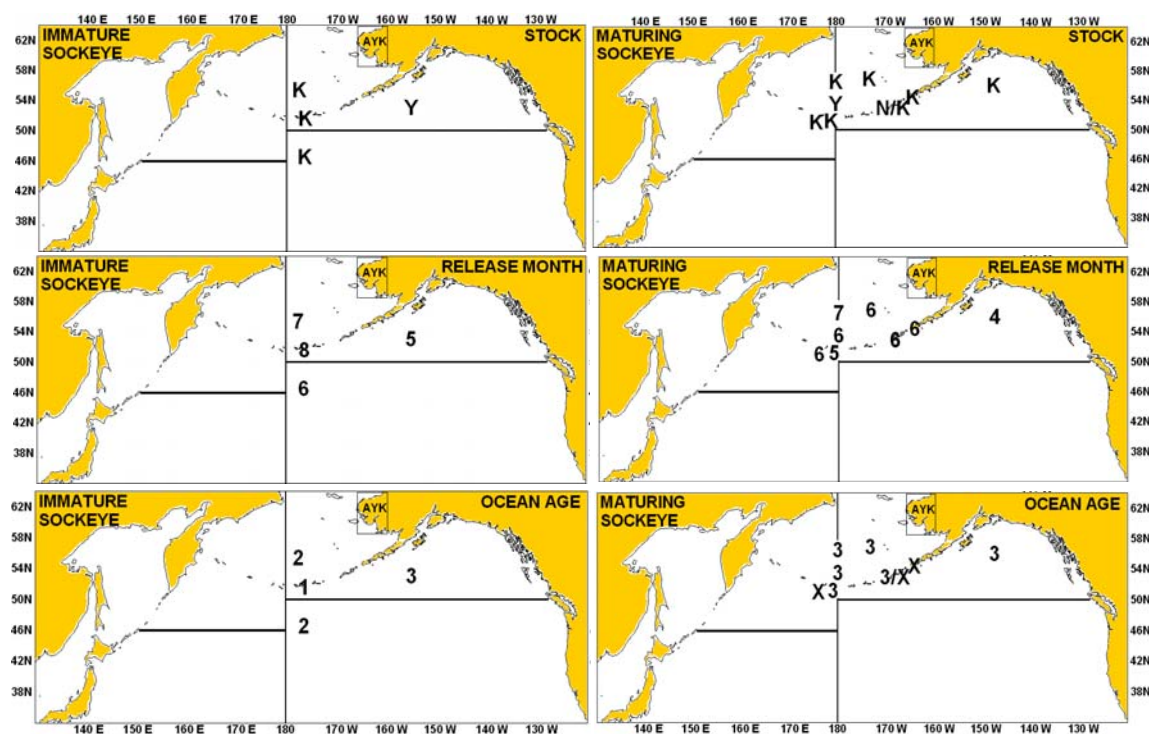


Figure 2- 12. The known ocean distribution of immature (left panels, 4 fish) and maturing (right panels, 9 fish) Yukon (Y) and Kuskokwim (K) sockeye salmon by stock (top panels), month of release (center panels), and ocean age group at release (bottom panels, X = ocean age unknown), as indicated by high seas tag experiments, 1954-2006. Forward slash between numbers or letters indicates data for two fish released at the same location. Reported dates of recovery of adult fish in the AYK region ranged from June 17 to September 8. Reference lines indicate ocean regions shown in Fig. 2-1.

AYK sockeye salmon

AYK sockeye salmon typically migrate to the ocean after one or two winters in freshwater, and spend two, three, or four winters at sea, returning to spawn at ocean age-2, age-3, or age-4. The few reported recoveries of tagged AYK sockeye salmon were from high seas releases of both immature (n=4 fish; Fig. 2-12, left panels) and maturing (n = 9 fish; Fig. 2-12, right panels) fish. Recoveries were made in Norton Sound (1 fish), Yukon (2 fish), and Kuskokwim (10 fish). The high seas release locations of four immature AYK sockeye salmon indicated that they were distributed in the GOA in May (n=1, Yukon, age 2.3; 590 mm FL at release), and their distribution shifted westward in late spring and summer (Fig. 2-12, left panels), extending into the western NEP (June, n=1, age 1.2, 428 mm FL at release), central Aleutians (August, n=1, age x.1, 385 mm FL at release), and EBS (July, n=1, age 1.2, 452 mm FL at release). High seas release locations of maturing AYK sockeye salmon (Fig. 2-12, right panels) indicated that they were distributed in the GOA in early spring (April, n=1, age 1.3, 600 mm FL at release), and their distribution shifted westward in May (n=1, age x.3, 580 mm FL) and June into the western GOA, Aleutians, NWP, and EBS (n=6, mean size at release: 555 mm FL). By July most maturing AYK sockeye salmon are probably distributed in the Bering Sea (n=1, age 1.3, 617 mm FL at release) or have already returned to coastal areas and spawning streams.

Comparison of Vertical Distribution of Salmon Species from Tag Data

The results presented herein were published in Myers et al. (2009).

Data storage tags (DSTs) have yielded precise information about the behavior of salmon and their vertical distribution. Prior to this project, nine tags with depth data came from recoveries of salmon in western Alaska: seven sockeye salmon (Yukon delta, Kanektok, Nushagak, Egegik, Ugashik, Bear River, and Nelson Lagoon) and two Chinook salmon, both from the Yukon River. Depth data from tags indicated that salmon often remained near the surface at night and moved between the surface and greater depths during the day. Simple descriptors of depth, such as “average depth”, did not capture some of the variation in salmon behavior. In summarizing the data, we have taken the maximum depth recorded for each day and averaged all of these daily maxima. This approach gave an overestimate of the usual daily range of the salmon. Depth data from a limited number of data tags from the Bering Sea and North Pacific (n=38) indicated that Chinook salmon (data from two Yukon River fish) and chum salmon (data from 11 Asian fish) have the deepest vertical distributions (Table 2-1). Average depths (Chinook salmon: 42 m; chum salmon: 16 m) and average daily maxima (Chinook salmon: 130 m; chum salmon: 58 m) were deeper than those of the other three species. Among sockeye, pink, and coho salmon, sockeye salmon have the shallowest vertical distribution (average 4 m, average daily max 21 m, with occasional excursions to 30-80 m), followed by pink salmon (average 10 m, average daily max 37 m) and coho salmon (average 11 m, average daily max 46 m). The diel pattern was strongest in chum and pink salmon, and was variably expressed, even in a single fish.

Table 2- 1. Average ocean swimming depths (meters) of five species of Pacific salmon, as recorded by electronic data storage tags (N = number of tagged fish, Avg = average, Min = minimum depth, Max = maximum depth). The maximum depth that the tags were capable of recording was 344 m.

	Sockeye	Pink	Coho	Chum	Chinook
N	12	3	10	11	2
Avg depth (m)	3	10	11	16	42
Avg daily min (m)	0	1	0	1	17
Avg night (m)	3	4	8	8	40
Avg day (m)	4	13	12	20	43
Avg night max (m)	9	19	29	33	84
Avg day max (m)	18	36	42	56	125
Avg daily max (m)	19	37	46	58	130
Max (m)	83	74	97	253	344

Vertical and Horizontal Distribution from DST Recoveries of Yukon River Chinook salmon

The results presented herein were published in Walker and Myers (2009).

To date, only two DSTs with usable data have been recovered from Chinook salmon in the AYK region (Fig. 2-13). Fish were captured for tagging by Japanese research vessels in 2002 and 2006 in the eastern part of the central basin of the Bering Sea. A Chinook salmon carrying tag 1401 (hereafter, “fish 1401”) was caught with longline gear on 7 July 2002 (Alaska Daylight Time) at 56°30'N, 179°00'W. At tagging, the fork length of the fish was measured as 562 mm. The age of the fish was determined from a

scale as 1.2 (1 winter in fresh water, 2 winters at sea). Fish 1401 was captured 72 km upstream from Kotlik, Alaska on 21 June 2004. A Chinook salmon carrying tag 1899 (“fish 1899”) was caught by trawl on 6 June 2006 at 54°50’N, 175°08’W. The fork length of the fish at tagging was 850 mm. Fish 1899 was captured at Mountain Village, Alaska on 30 June 2006.

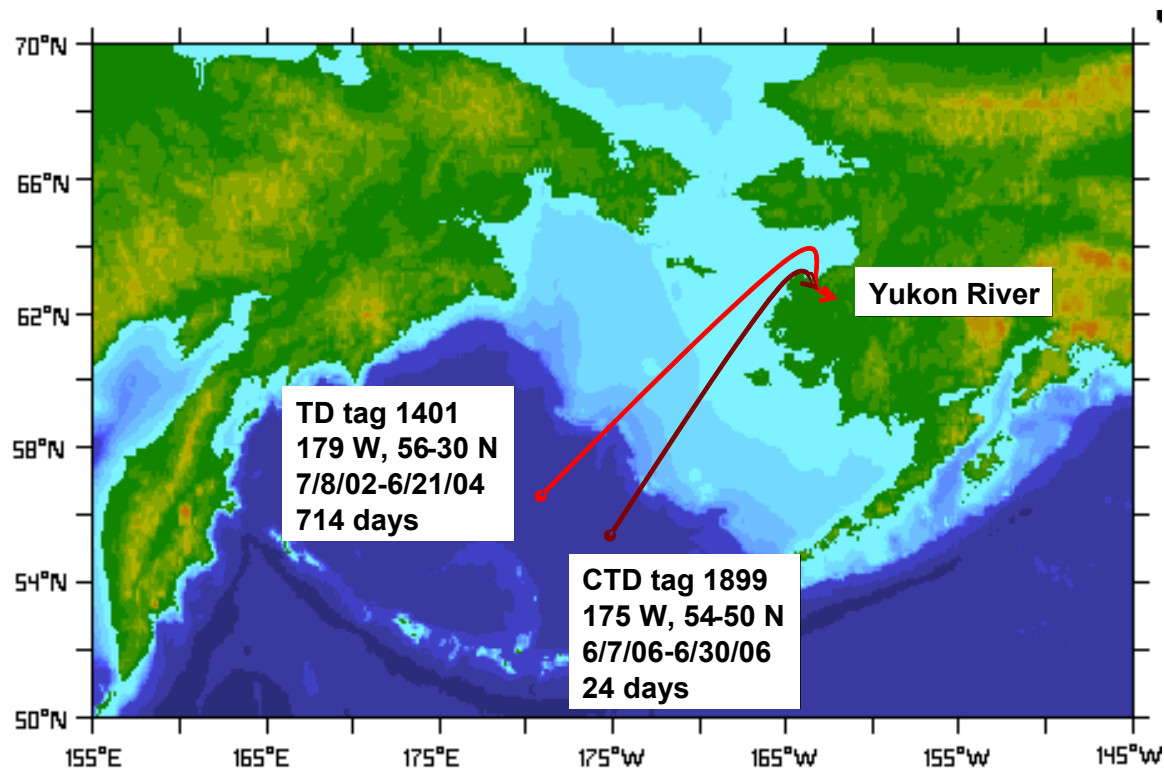


Figure 2- 13. Tagging and recovery locations of two Yukon River Chinook salmon tagged with archival tags in the Bering Sea. (Base map modified from a map on the PMEL website: <http://www.pmel.noaa.gov/np/pages/seas/bseamap2.html>).

Tag 1401 contained 16,246 data points for both temperature and depth. Fish 1401 underwent major changes in behavior during the two years it was at large (Fig. 2-14). In summer 2002, temperature/depth profiles (compiled from data on the tag) in the two months following tagging were similar to those from the tagging vessel and Argo floats in the Bering Sea Basin (Fig. 2-15). They did not match data from moorings in the eastern Bering Sea shelf, or sea surface temperatures as measured by satellite for most other regions of the Bering Sea. Beginning in October 2002, the fish began an overall descent in the water column that culminated in its remaining at approximately 125 m depth during the winter, until it gradually returned to surface waters in March 2003 (Fig. 2-16A). Because the fish remained at a constant depth well below the surface, it was not possible to construct temperature profiles or compare data to SSTs. However, the fish experienced near-constant water temperatures of 4°C at 125 m, a relatively warm temperature for the Bering Sea in winter at that depth. Temperatures of 4°C were not recorded by moorings on the eastern Bering Sea shelf or by Argo floats in the Bering Sea Basin north of about 54°N. However, moorings in the Aleutian Islands did record 4°C temperatures at depths of 142–453 m in Tanaga and Amukta passes in the winter of 2002–2003, and similar temperatures at Seguam Pass at 145–154 m in the winter of 2001–2002 (Stabeno et al. 2005).

In spring (April 2003) fish 1401 undertook a series of movements between the surface and 350 m (maximum depth the tag was capable of recording) or more (Fig. 2-17A). The deep vertical movements by the fish in April 2003 indicate the fish was either in the Bering Sea Basin or near the shelf break. In summer 2003 temperature profiles show three different patterns, roughly June, July, and August (Figs. 2-18 and 2-19). In all periods the water column is highly stratified with a sharp thermocline around 20–40 m. In June and August temperatures below the thermocline were 3°–4°C, while in July temperatures were 1°–2°C. Maximum depths were about 140 m in June and July, but below 300 m in August. It appears the fish moved from the basin onto the eastern Bering Sea shelf in June and moved off again later in August. The coldest (1°–2°C) waters at relatively shallow depths (40–80 m) in July were typical of the “cold pool” on the eastern Bering Sea shelf south of St. Lawrence Island, and found around 60° N in 2003 (Schumacher et al. 1983; Stabeno et al. 2001; Wang et al. 2007). Temperatures at mooring M2 (56.9°N) on the shelf (Fig. 2-19A) during June and August are similar to those on the tag, but in July deepwater temperatures are warmer (3.3°C), as are deep temperatures at mooring M4 further north (57.9°N; temperature of 2.9°C). Fish 1401 was likely both further north and farther toward the edge of the shelf. Maximum depths on the tag were greater than 80 m, while the maximum sensor depths of M2 and M4, near the bottom, are 62 m and 67 m, respectively.

As autumn approached in 2003 fish 1401 did not substantially change its vertical behavior, remaining mostly above 100 m (Fig. 2-16B). Surface temperatures gradually declined and daily temperature ranges decreased. In early November, temperature ranges abruptly changed to a single temperature (6°C) at all depths recorded by the tag (down to 70 m), presumably following a storm that mixed waters to at least that depth. In contrast to the previous winter, the fish continued moving between the surface and relatively shallow (50–70 m) depths. Temperatures dropped over the course of the winter, reaching 1.2°C in January 2004. While temperatures were uniform with depth, precluding construction of informative profiles, SSTs were similar to those from satellite imagery in the southern and central portions of the Bering Sea, but were warmer than the range of SSTs in the western, northern, or eastern portions of the Bering Sea.

In late winter and spring of 2004 the fish resumed the deep vertical movements it made in spring 2003, indicating the fish was in the Bering Sea Basin or near the shelf break (Fig. 2-17B). During this period there are intervals when the fish does not return to the surface, though generally the fish is moving between the surface and depths of over 340 m. As in 2003 there is a relatively small temperature range (2.5°–4.4°C) despite the large range of depths. In February the fish was encountering temperatures of about 4°C even at depth. Again, these temperatures match those in the southern Bering Sea just north of the eastern Aleutians. After three months of this behavior, it abruptly ceased deep vertical movement on 26 May. Later on this day it encountered its coldest temperatures of 0.2°–1.8°C at depths of about 20 m. This may be the edge of the cold pool, which in 2004 was north of about 58°N. At this point the fish had begun its return to the Yukon, which it reached around 12 June. During this 17-day journey the fish was mostly above 30 m and temperatures were mostly 2°–4°C.

For most of the period fish 1401 was at liberty it showed diel behavior patterns, with the exception of the deep diving periods of late winter and early spring. However, these patterns differed with season. In summer the fish was nearer the surface at night and moved deeper during the day. During the first autumn transition the fish remained about 25 m below the surface at night but initially made small upward vertical movements during the day, coming to the surface, and later made larger vertical movements down to 100 m. In the first winter, the fish remained at about 125 m during the night, and made small (to 50 m) vertical movements toward the surface during the day. In the second winter, fish 1401 remained near the surface, making small (40 m) movements downward during the day. During the deep dive periods of late winter and spring, there was no apparent diurnal pattern.

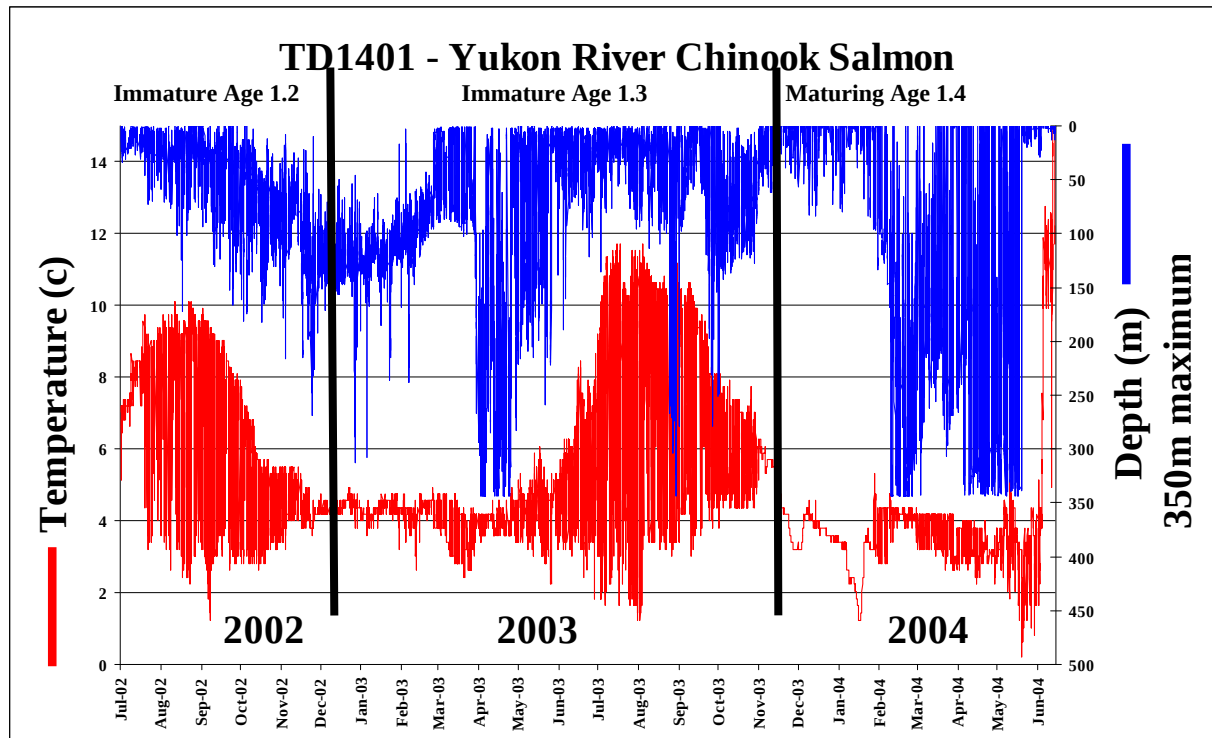
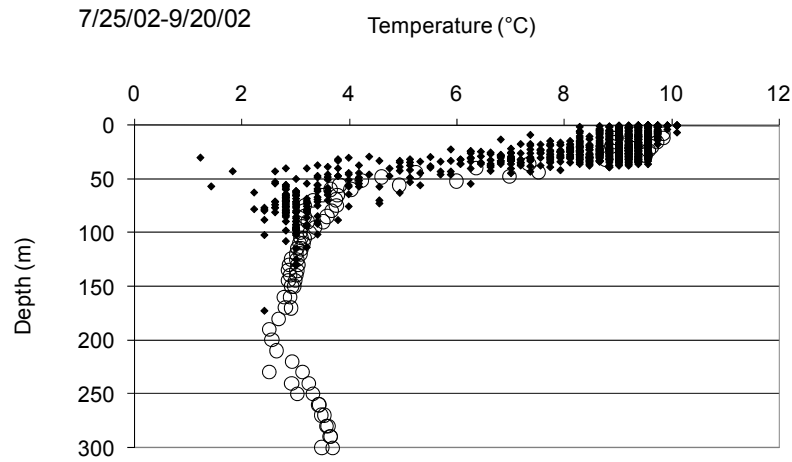


Figure 2- 14. Temperature (red) and depth (blue) data record from an age 1 1.2 (562 mm FL) tag 1401 on a Chinook salmon tagged at 56°30'N, 179°00'W in the Bering Sea on 8 July 2002 and recovered at age 1.4 near Kotlik, Alaska, in the Yukon River on 21 June 2004. Maximum depth the tag could record was 340 m.

Fish 1401 moved below the shallow (less than 40 m) thermocline to cooler waters below in the summer. There is a diurnal pattern to the movement, as seen in many species of Pacific salmon (Walker et al. 2000, 2007; this report), where the fish is near the surface at night and makes occasional deeper vertical movements during the day. This may be related to feeding, with fish feeding on organisms that come to the surface at night, and moving deeper during the day to search for food or as a thermoregulatory behavior (Azumaya and Ishida 2005).

A diurnal pattern of dives continued through both winters, but was not as pronounced as in summer and fall. In the first winter, the pattern was reversed, with the fish moving toward the surface during the day. The average depth in the first winter increased, perhaps to avoid the cold turbulent surface waters and perhaps for feeding on other organisms at that depth. Water temperatures at that depth were warmer than the surface and may have been more optimal for growth. In the second winter, before it returns to spawn, the fish was much shallower, in surface waters (less than 50 m). Having obtained sufficient size to spawn, perhaps it was more important to position closer to its home river than to feed extensively or put on more somatic growth. The colder surface waters would also conserve energy.

A



B

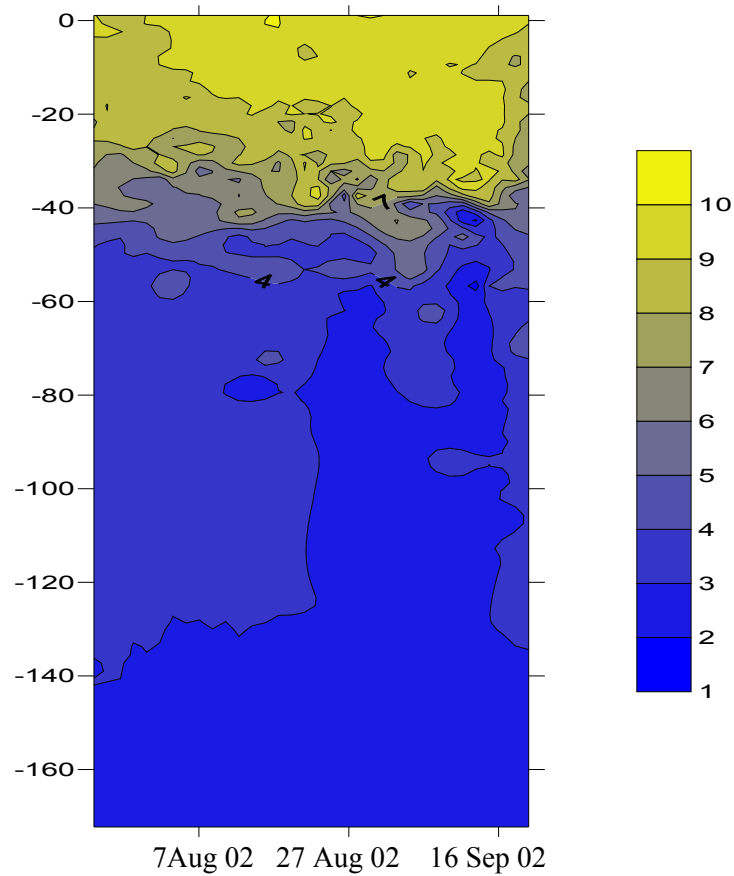
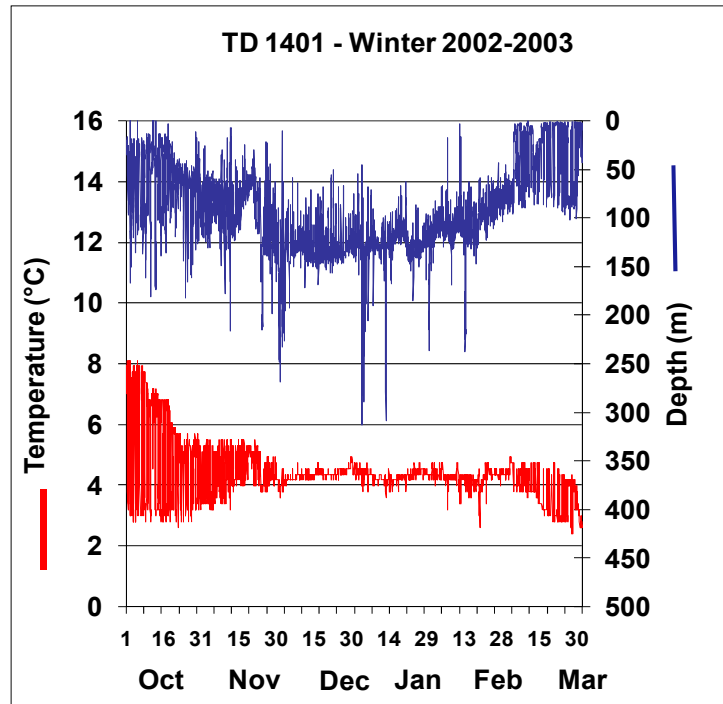


Figure 2- 15. Temperature-depth profiles from tag 1401 on a Yukon River Chinook salmon in the Bering Sea in summer 2002. In (A) solid marks are data from tag, 25 July – 20 September; open circles are data from PMEL Argo float 11490, 26 July 2002 at 176.058° W, 57.072° N and 5 August 2002 at 175.889° W, 56.693° N. (B) includes data from the tag only and shows changes in the temperature-depth profile over time.

A



B

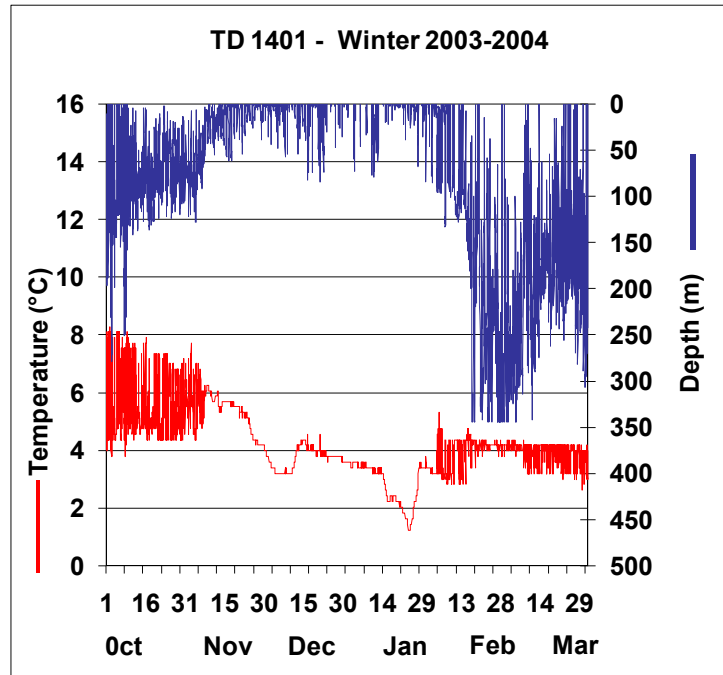


Figure 2- 16. Temperature (red) and depth (blue) data records from tag 1401 on a Yukon R. Chinook salmon tagged in the Bering Sea for (A) winter 2002-2003 and (B) winter 2003-2004. Maximum depth tag could record was 340 m.

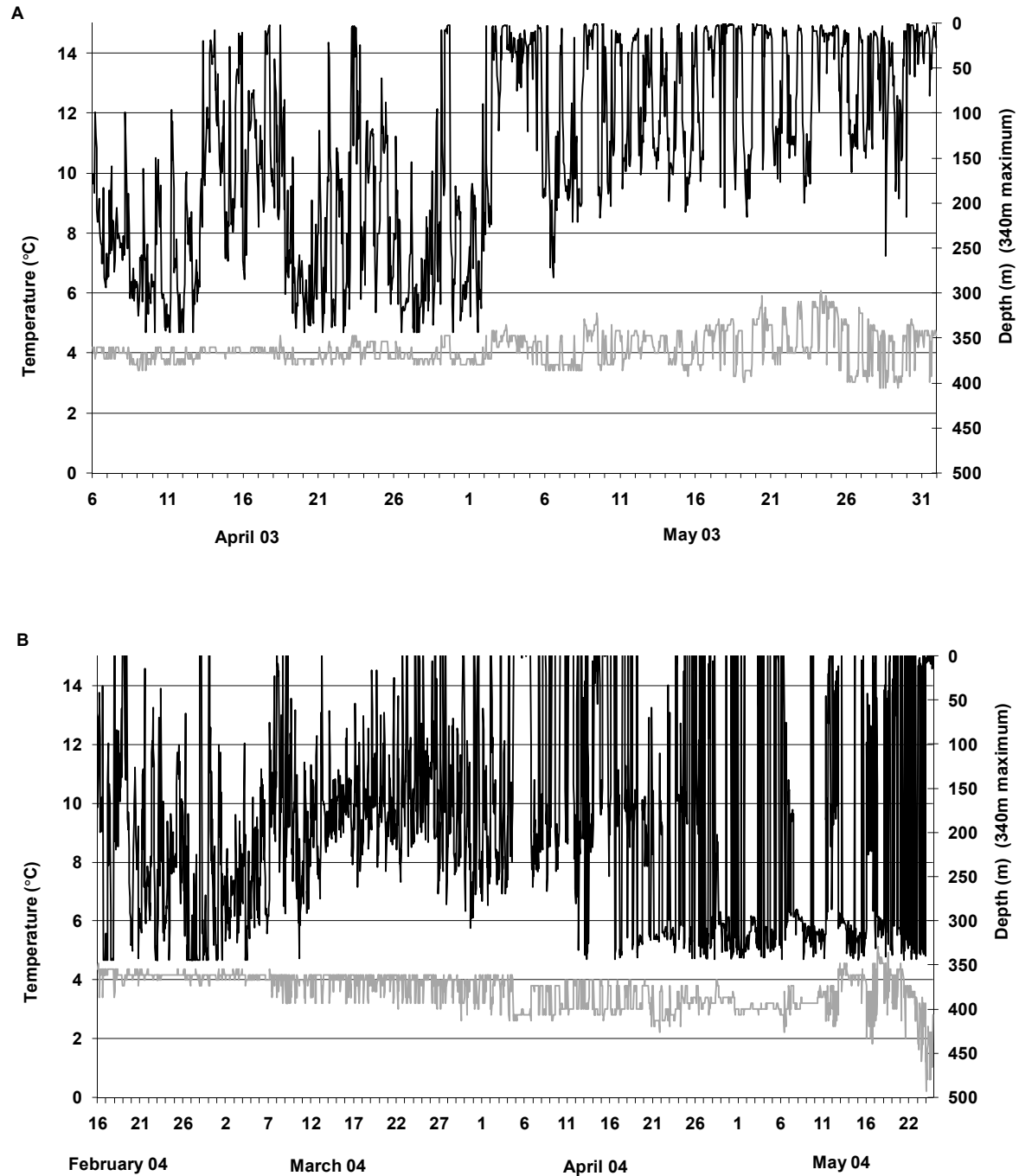


Figure 2- 17. Temperature (grey) and depth (black) data records from tag 1401 on a Yukon R. Chinook salmon tagged in the Bering Sea for deep diving periods in (A) spring 2003 and (B) late winter and spring 2004. Maximum depth the tag could record was 340 m.

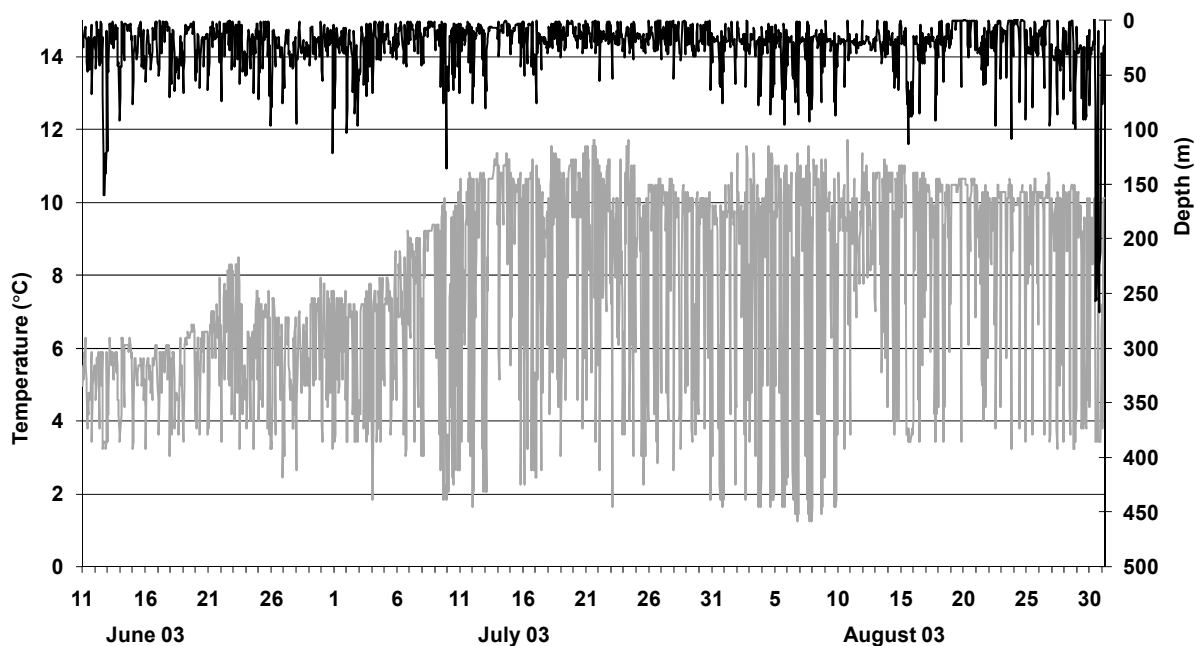


Figure 2- 18. Temperature (grey) and depth (black) data records from tag 1401 on a Yukon R. Chinook salmon tagged in the Bering Sea for summer 2003.

One puzzling and dramatic feature of the behavior of fish 1401 was the very deep periodic dives undertaken in late winter and spring. The frequency and constancy with which the dives occur over a period of time, and at only one period of the year, make it unlikely that they are to escape predators. The behavior occurs in years both as an immature and as a maturing fish, so is not likely a feature of maturation or sensing a migratory path. The dives are quite possibly related to feeding. In late winter and early spring, some fish and squid prey species may be overwintering at depth to avoid predation, because there is less food at the surface before development of the spring phytoplankton bloom and the zooplankton that feed on it. The diet of Chinook salmon caught deeper than 200 m in trawl fisheries in the winter is almost entirely squid; fish at shallower depths fed on a mixture of euphausiids, discarded fish offal, squid, and fish (Davis et al. 2009a). If food is more abundant at depth, why did not fish 1401 simply remain there? Perhaps Chinook have difficulty enduring the continual pressure, or perhaps there is a small thermoregulatory benefit from the slight temperature differences between the surface and deeper waters. The fish reached depths over 300 m, and although at this season the mixed layer was very deep and temperatures were relatively uniform with depth, temperatures at depth were sometimes 1°C higher than at the surface, indicating that this was below the mixed layer; later in the spring, surface temperatures were slightly warmer. Thus although the temperature variation was small and the fish did not remain deep, thermoregulatory behavior cannot be ruled out.

Fish 1899 was at liberty only 24 days after tagging. Data from tag 1899 show the fish at depths less than 40 m until it reached the mouth of the Yukon River, except for two days midway through the journey when it made dives to 100 m (Fig. 2-20). Temperatures ranged from 6°C to 8°C. The fish covered a minimum of 1040 km (great circle distance) in the 22 days until it entered the Yukon (as indicated by a sharp drop in salinity), implying a minimal travel rate of 1.96 km/h (0.64 body lengths/s). Given the

distance and necessary rate of travel, it is likely this fish moved in a relatively direct line from the tagging location to the Yukon.

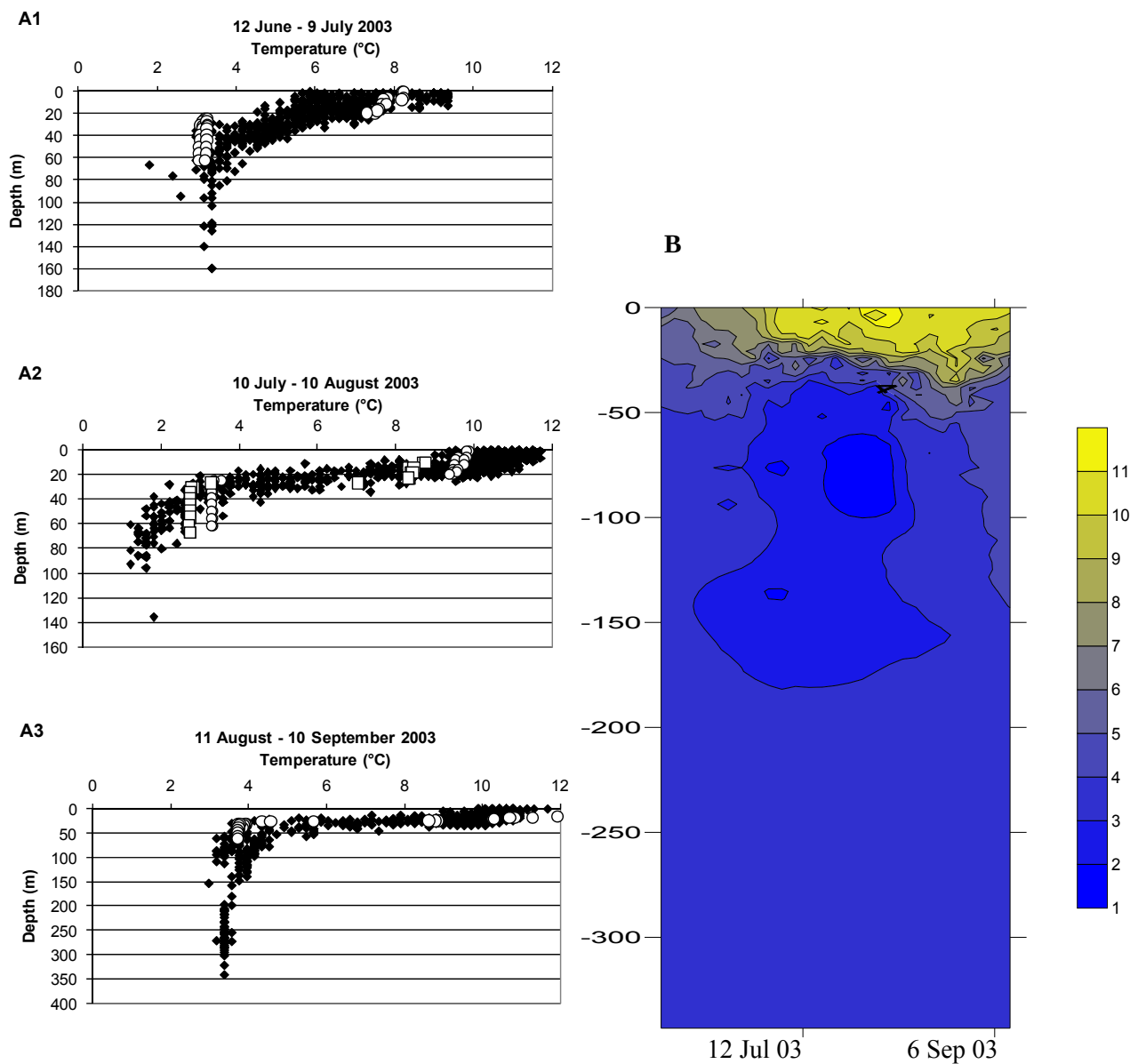


Figure 2- 19. Temperature-depth profiles from tag 1401 on a Yukon R. Chinook salmon in the Bering Sea in summer 2003. Profiles from two moorings on the eastern Bering Sea shelf are included in (A): M2, at 56.9°N, 164.1°W (open circles), and M4 at 57.9°N, 168.9°W (open squares). Maximum sensor depths are 62 m for M2 and 67 m for M4. Representative data from two days within the time range of the tag data were plotted (A1: 22–23 June for M2 only; A2: 20–21 July for both moorings; A3: 11–12 August for M2 only). (B) includes data from the tag only and shows changes in the temperature-depth profile over time.

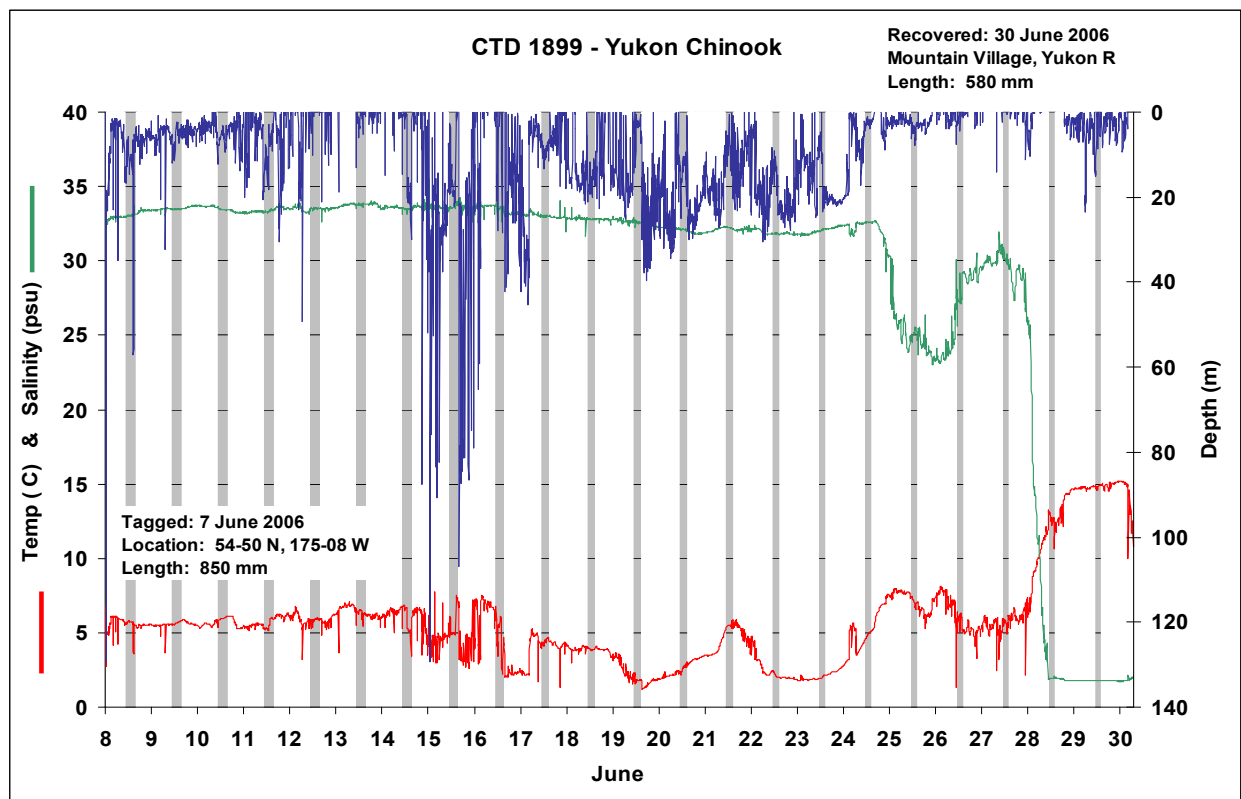


Figure 2- 20. Temperature, depth, and salinity data record from tag 1899 on a Chinook salmon tagged at 54°50'N, 179°00'W in the Bering Sea on 7 June 2006 and recovered near Mountain Village, Alaska, in the Yukon River on 30 June 2006. Grey bars = night.

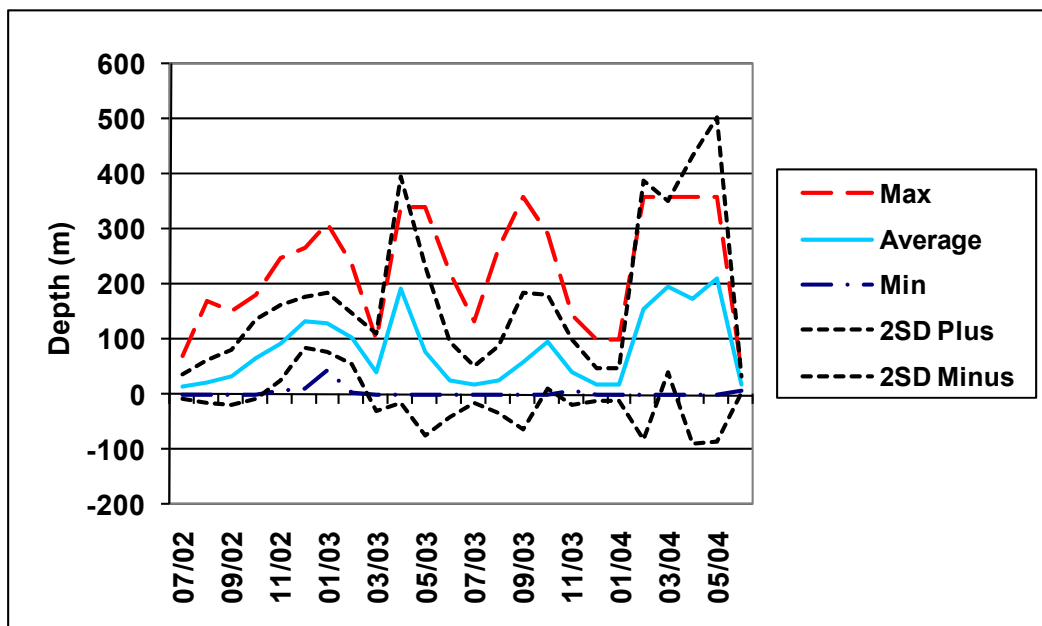
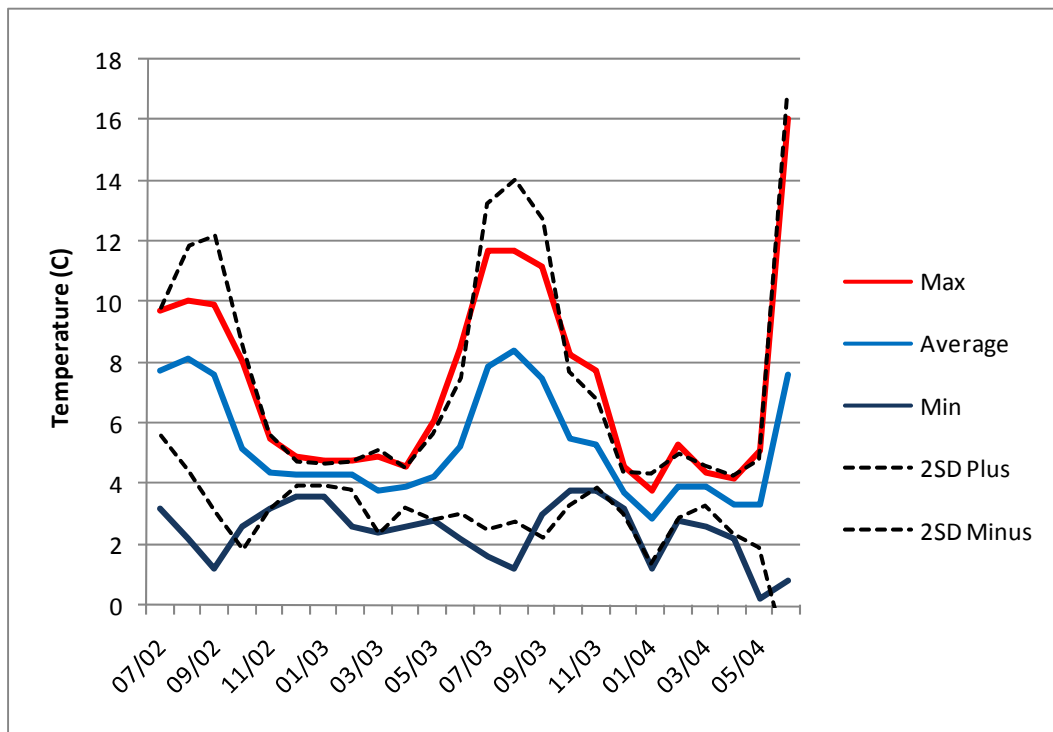


Figure 2- 21. Temperature and depth variation for data from tag 1401.

DST releases and recoveries of Chinook salmon tagged in 2008-2009

During this project, we tagged and released twenty-five Chinook salmon with temperature-depth recording DSTs in the central North Pacific Ocean and Bering Sea in 2008 and 2009 (Table 2-2). Although we had originally planned to tag up to 50 Chinook salmon with DSTs, research vessel catches of Chinook salmon in 2008 and 2009 were low, and all viable Chinook salmon caught during longline fishing operations aboard the *Wakatake maru* were tagged and released. To date, recovery of only one tagged fish has been reported. This fish was tagged in the central Bering Sea (57°34'N, 179°58'W) on June 29, 2009, and recovered approximately one year later along the north coast of the Alaska Peninsula (off Stroganof Point, at approximately 56°53'N, 158°56'W) on July 10, 2009 (377 days after tagging). The tag recorded external temperature and pressure (depth) every 12 minutes (a total of 45,056 data points). As the fish was caught in nearshore waters, we assumed it was maturing and returning to a spawning river in the Bristol Bay area, but its true stock of origin is unknown. At capture, the fish was determined to be a female. Scale samples taken at the time of tagging were regenerated and an age could not be determined. The length of the fish at tagging was 561 mm fork length (22 in), which indicates it had likely spent two winters at sea (ocean age .2). The distance between release and recovery points (1,262 km; 784 mi) is likely far less than the actual distance covered by the fish during the course of a year.

During the year, the fish encountered temperatures from -1°C to 12.5°C (30°F – 54°F) at depths ranging from the surface to 523 m (1,717 ft) (Table 2-3). Temperatures and depths varied greatly over the course of the year (Fig. 2-22). In the first summer there was little range of depth (generally 0-50 m), but temperatures range from 1°C to 12°C, reflecting the great stratification and stability of the water column of the central Bering Sea basin. During the autumn, the fish made a transition to deeper waters, where it was mostly below the surface at depths between 75 and 225 m, but with major vertical movements and a total range from the surface to over 300 m. The average depth over about five months of winter was about 140 m. In contrast to summer, the temperature range was quite narrow (1.4°C-4.4°C), with an average of 3.2°C. This was warm for the Bering Sea in winter, and the fish was likely off the eastern shelf and along the Aleutian Islands, where warmer North Pacific water moves into the Bering Sea (Stabeno et al. 2005).

In spring, the fish made some wide vertical excursions from the surface to over 300 m, but not as extreme as the spring movements of a Yukon Chinook tagged in 2002 and recovered in 2004 (Walker and Myers 2009). Temperatures were within a similar range, and the fish was likely in the same area or slightly further north along the shelf break. In late May, depths abruptly become much shallower (less than 100 m, mostly less than 75 m) as the fish was likely moving onto the Bering Sea shelf. Temperatures gradually rose and the range increased as summer warmed the surface waters. However, the fish also experienced its coldest temperatures (below -1°C) in June, where it likely encountered the “cold pool” of the shelf, an annual feature related to ice cover (Schumacher et al. 1983; Stabeno et al. 2001). The warmest temperatures of the second summer (10°-12°C) were in July in coastal waters just before recapture.

Data from recoveries of DST-tagged Chinook salmon were used to fine tune bioenergetics models (Obj. 6), where temperature is an important input into the energy balance equations. The data were also useful for inferring behavior and location, which may be relevant to reducing bycatch in marine fisheries.

Table 2- 2. Release and recovery (through August 2010) data for Chinook salmon tagged with external temperature-depth data storage tags (DST; Lotek model LAT 1400) and disk tags during the June-July 2008-2009 tagging operations aboard the R/V *Wakatake maru* in the North Pacific Ocean and Bering Sea. SST = sea surface temperature, NPAFC = North Pacific Anadromous Fish Commission, JFRA = Japan Fisheries Research Agency.

Release/ Recovery	DST No.	Species	SST °C	Latitude (deg-min)	Longitude (deg-min)	Date (yyyymmdd)	Local Time	FL (mm)	Age	Disk Tag Numbers	
										NPAFC	JFRA
Release	0592	Chinook	7.9	47-30N	179-59W	20080620	20:47	557	1.2	NA0140	LL6140
Release	0593	Chinook	7.3	57-34N	179-58W	20080630	21:58	504	1.2	¹ MM3578	LL6578
Release	0594	Chinook	7.3	57-34N	179-58W	20080630	22:24	363	X.X	NA0601	LL6601
Release	0595	Chinook	7.3	57-34N	179-58W	20080630	22:28	529	X.X	NA0602	LL6602
Release	0597	Chinook	7.3	57-34N	179-58W	20080630	22:30	510	1.2	NA0603	LL6603
Release	0598	Chinook	7.3	57-34N	179-58W	20080630	22:35	762	X.X	NA0604	LL6604
Release	0599	Chinook	7.3	57-34N	179-58W	20080630	22:38	688	1.3	NA0605	LL6605
Release	0601	Chinook	7.3	57-34N	179-58W	20080630	22:43	561	X.X	NA0607	LL6607
Recovery	0601	Chinook		56-53N	158-56W	20090710				NA0607	LL6607
Release	0602	Chinook	7.3	57-34N	179-58W	20080630	22:41	568	X.X	NA0606	LL6606
Release	0603	Chinook	7.3	57-34N	179-58W	20080630	22:46	580	X.X	NA0608	LL6608
Release	0604	Chinook	6.5	58-30N	179-55E	20080701	22:05	772	1.3	NA0637	LL6637
Release	0605	Chinook	7.0	57-27N	179-12W	20080702	21:52	470	1.2	NA0669	LL6669
Release	0606	Chinook	7.0	57-27N	179-12W	20080702	22:41	747	1.3	NA0721	LL6721
Release	0607	Chinook	7.1	57-28N	178-05W	20080703	21:51	555	X.2	NA0738	LL6738
Release	0608	Chinook	7.1	57-28N	178-05W	20080703	21:52	519	1.2	NA0739	LL6739
Release	0610	Chinook	7.1	57-28N	178-05W	20080703	22:33	504	X.2	NA0781	LL6781
Release	0611	Chinook	7.1	57-28N	178-05W	20080703	22:35	556	X.2	NA0782	LL6782
Release	0612	Chinook	7.1	57-28N	178-05W	20080703	22:37	390	1.1	NA0783	LL6783
Release	0613	Chinook	7.1	57-28N	178-05W	20080703	23:09	730	1.3	NA0830	LL6830
Release	0614	Chinook	7.0	47-30N	180-00W	20090620	20:58	558	1.2	NA2586	KK3086
Release	0615	Chinook	7.0	47-30N	180-00W	20090620	21:19	696	1.3	NA2601	KK3101
Release	0766	Chinook	5.8	52-30N	180-00W	20090625	21:53	652	1.3	NA2711	KK3211
Release	0767	Chinook	6.9	58-30N	180-00W	20090701	22:32	578	1.2	NA3401	KK3901
Release	0770	Chinook	7.0	56-30N	179-00W	20090705	22:15	700	1.3	NA3689	MM3689
Release	0771	Chinook	6.4	57-30N	177-00E	20090708	22:22	560	1.2	NA3971	MM3971

¹UW tag number, NPAFC tag not available

Table 2- 3. Temperature and depth data from tag 601 placed on a Chinook salmon in the central Bering Sea in June 2008 and recovered along the north shore of the Alaska Peninsula in July 2009.

Year	Month	N	Temperature (°C)			Depth (m)		
			Max	Average	Min	Max	Average	Min*
2008	6	122	7.0	6.58	4.6	23.5	11.24	0.0
2008	7	3720	11.2	8.52	2.3	53.5	6.52	0.0
2008	8	3720	12.1	10.11	1.1	98.5	9.33	0.0
2008	9	3600	12.5	10.67	0.4	71.0	11.26	0.0
2008	10	3720	10.1	6.67	0.4	203.3	20.42	0.0
2008	11	3600	5.6	4.16	1.1	236.5	50.08	0.0
2008	12	3720	4.4	3.26	1.4	325.8	129.88	0.0
2009	1	3720	4.3	3.50	1.8	364.3	145.12	0.0
2009	2	3360	4.0	3.38	2.2	293.3	146.72	0.0
2009	3	3720	3.9	3.12	1.8	400.5	161.89	0.0
2009	4	3600	3.8	3.10	1.8	336.8	132.02	0.0
2009	5	3720	6.3	3.82	2.0	523.5	59.37	0.0
2009	6	3600	9.2	4.94	-1.1	108.5	13.94	0.0
2009	7	1134	12.1	7.17	2.4	39.8	10.08	0.0
Overall		45056	12.5	5.50	-1.1	523.5	71.76	-4.3

*minimum depths corrected from small negative numbers due to atmospheric anomalies

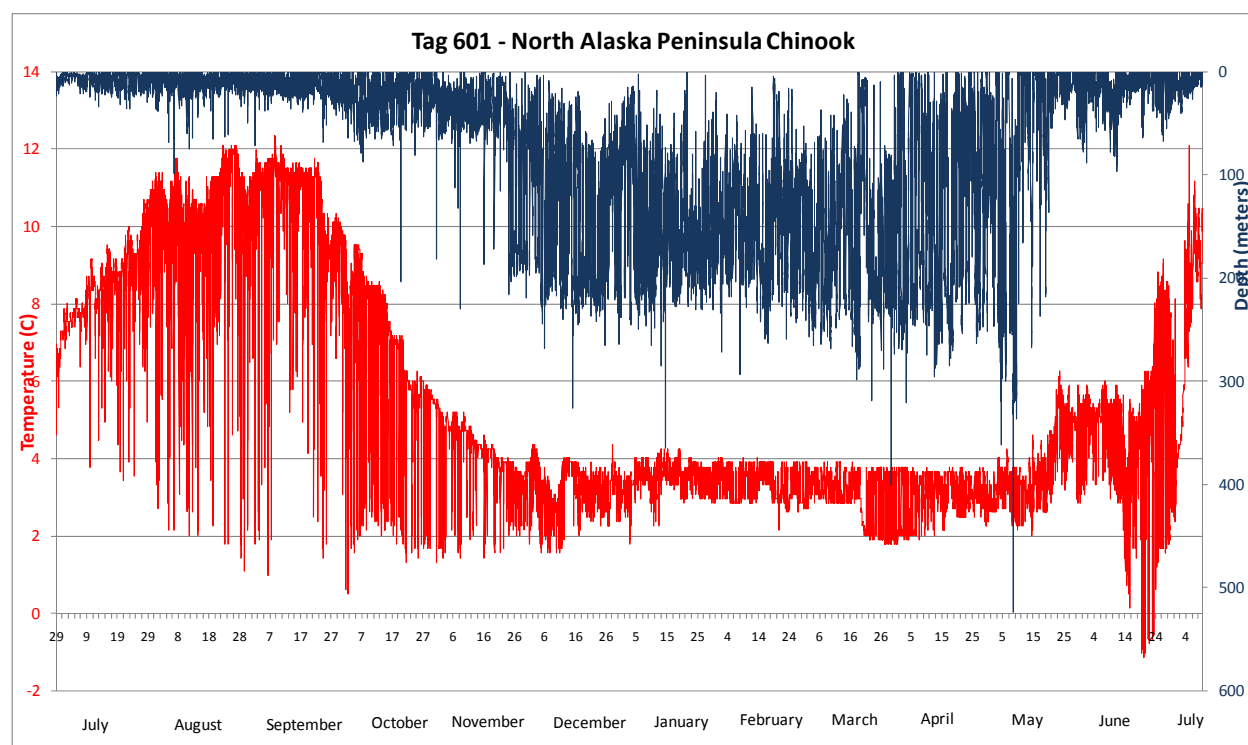


Figure 2- 22. Temperature and depth data from tag 601 placed on a Chinook salmon in the central Bering Sea in June 2008 and recovered along the north shore of the Alaska Peninsula in July 2009.

Vertical Distribution of Chinook Salmon in the Eastern Bering Sea Trawl Bycatch

We corrected a previously published analysis of age-specific seasonal variation in depth distribution of Chinook salmon in the NOAA Fisheries Groundfish Observer Program data (1997-1999) that used incorrect units of depth measurement (corrected from Walker et al. 2007 and Myers et al. 2009; Table 2-4). Eastern Bering Sea trawl bycatch of Chinook salmon in 1997-1999 included a high percentage of older fish in winter (87% ocean age -.3 and older) and younger fish in summer-fall (78% ocean age -.1 and -.2). Over 90% were caught at depths between 50 m and 325 m below the surface; fewer than 3% were deeper than 500 m (Table 2). Chinook salmon were slightly deeper in autumn (140 m average fishing depth in September-October, vs. 120 m January-February), and younger fish tended to be slightly deeper than older fish. Depth distribution showed a bimodal tendency in winter, with the bulk of fish at 50-125 m and a smaller peak at 425-500 m.

Table 2- 4. Table of average depth (meters) of bycatch of Chinook salmon in eastern Bering Sea trawl fisheries (1997-1999), by ocean age. Percentage of catch by 25-m depth interval is also presented. Note: This table corrects errors in a previously published table that reported depths in fathoms as depths in meters (Walker et al. 2007; Myers et al. 2009).

Ocean age	January-February						September-October				
	-1	-2	-3	-4	-5	All ages	-1	-2	-3	-4	All ages
N	39	279	1,317	798	82	2,515	368	1,455	497	20	2,340
Avg. depth	106.2	197.2	120.6	93.6	87.2	119.2	147.4	142.8	127.3	115.1	140.0
25m %											
depths											
0			0.2		1.2	0.1					
25	2.6	1.8	3.0	3.9	41.5	3.1	0.5	0.3	0.6		0.4
50	46.2	23.7	30.7	39.0	45.1	33.1	14.4	7.6	12.7	10.0	9.7
75	33.3	27.2	38.8	41.2	6.1	38.4	25.5	21.2	21.1	35.0	22.0
100	7.7	10.8	13.2	10.8	1.2	11.8	10.0	20.4	29.0	30.0	20.7
125		2.9	2.0	0.8		1.7	8.2	13.5	13.9	15.0	12.8
150		1.4	1.0	0.3		0.8	8.7	11.8	8.2	5.0	10.5
175		0.4	0.2			0.2	6.8	7.1	4.2		6.4
200		1.8	0.2			0.3	6.8	7.1	3.4		6.2
225		0.7	0.3	0.1		0.3	5.7	4.3	2.8	5.0	4.2
250	2.6		0.2	0.1		0.2	6.5	3.9	2.4		4.0
275				0.1		0.0	3.3	1.1	0.8		1.4
300			0.5			0.2	1.6	0.8	0.4		0.9
325		2.2	0.9	0.4		0.8	1.1	0.8	0.4		0.7
350	5.1	2.5	0.9	0.6		1.0	0.5				0.1
375		1.4	0.6	0.5		0.6					
400		3.2	1.1	0.8	1.2	1.2					
425		2.9	2.1	0.5		1.6					
450		4.3	1.3	0.1		1.2					
475	2.6	5.7	1.2	0.3		1.4	0.3				0.0
500		6.1	1.2	0.6	1.2	1.6					
525		0.7	0.3			0.2					
550		0.4	0.1			0.1					

Horizontal Distribution from Scale Pattern Analyses

Information from historical scale pattern analyses indicated that western Alaska (particularly Yukon River) were the predominant regional stock of Chinook salmon migrating in the Bering Sea (e.g., Major et al. 1978; Myers et al. 1984, 1987, 2003; Myers and Rogers 1988; Davis 1990, 1991; Bugaev 2004, 2005). In contrast to the results from tagging studies, however, scale pattern analyses indicated that Asian and North American stocks of Chinook salmon (primarily western and south-central Alaskan) mixed in areas south of the Aleutians to 46°N, with wide variations between years in their estimated proportions. In the western North Pacific Ocean south of 46°N, which was the primary fishing area of the Japanese landbased driftnet salmon fishery, scale pattern estimates indicate that most Chinook salmon were from Russian stocks (Myers et al. 1993).

Myers et al. (1987) noted considerable annual variability in scale pattern estimates of the proportions of age 1.2 Yukon River, Kuskokwim River, and Bristol Bay Chinook salmon in the central Bering Sea in July 1975-1981. In June, Yukon River Chinook salmon were the predominant stock in catches in the central North Pacific Ocean between 170°E and 175°E and in the central Bering Sea between 175°E and 180°. In July 1979-1981, proportions of Yukon river Chinook salmon were higher in catches from the western portion of the fishery area (175°E-180°) than in the eastern portion (180°-175°W). Rogers (1987) used these estimates to calculate interceptions of Yukon River Chinook salmon by the Japanese high seas driftnet fisheries, and found that these interceptions often amounted to over 20% of the domestic catch in the 1970s.

Healey (1991) used high seas disk tag data (1956-1984), coded wire tag recovery data (1980-1986), and the results of scale pattern analyses to describe the distribution and relative abundance of regional stock groups of Chinook salmon in the Bering Sea and North Pacific Ocean. He concluded that in the Bering Sea western Alaskan Chinook salmon (including Canadian Yukon River fish) were the most abundant stock group, and Russian and central Alaskan stocks are about half as abundant as western Alaskan Chinook salmon. In the western North Pacific Ocean, there is a broad mixture of Russian, western Alaskan, and central Alaskan stocks, and western Alaskan Chinook are probably no more abundant than Russian stocks (Healey 1991).

Myers and Rogers (1988) estimated that Chinook salmon in the 1979, 1981, and 1982 catches by foreign and joint-venture groundfish fisheries in the EBS were predominantly ages 1.2 (56%) and 1.3 (26%). Regional stock proportion estimates from scale pattern analysis indicated that western Alaska, which included Canadian Yukon fish, was the predominant regional stock of ages 1.2 and 1.3 fish. The proportions of the three western Alaskan subregional stocks (Yukon, Kuskokwim, and Bristol Bay) varied considerably with such variables as brood year, time, and area. Bristol Bay and central Alaska (primarily Cook Inlet) stocks predominated in fall (October-November) catches in the eastern portion of the fishery area (east of 170°W), and Yukon fish predominated in winter (January-February) catches in the western portion (west of 170°W).

Myers et al. (2003, 2004b) used scale pattern analysis to estimate the age and stock composition of Chinook salmon in the bycatch of U.S. groundfish fisheries in the EBS. They found a strong seasonal difference in the age composition of Chinook salmon in the 1997-1999 bycatch samples, with young (age 1.2) fish dominating fall samples and old (age 1.3 and 1.4) fish dominating winter samples. Myers et al. (2003) concluded that in the EBS in winter, immature (age 1.2 and 1.3) Chinook salmon may be more abundant along the outer shelf break (west of 170°W) and maturing (ages 1.3, 1.4, and 1.5) Chinook salmon may be more abundant along the inner shelf break (east of 170°W). Other factors that may influence the age composition of Chinook salmon in the EBS groundfish fishery bycatch included year class strength, seasonal- and age-specific changes in the vertical distribution of Chinook salmon, and long-term decreases in body size and increases in age at maturity of western Alaska Chinook salmon.

Despite the decline in abundance of western Alaska Chinook salmon in the late 1990s, Myers et al. (2003) found that western Alaska was the dominant regional stock (average 56%) in bycatch samples of from U.S. domestic trawl fisheries operating in the EBS in 1997-1999. They concluded that: (1) the proportions of western Alaskan regional stocks (Yukon, Kuskokwim, and Bristol Bay) in the EBS varied considerably with such variables as brood year, time, and area; (2) Yukon River Chinook salmon were often the dominant stock in the EBS in winter, particularly among age 1.2 fish in areas west of 170°W and age 1.4 fish in areas east of 170°W; (3) Bristol Bay and Cook Inlet are the dominant stocks of age 1.2 Chinook salmon in the EBS in fall; and (4) age 1.1 Chinook salmon in the EBS in fall were largely Gulf of Alaska stocks (Cook Inlet, southeast Alaska-British Columbia). The combined results of tagging studies and scale pattern analyses of Chinook salmon catches in the Russian EEZ (Bugaev 2005) suggested that in summer young (primarily age 1.1) immature AYK Chinook salmon were distributed farther to the northwest in the WBS than any other North American stocks, which may explain their relatively low percentages in fall 1997-1999 bycatch samples from the EBS.

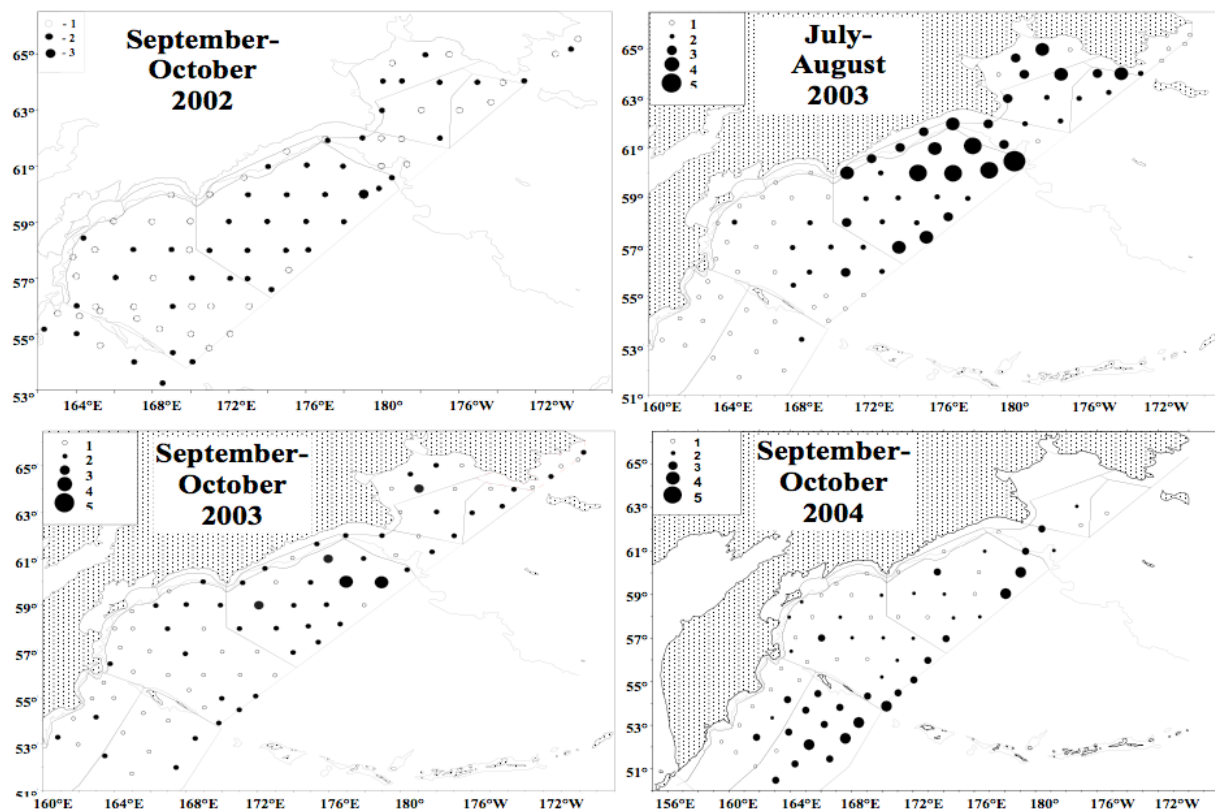


Figure 2- 23. The spatial distribution and relative abundance of Chinook salmon determined by BASIS research in the western Bering Sea, 2002–2004 (Source: Bugaev and Myers 2009a).

Note that scales vary among years. The size of the circles indicates relative abundance (number of fish/km²). Upper left panel (2002): 1 = no catch, 2 = 1–10, 3 = 11–100. Upper right and lower left panels (2003): 1 = no catch, 2 = 1–50, 3 = 51–100, 4 = 101–250, 5 = 251–500. Lower right panel (2004): 1 = no catch; 2 = 1–10; 3 = 11–50; 4 = 51–100; 5 = > 100.

We collaborated with a Russian scientist to estimate distribution and abundance of Asian and North American Chinook salmon migrating in the western Bering Sea inside the Russian EEZ in summer 2003

and fall 2002–2004 (Bugaev and Myers 2009a). Chinook salmon were sparsely distributed in this region, which greatly limited the number of samples available for stock identification research (Fig. 2-23). Russian BASIS research trawl catches of immature Chinook salmon were highest in northern areas, and catches throughout the region were dominated by fish in their second ocean summer (age 1.1 fish). In 2003, abundance of Chinook salmon was higher in summer (July–August) than in autumn (September–October) indicating a seasonal southeastward shift in distribution. Estimated percentages of immature Chinook salmon of North American origin (Western Alaska; 50.2–71.2%) were consistently higher than those of Asian (Russia) origin. The highest estimated abundance of immature Chinook salmon was in summer 2003 (~21 million North American and ~20 million Asian fish) was extraordinarily high compared to adult returns to Asia and North America in 2004–2006. Bugaev and Myers (2009a) concluded that BASIS stock assessment methods likely overestimated the abundance of this species. Nevertheless, this study provided the first quantitative evidence of the extensive distribution of young, immature Chinook salmon of Western Alaska origin in the western Bering Sea in summer and fall. Bugaev and Myers (2009a) concluded that the western Bering Sea ecosystem is an important summer–fall foraging area for immature Chinook salmon of both Asian and North American origin.

Scale pattern analysis could not be used to estimate freshwater age composition or stock composition of juvenile salmon (ocean age-0) in the Russian EEZ because of scale loss during BASIS trawl fishing operations. Juvenile Chinook salmon in summer–fall BASIS catches in the western Bering Sea were likely of Asian origin, however, similarities in 1st-ocean year scale patterns of adult salmon of known origin indicated possible intermixing of Kamchatka and western Alaska stocks during their first ocean year (Bugaev and Myers 2009a). This issue may be resolved by future genetic (DNA) stock identification analyses of juvenile Chinook salmon collected in the northern Bering Sea and the Chukchi Sea in summer–fall (Bugaev and Myers 2009a).

Horizontal Distribution from Genetic Stock Identification

Genetic diversity of northern populations of Chinook salmon is low compared to southern populations (Martin et al. 2010), and to date this has somewhat limited the effectiveness of genetic methods for identification of AYK Chinook salmon stocks in ocean mixture samples. Murphy et al. (2009) estimated the distribution and genetic stock composition of juvenile (age-0) Chinook salmon caught during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf in mid August–early October 2002–2007. The genetic (42 single nucleotide polymorphism markers) baseline used in this study included stocks only from eastern Bering Sea rivers. Four stock groups were identified: (1) Middle Yukon, (2) Upper Yukon, (3) Other, i.e., upper Kuskokwim and North Alaska Peninsula, and (4) Coastal, i.e., lower Yukon river and all other eastern Bering stocks. Juvenile Chinook salmon were caught primarily in shallow water habitats (< 50 m bottom depth, Fig. 2-24). Upper and middle Yukon stocks were distributed primarily on the northern shelf (north of 60°N, Fig. 2-24), indicating limited mixing of stocks from northern- and southern-production regions during their first summer–fall at sea (Murphy et al. 2009).

Genetic methods have also been used to estimate the stock composition of Chinook salmon in the salmon bycatch of the BSAI pollock fishery (NPFMC 2008, 2009). Despite differences in sample years analyzed, both genetic and scale pattern techniques have provided similar estimates of the proportions of western Alaska, including Canadian Yukon, Chinook salmon in the BSAI bycatch (54–60%).

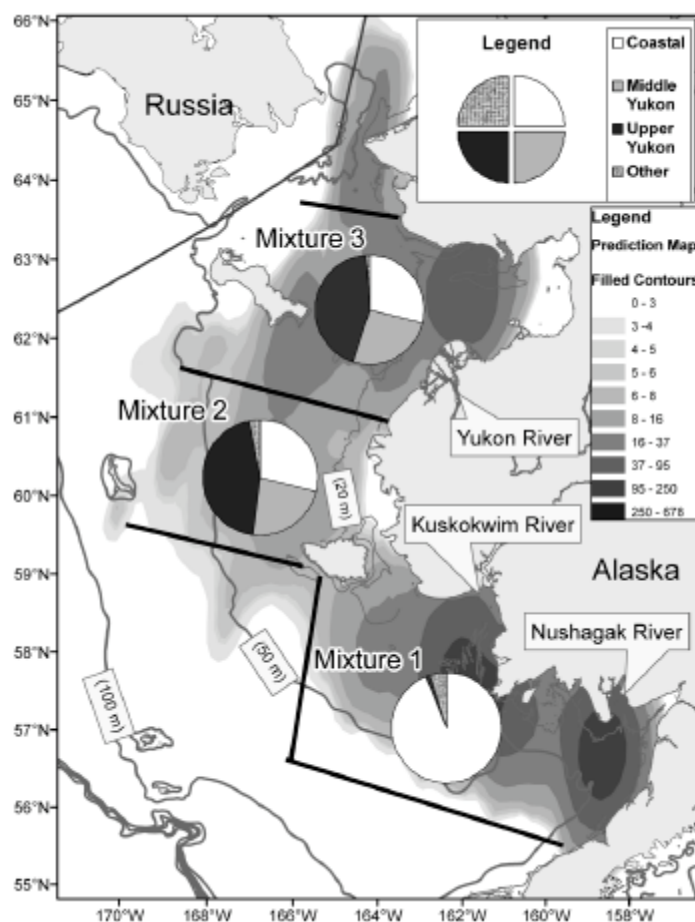


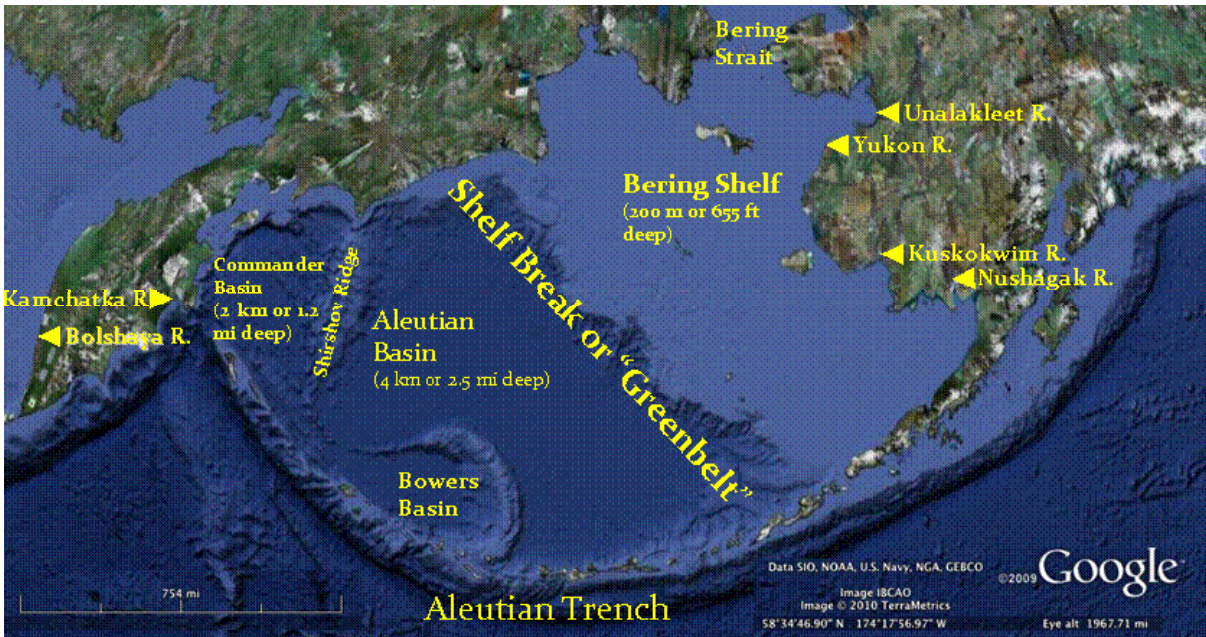
Figure 2- 24. Estimated genetic stock composition of mixtures of juvenile Chinook salmon caught during U.S. BASIS trawl surveys in the eastern Bering Sea (mid August-early October, 2002-2006). (Source: Murphy et al. 2009; the shading represents estimated catch per unit effort of juvenile Chinook salmon on the eastern Bering Sea shelf during the survey period. Bottom depths shallower than 20 m could not be sampled by surface rope trawl (average 14 m vertical opening), and salmon distribution in these habitats was estimated by kriging models. The 50-m and 100-m bottom depth contours are labeled. Four stock groups were identified: coastal, middle Yukon, Upper Yukon, Other).

Conceptual Model of Distribution and Migration of AYK Chinook Salmon in the Bering Sea

We developed a simple conceptual model that identified four major life stage-specific spatiotemporal patterns in distribution and migration of AYK Chinook salmon that may influence their response to climate-ocean conditions and marine fisheries in the Bering Sea (Figure 2-25):

1. During the 1st summer-fall at sea, juvenile (ocean age-0) AYK Chinook salmon are distributed primarily in waters over the eastern Bering Sea shelf (<200 m).
2. During winter, all age/maturity groups AYK Chinook salmon are distributed south of the ice edge in surface layers (0-525 m) in the vicinity of the continental slope/shelf break in the Bering Sea and Aleutian Islands (BSAI), as indicated by salmon bycatch in the winter BSAI pollock fishery (NPFMC 2008, 2009). The general pattern of seasonal movement in winter is southeastward.

A



B

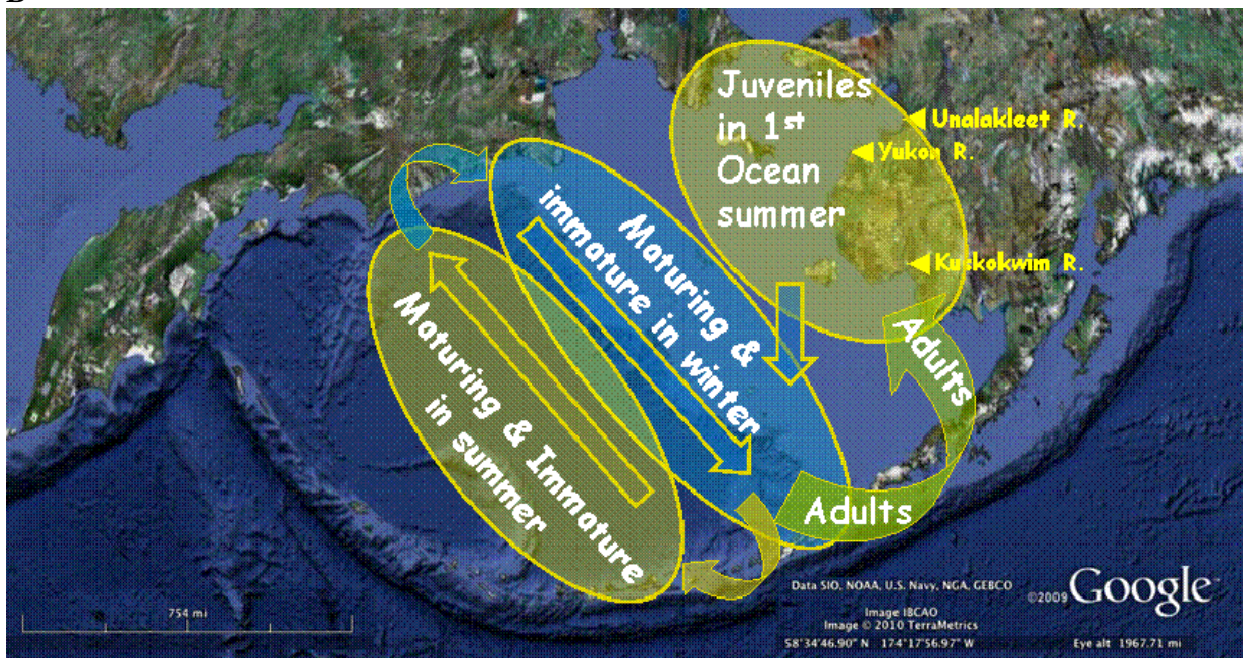


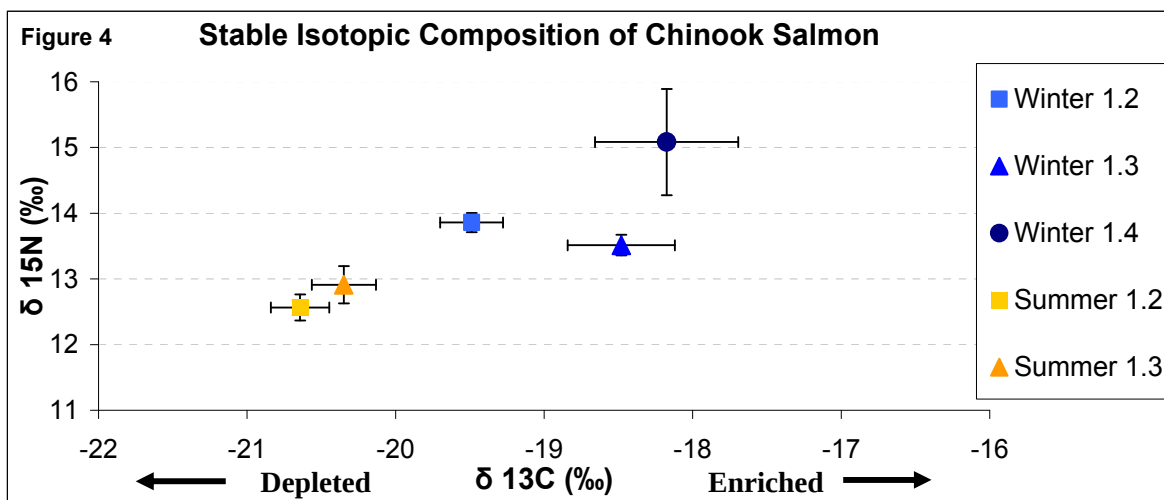
Figure 2- 25. Conceptual model of ocean distribution and migration of AYK Chinook Salmon. (A) Map of Bering Sea showing location of major Chinook salmon-producing river in Kamchatka, Russia, and Western Alaska, and major bathymetric features. (B) Conceptual model of ocean distribution and migration of AYK Chinook Salmon (see text for explanation).

3. During summer, all age groups of immature and maturing AYK Chinook salmon are distributed in productive surface layers (epipelagic habitat) over the deep Aleutian Basin in the central and western Bering Sea. The general pattern of seasonal movement in summer is northwestward.
4. In their last winter and spring in the ocean, maturing AYK Chinook salmon return to coastal (shelf) habitats before entering their home streams.

Seasonal and Age-Specific Distribution from Stable Isotope Analysis

Stable isotope analysis results support our general seasonal migration model for Chinook salmon in the Bering Sea (Fig. 2-26). Depleted levels of $\delta^{13}\text{C}$ in summer indicate that fish were feeding in pelagic (basin) habitats, while enriched levels of $\delta^{13}\text{C}$ in winter indicate feeding in neritic (shelf/slope) habitats. There also appears to be trend for older fish to be more enriched in carbon within each season, suggesting a closer proximity to the coast. Further investigation is required to explain the nitrogen enrichment in the winter, indicative of elevated trophic level feeding during that season.

Figure 2- 26. Mean ($\pm$ SE) stable isotope ratios of age 1.2, 1.3, and 1.4 Chinook salmon muscle tissue during winter and summer in the Bering Sea.



Results: Objective 3 - Reconstruct Histories of Ocean Age, Growth, and Size-Selective Mortality

We reconstructed histories of ocean age, growth, and potential size-selective mortality of Chinook salmon using age and body length at time of capture and measurements of seasonal and annual growth increments on scales. Three primary sources of Chinook salmon scale samples were used in this analysis: (1) winter samples collected by the NOAA Fisheries Observer (OBS) Program from the Chinook salmon bycatch of the U.S. pollock trawl fishery in the eastern Bering Sea in 1997-2008 (ages 1.2, 1.3, and 1.4, $n=1,837$ Chinook salmon); (2) summer samples collected during salmon surveys of the Japanese research vessel *Wakatake maru* (WAK) in the central Bering Sea region in 1991-2009 (age 1.2, $n=573$ Chinook salmon); and an existing time series (1964-2004) of adult Yukon (YUK) and Kuskokwim (KUS) Chinook (ages 1.3 and 1.4; Ruggerone et al. 2007, 2009a,b). We extended the YUK time series to include ages 1.3 and 1.4 females caught in 2005-2009 ($n=267$ fish). In general, the time series of BASIS samples (Russian and U.S.) were too short for use in our analyses.

Relationships of Scale Radius, Fork Length, and Body Weight

Scale size of OBS Chinook salmon was positively correlated to fish body length (Corr. Coefs. = 0.543, 0.469 and 0.535 for ages 1.2, 1.3 and 1.4, respectively). Regressions of total scale size on fish body length for all three age groups showed significant relationships in 86% of age/year groups. No common patterns were discerned for instances in which fish body length was not highly correlated to total scale size, including age 1.2 and 1.3 fish collected in 1997, age 1.3 from 2003, and age 1.4 fish from both 2005 and 2007.

All mixed-stock ocean scale measurement data and associated biological data were used to develop simple linear regression models that can be used to estimate tip-of snout-to-fork (SNF) length from scale radius and body weight from fork length (Figs. 3-5 and 3-6).

Trends in Body Lengths and Scale Size

The OBS Chinook data were grouped by age of fish (1.2, 1.3 and 1.4) with sexes combined (Fig. 3-7), and normalized SNF lengths (mm) were plotted by last growth year at sea. Normalized fork lengths attained by the end of the growth year did not appear to show a consistent odd-even year pattern for any of the ages sampled nor did mean lengths of younger, age 1.2s, appear to be correlated with older ages within the same growth year. Sizes of ages 1.3 and 1.4 fish were highly correlated (Table 3-5.; corr. coef. = 0.70) and exhibited similar size fluctuations during the 12-year period with above average sizes before the 1997 El Niño, a period of smaller sizes between 1998-2001, above average sizes during the warm period from 2002-2004, and below average sizes in the last period (2005-2007).

Mean lengths of OBS Chinook salmon in January-March were always significantly less than mean lengths of YUK and KUS fish in June-July for both age 1.3 and 1.4 males and females (Figs. 3-8 and 3-9; ANOVA, $p<0.0001$). For male age 1.3 fish (Fig. 3-10), single-factor ANOVAs showed no significant differences ($p>0.05$) in mean total scale size at SW3 in OBS, YUK, and KUS Chinook samples (1997-2004). In contrast, scale sizes of female age 1.3 OBS fish (Fig. 3-10) were significantly smaller than YUK ($p<0.05$) and KUS (not significantly different, $p>0.05$) Chinook. For age 1.4 males (Fig. 3-11), mean total scale sizes at SW4 of OBS and KUS Chinook were not significantly different ($p<0.05$) and both were significantly larger than Yukon fish ($p<0.01$). For age 1.4 females (Fig. 3-11), KUS fish were significantly larger than YUK fish ($p>0.01$), and OBS fish were significantly smaller than KUS fish ($p<0.05$) and significantly larger than YUK fish ($p>0.01$). We assume that most age 1.4 OBS fish would have matured in the year that they were caught, whereas age 1.3 OBS fish, particularly females, may be more likely to include a mix of immature and maturing fish. Statistically significant differences among the groups may reflect differences in maturity schedules or size-selective fishing mortality or both.

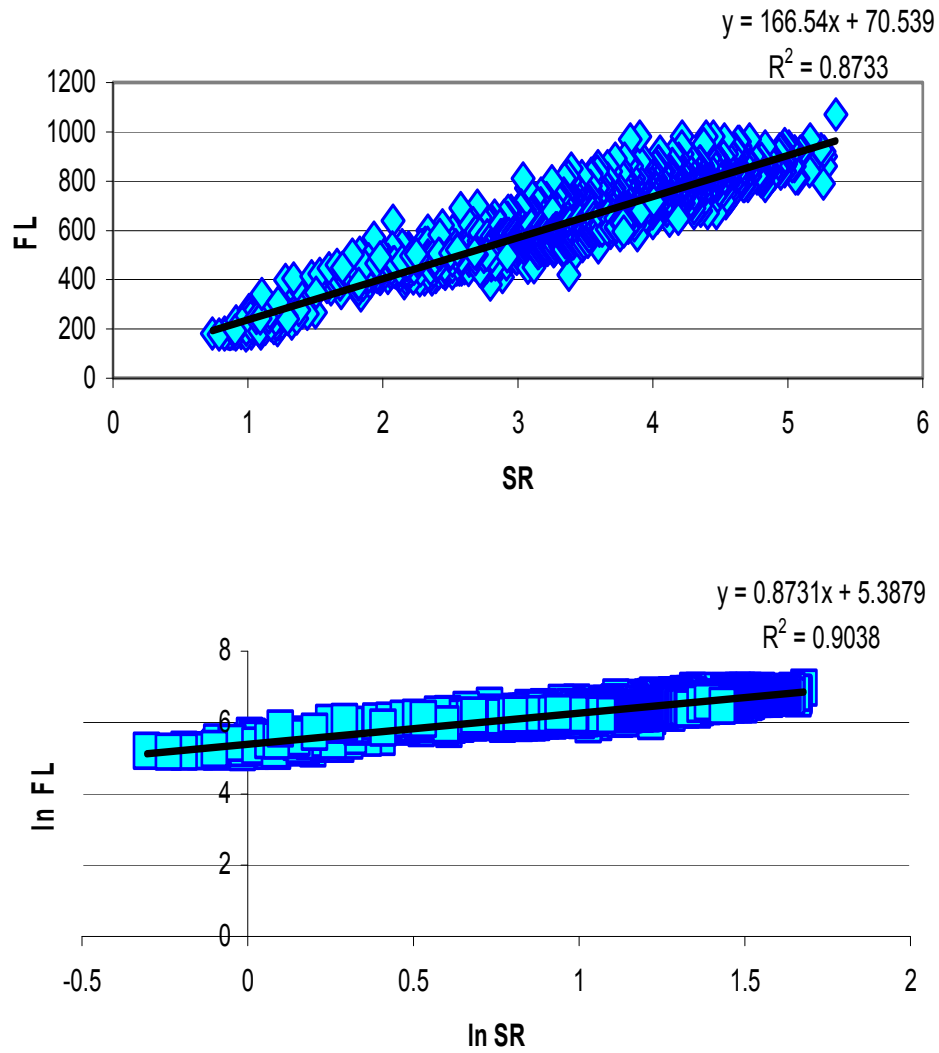


Figure 3- 5. Tip-of-snout-to-fork-of-tail length (FL, mm) as a function of scale radius (SR, mm) (top panel) and natural log transformation (bottom panel). SR was measured from the center of the scale focus to the edge of the scale along the longest axis.

I

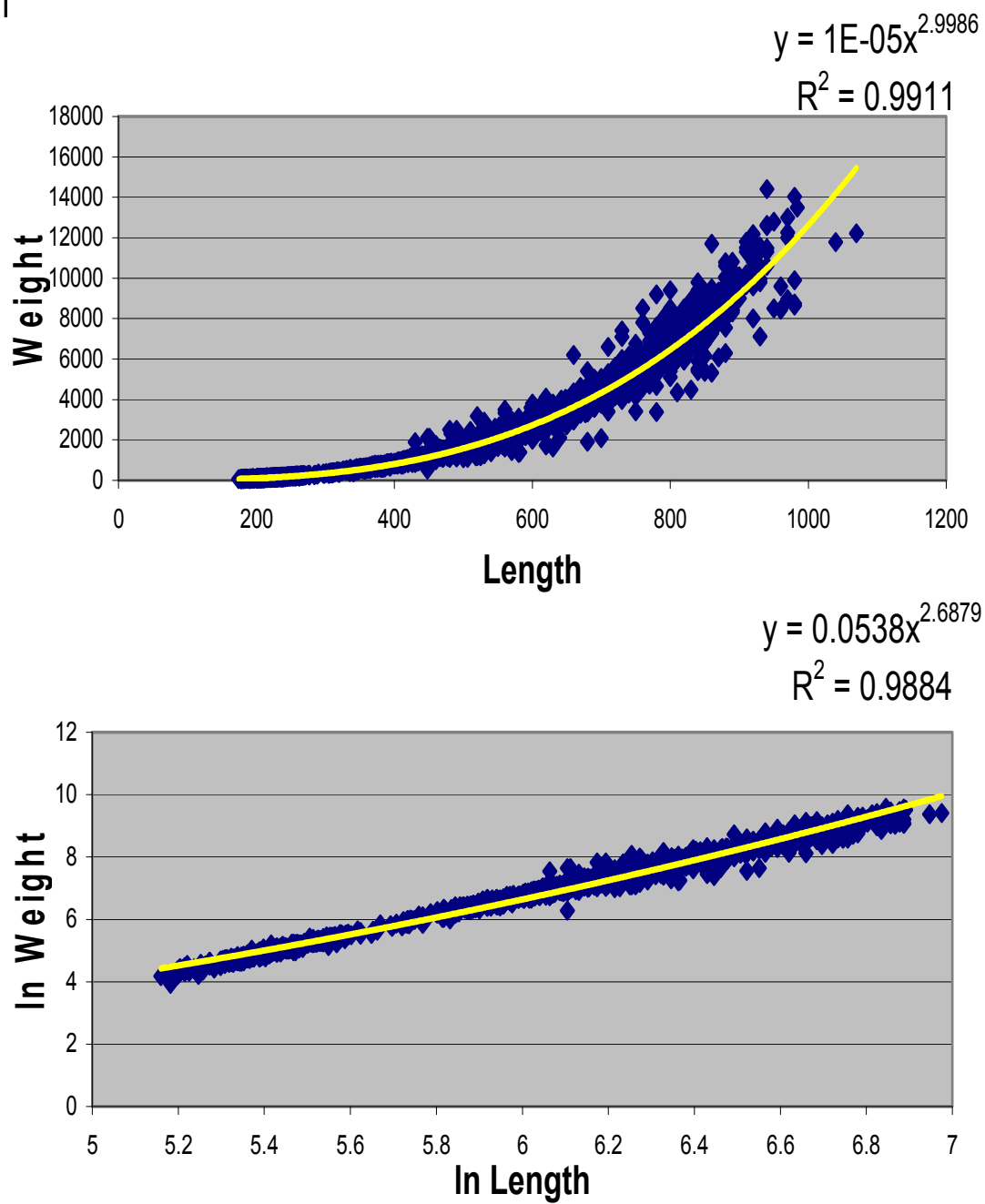


Figure 3- 6. Body weight (g) of Bering Sea Chinook salmon as a function of tip-of-snout-to-fork-of-tail length (mm; top panel) and natural log (ln) transformation (bottom panel).

Table 3- 5. Correlation between normalized mean tip-of-snout-to fork-of-tail lengths of ages 1.2, 1.3, and 1.4 OBS Chinook salmon.

Age	1.2	1.3	1.4
1.2	1		
1.3	0.0813	1	
1.4	0.1658	0.7050	1

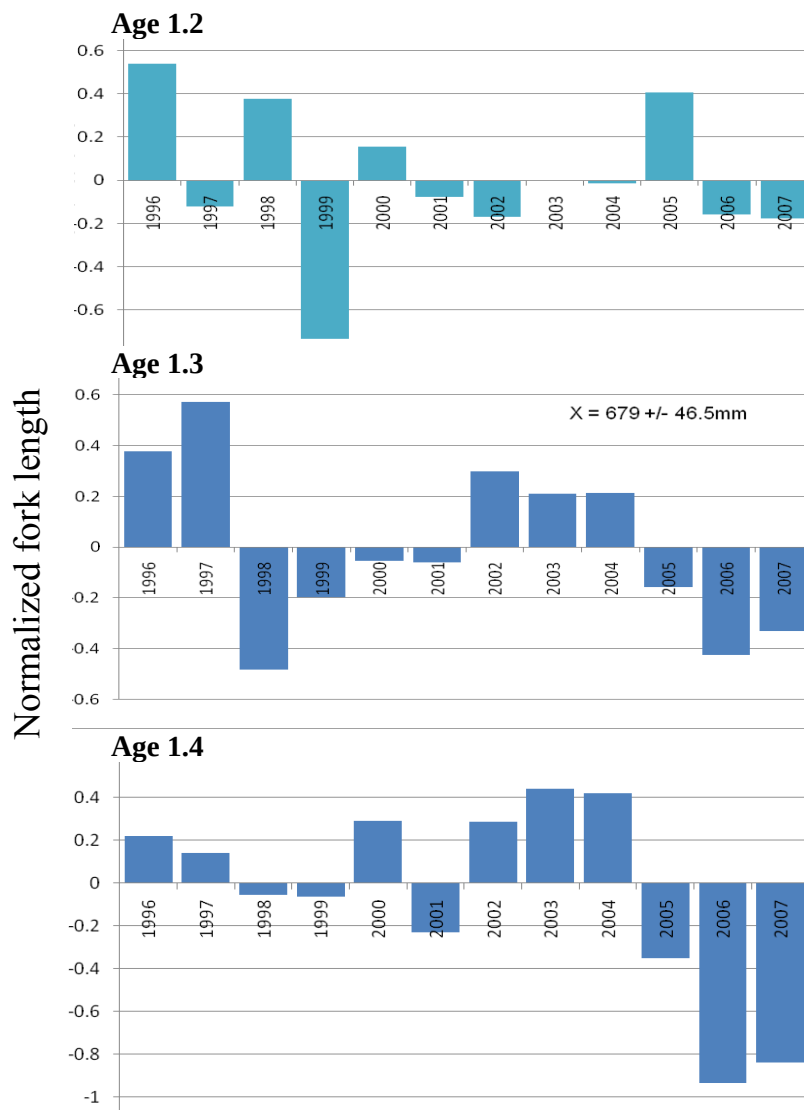


Figure 3- 7. Normalized fork lengths (tip-of-snout-to-fork-of-tail) of ages 1.2 (top panel), 1.3 (center panel), and 1.4 (bottom panel) of OBS Chinook (males and females combined) for growth years 1996-2007.

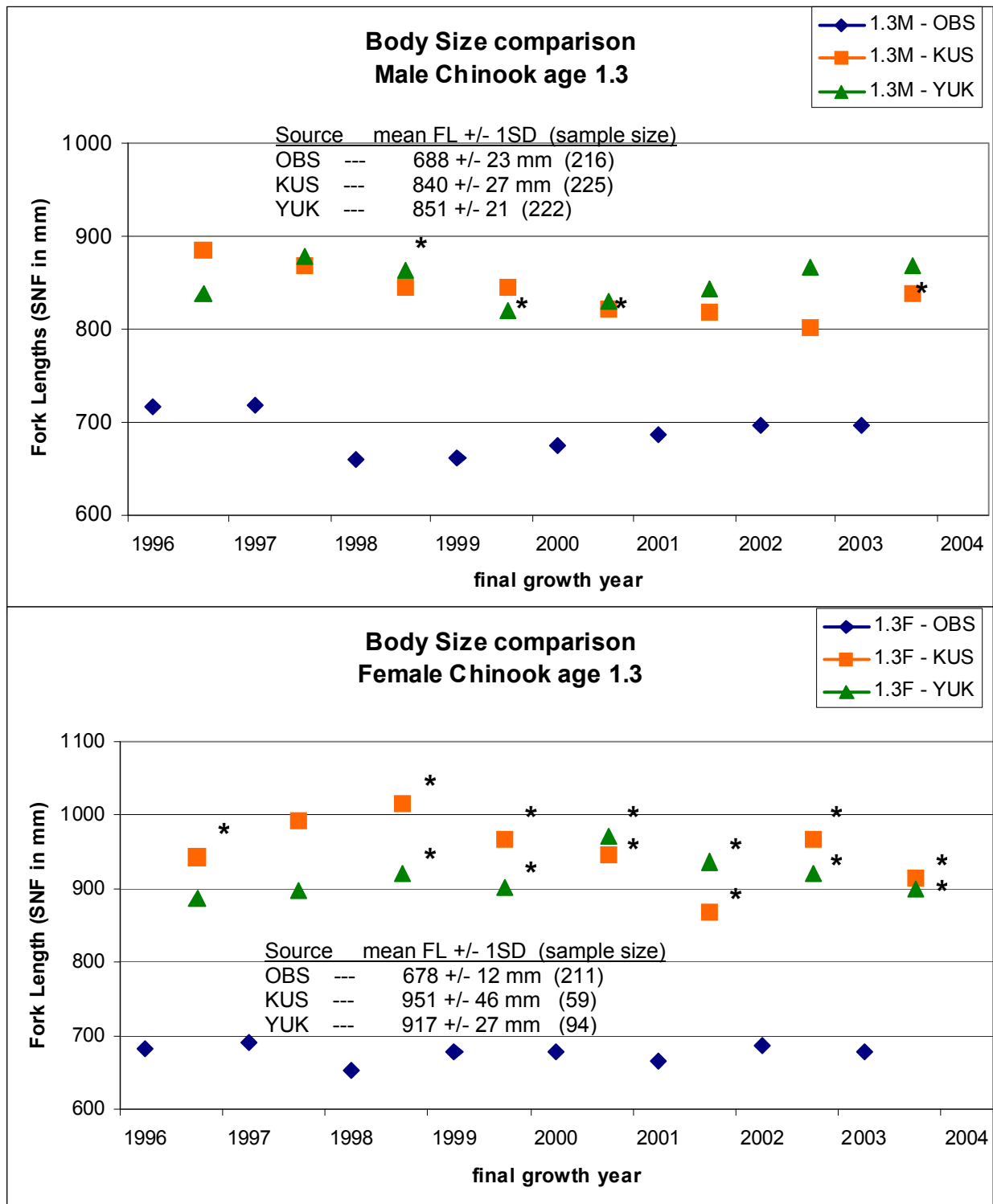


Figure 3- 8. Comparison of tip-of-snout-to-fork-of-tail (FL) lengths of age 1.3 male (upper panel) and female (lower panel) Chinook salmon in winter (January-March) NOAA Fisheries Observer (OBS) Program samples from the eastern Bering Sea pollock trawl fishery and summer (June-July) gillnet test fishery samples from the Yukon (YUK) and Kuskokwim (KUS) rivers (Ruggerone et al. 2007). * = sample sizes <20 fish.

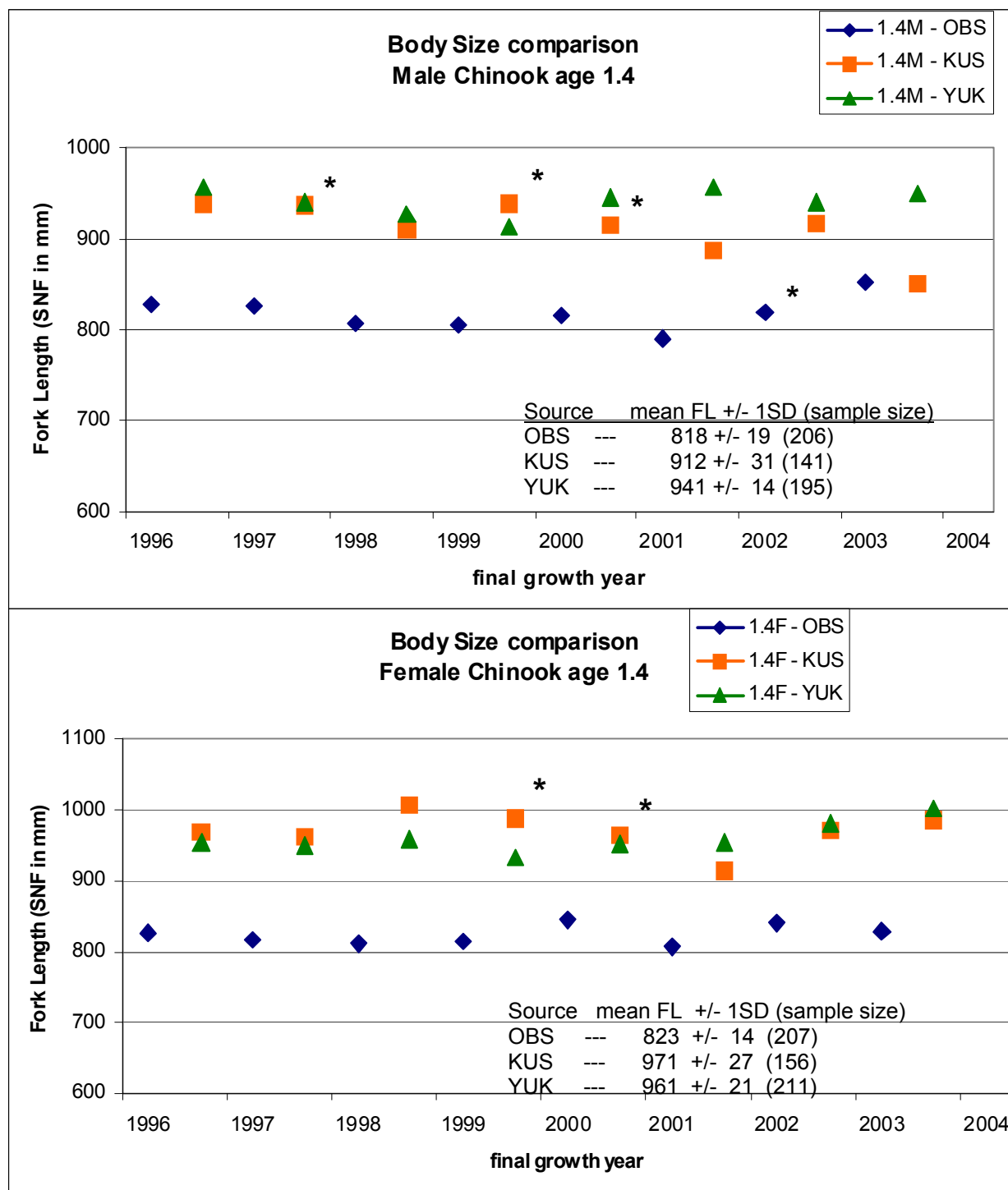


Figure 3- 9. Comparison of tip-of-snout-to-fork-of-tail (FL, mm) lengths of age 1.4 male (upper panel) and female (lower panel) Chinook salmon in winter (January-March) NOAA Fisheries Observer (OBS) Program samples from the eastern Bering Sea pollock trawl fishery and summer (June-July) gillnet test fishery samples from the Yukon (YUK) and Kuskokwim (KUS) rivers (Ruggerone et al. 2007). * = sample sizes <20 fish.

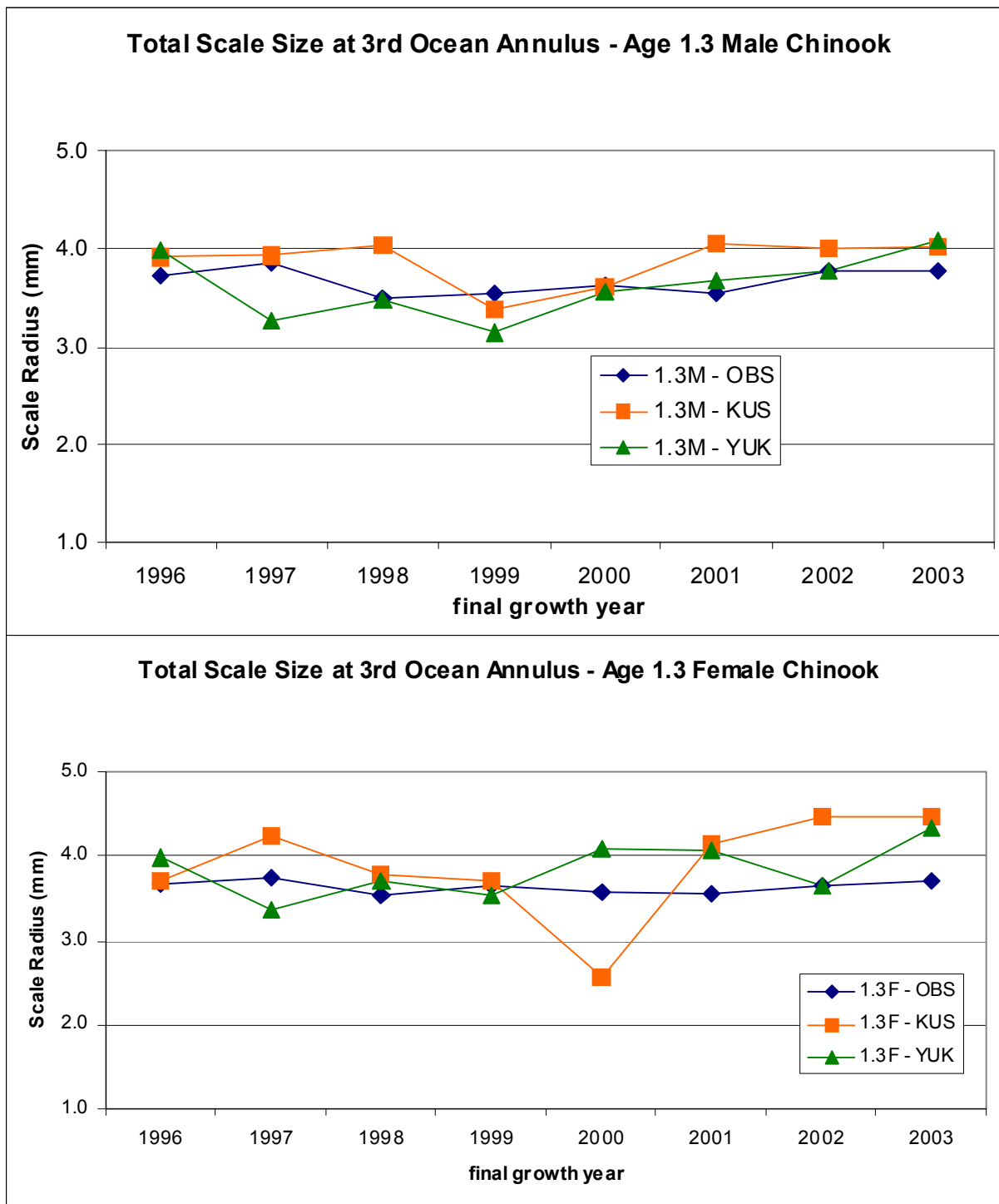


Figure 3- 10. Comparison of mean total scale radius (mm) through the end of the 3rd ocean annulus on the scales of age 1.3 male (upper panel) and female (lower panel) Chinook salmon in winter (January-March) NOAA Fisheries Observer (OBS) Program samples from the eastern Bering Sea pollock trawl fishery and summer (June-July) gillnet test fishery samples from the Yukon (YUK) and Kuskokwim (KUS) rivers (Ruggerone et al. 2007). * = sample sizes <20 fish.

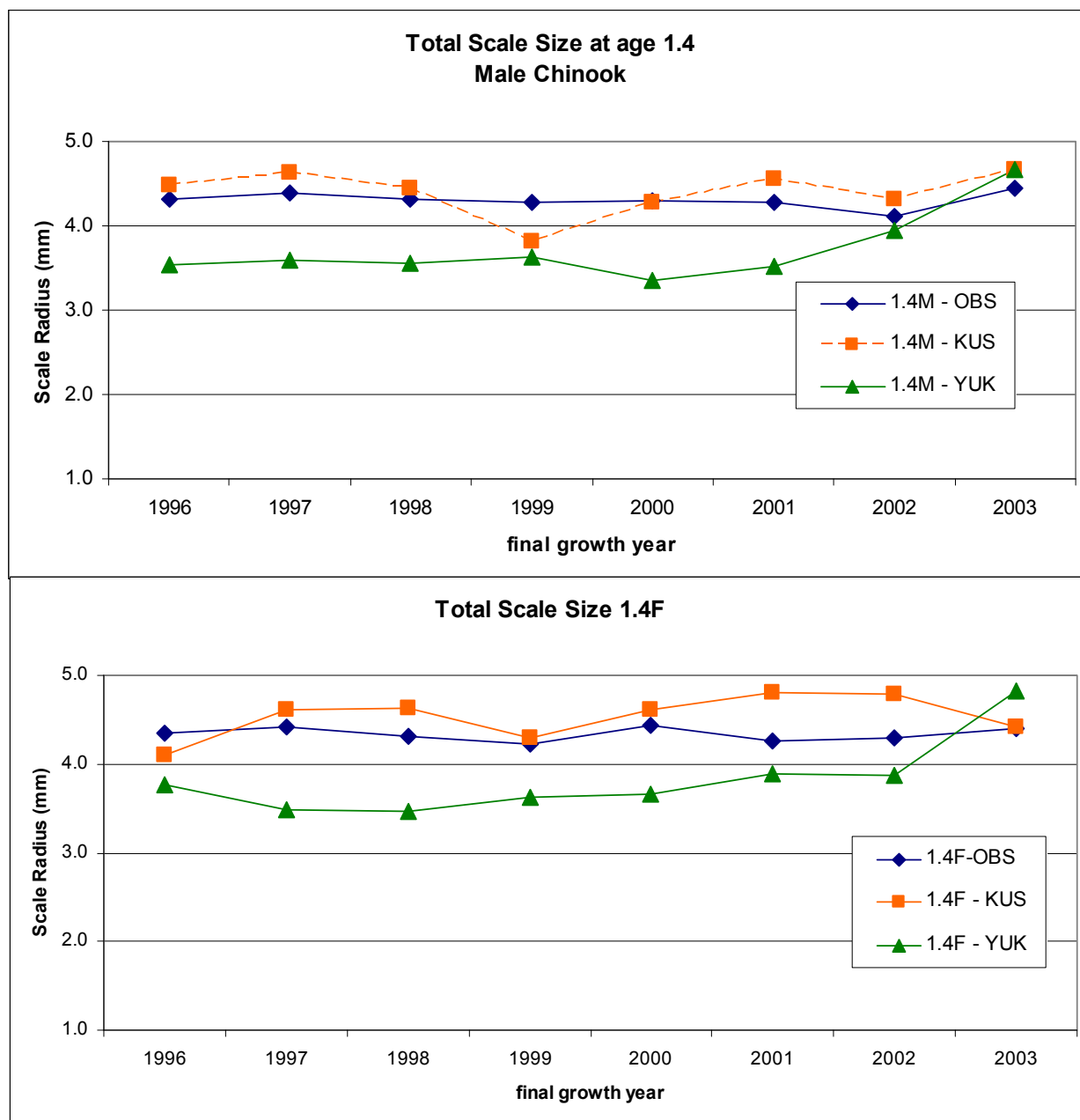


Figure 3- 11. Comparison of mean total scale radius (mm) through the end of the 4th ocean annulus on the scales of age 1.4 male (upper panel) and female (lower panel) Chinook salmon in winter (January-March) NOAA Fisheries Observer (OBS) Program samples from the eastern Bering Sea pollock trawl fishery and summer (June-July) gillnet test fishery samples from the Yukon (YUK) and Kuskokwim (KUS) rivers (Ruggerone et al. 2007). * = sample sizes <20 fish.

Because significant size differences were not consistently found between OBS males and females, data for both sexes of OBS Chinook were combined. Normalized growth values were calculated, plotted and compared for life stages FW1 through SW4 for each age group lagged to year of growth (Figs. 3-12 – 3-14). During the FW1 stage there was a distinct change between 1996 and 1997 from years of positive to negative mean growth demonstrated by all 3 age groups, 1.2, 1.3 and 1.4 of OBS Chinook. Growth in the first year, SW1, at sea did not show any consistent patterns across the various age groups. For ages 1.3 and 1.4 fish, SW2, SW3, and SW4 growth trends were lower than average during the 1997-1999 El Niño-Southern Oscillation (ENSO), followed by a few years (2000-2004) of better than average growth and another lower growth phase during the last years, 2005 – 2007. In contrast, ages 1.3 and 1.4 YUK female Chinook exhibited a consistent pattern of below average growth in the early years with a dramatic shift to above average growth that began in 1999 or 2000 with the freshwater zone and progressed through subsequent ocean life stages with a one year lag per life stage (Figs. 3-15 and 3-16).

The freshwater growth patterns of age 1.2 WAK Chinook were relatively similar to YUK Chinook and nearly the opposite of age 1.2 OBS Chinook salmon, including a distinct shift in 1997 from years of below average growth to years of above average growth (Fig. 3-17). Growth of WAK Chinook in the first ocean year showed a relatively strong alternating year pattern. Growth anomalies (negative or positive) were usually larger in odd-numbered years than in even-numbered years. There was a strong pattern of positive growth anomalies in odd-numbered years during the period from 1991-1997. Growth in the second ocean year also exhibited an alternating-year pattern in the first half of the 1990s, but the odd-year positive anomalies were not as strong as in the first ocean year. In contrast to the strong positive 1st-year growth anomaly in 1997, 2nd-year growth anomalies were negative over the entire 1997-1999 ENSO cycle. Growth in the second ocean year shifted to a positive phase in 2002, similar to age 1.3 YUK Chinook. The largest positive growth anomaly in the 2nd-year growth time series occurred during the “warm” ocean year of 2003. Partial growth in the third ocean growth year also shifted to a positive growth phase in 2002, similar to age 1.4 YUK Chinook. However, the positive growth phase ended in 2007 with a very strong negative growth anomaly.

Dependence of Annual Growth on Previous Years’ Growth

Average annular growth increments (expressed in mm) of OBS Chinook salmon unlagged and then lagged to actual year of growth are plotted in Figure 3-18 (unlagged values, age 1.2 to 1.4 – sexes combined) and Figure 3-19 (lagged values, age 1.2 to 1.4 – sexes combined). For ages 1.2 and 1.3 OBS Chinook, growth in SW2 was not in phase and was highly negatively correlated (corr. coef. -0.837 and -0.455) with growth in SW1 but positively correlated to FW1 (Table 3-6), indicating that growth was not strongly dependent on the initial size of the fish when it first entered the ocean. Growth in SW3 was not as strongly correlated with either the previous ocean zones. For age 1.4 OBS Chinook growth in SW2 was not in phase and was negatively correlated with SW4, whereas SW3 was in phase and positively correlated with SW4, indicating dependence on ocean conditions for growth. When annual increment growth values were lagged to the actual year of growth, age 1.2 growth in SW2 was in phase and positively correlated (corr. coef. 0.314) with growth in SW1 only for age 1.2, indicating dependence on ocean conditions (Table 3-7). For age 1.3, growth in SW2 was not in phase and negatively correlated with growth in SW1 but in phase and highly positively correlated with growth in SW3 (corr. coef. 0.769), again indicating dependence on ocean conditions. Strong positive correlations between SW2, SW3 and SW4 for age 1.4 fish implies that marine growth was dependent on ocean conditions rather than initial fish size. A decrease in amount of SW1 and SW2 growth after the 1997/1998 El Niño is evident in 1999 for all three age groups (Figure 3-19).



Figure 3- 12. Normalized annual scale growth increments by life stage of age 1.2 OBS Chinook (males and females combined). Life stages: freshwater (FW1), 1st ocean (SW1), and 2nd ocean (SW2).

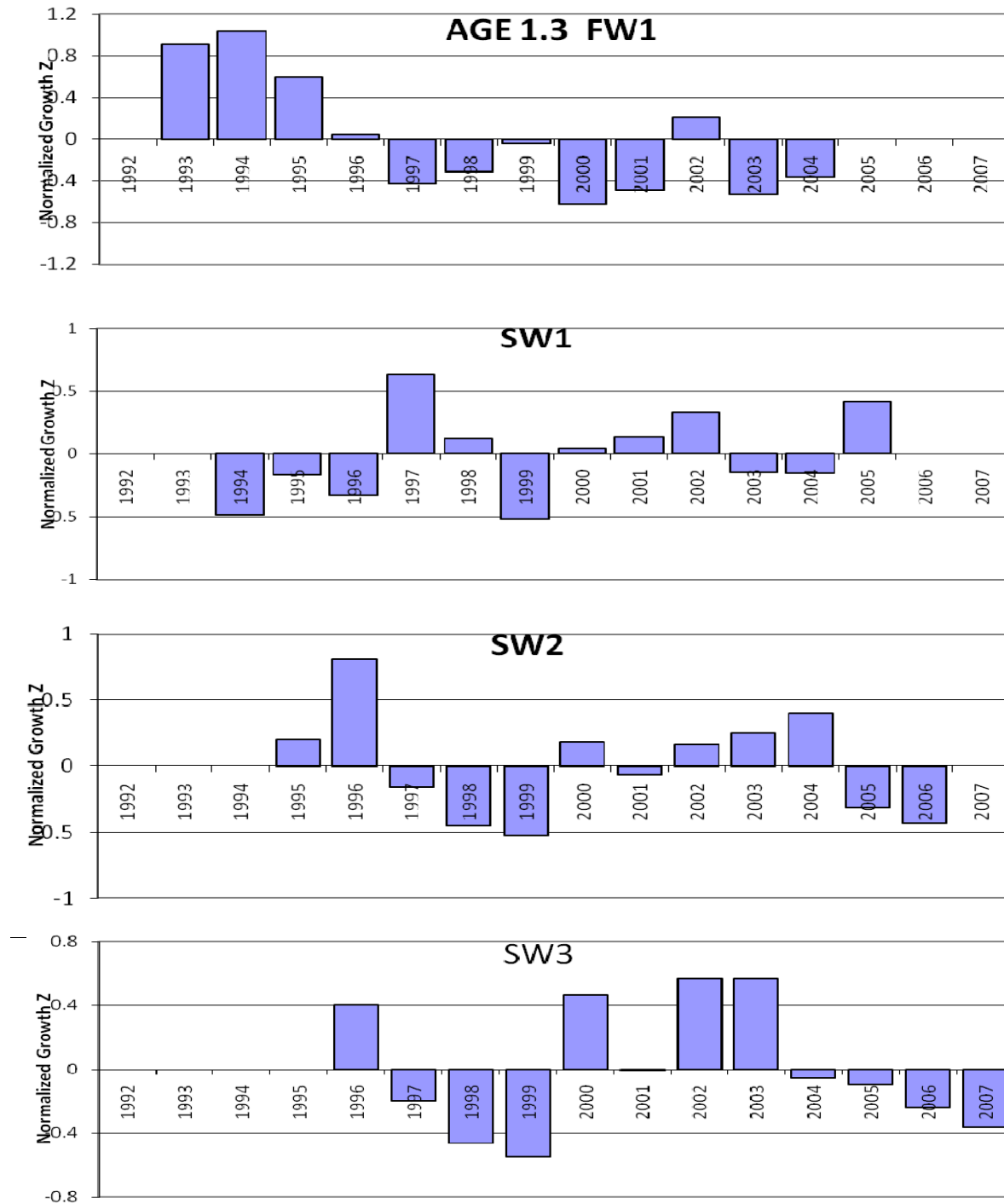


Figure 3- 13. Normalized annual scale growth increments by life stage of age 1.3 OBS Chinook (males and females combined). Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), and 3rd ocean (SW3).

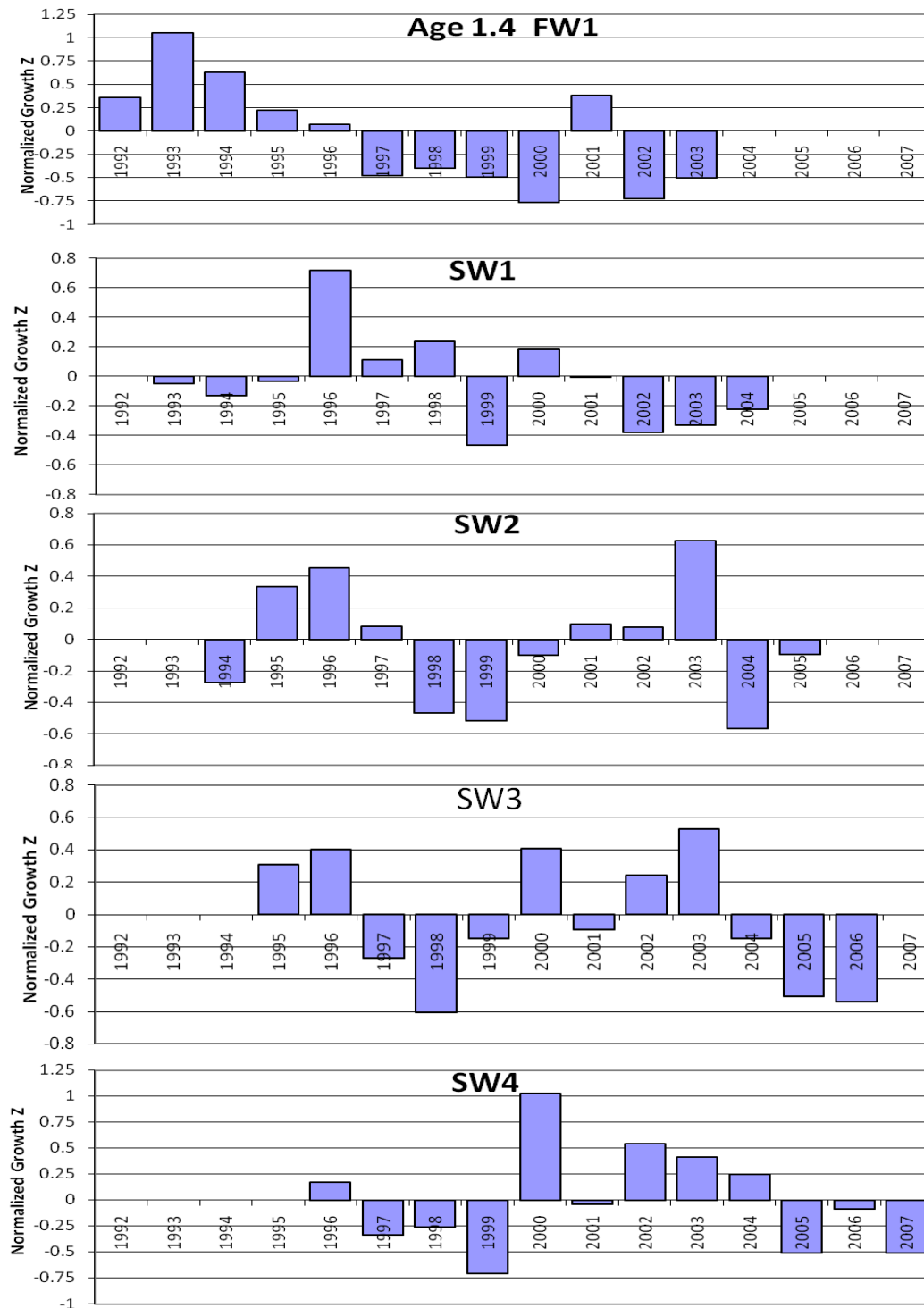


Figure 3- 14. Normalized annual scale growth increments by life stage of age 1.4 OBS Chinook (males and females combined). Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3), and 4th ocean zones (SW4).

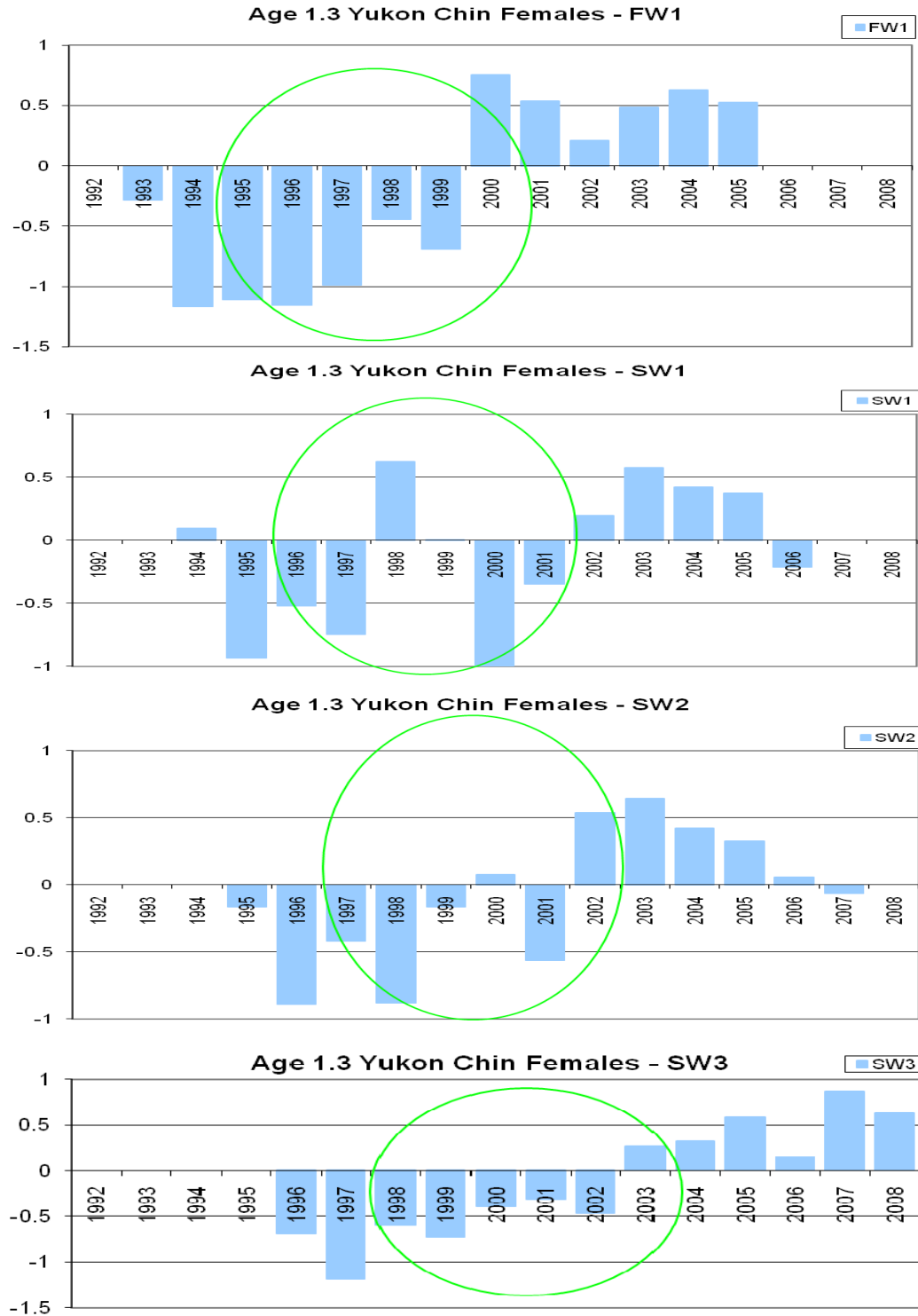


Figure 3- 15. Normalized annual scale growth increments by life stage for age 1.3 Yukon female Chinook salmon lagged to year of growth. Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), and 3rd ocean (SW3). Green circled years indicate shift from negative to positive growth phase.

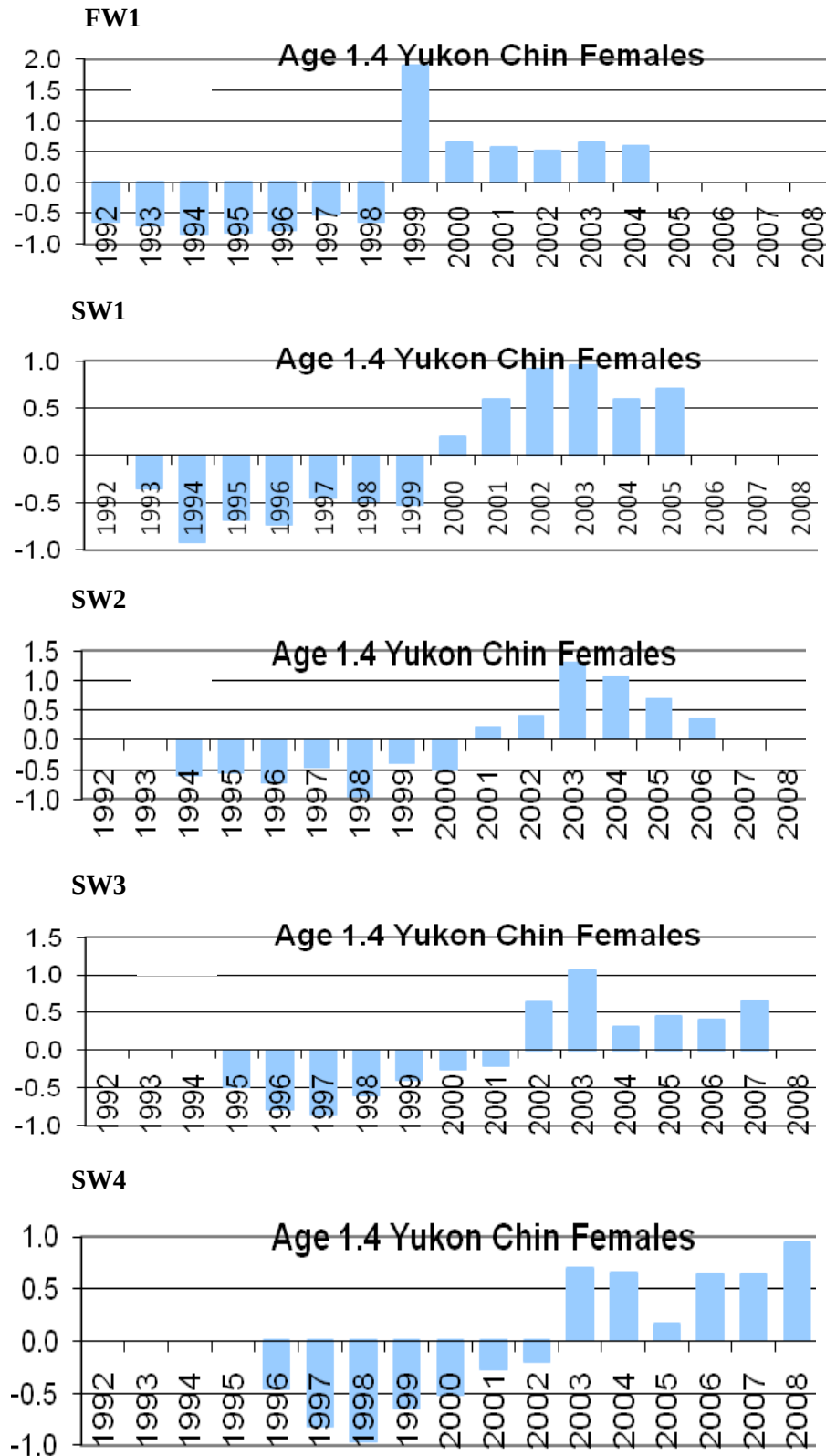


Figure 3- 16. Normalized annual scale growth increments by life stage for age 1.4 Yukon female Chinook salmon lagged to year of growth. Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3), and 4th ocean zones (SW4).

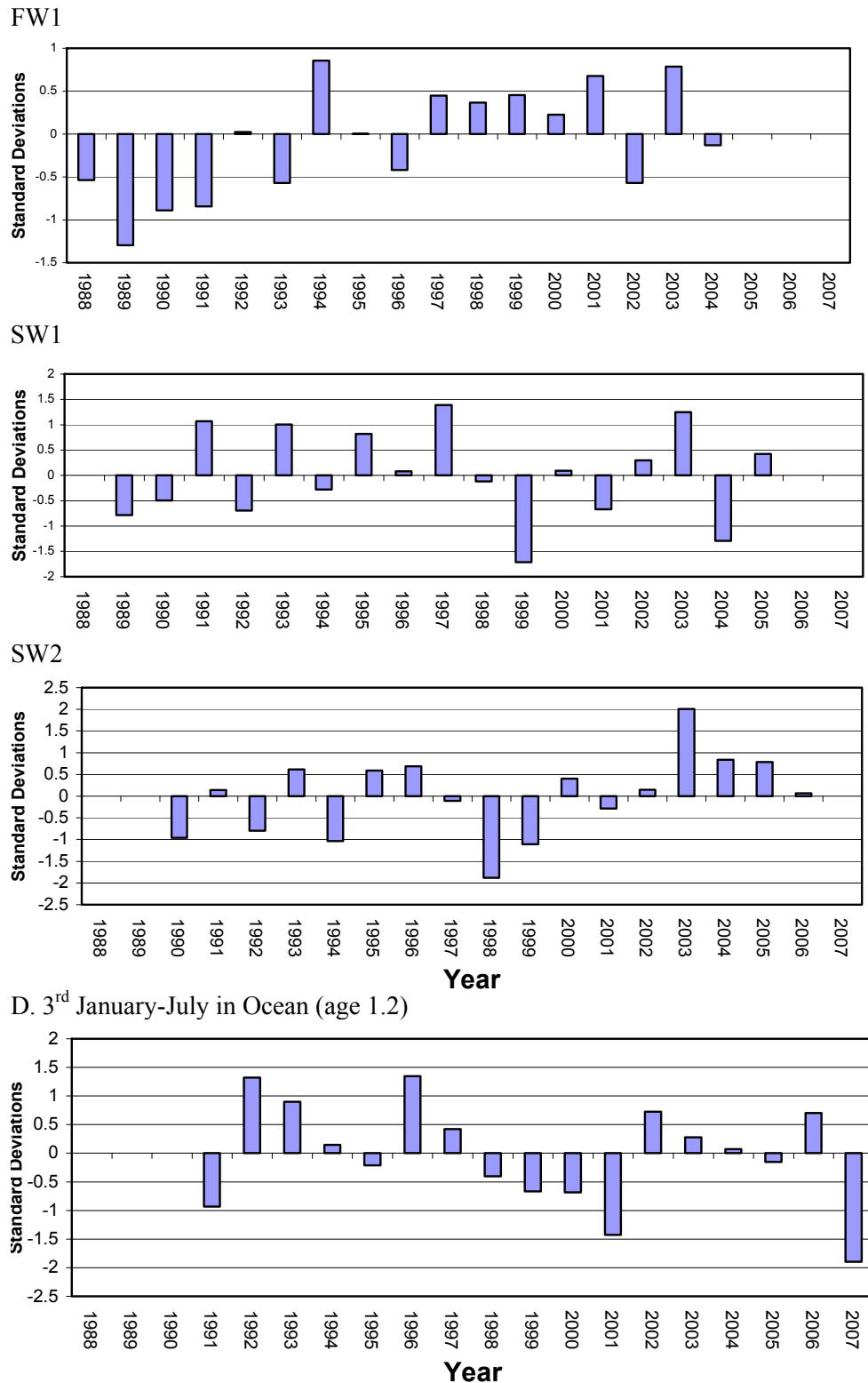


Figure 3- 17. Normalized annual scale growth increments by life stage, lagged to year of growth, for age 1.2 Chinook salmon (males and females combined) in *Wakatake maru* (WAK) samples from the central Bering Sea in July 1991-2007. Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), and plus growth in January-July of the 3rd ocean year (SWPL).

Table 3- 6. Correlations between scale growth by life stage and previous scale-growth increment for each age group of OBS Chinook salmon all years combined (data unlagged to actual year of growth). Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3), 4th ocean zones (SW4), Total Scale Size = TSS. Significant correlations are highlighted in yellow.

Age 1.2						
	<i>FW1</i>	<i>SW1</i>	<i>SW2</i>	<i>TSS</i>		
FW1	1					
SW1	-0.561	1				
SW2	0.727	-0.837	1			
TSS	0.844	-0.501	0.871	1		

Age 1.3					
	<i>FW1</i>	<i>SW1</i>	<i>SW2</i>	<i>SW3</i>	<i>TSS</i>
FW1	1				
SW1	-0.453	1			
SW2	0.498	-0.455	1		
SW3	-0.176	-0.196	0.132	1	
TSS	0.325	0.080	0.712	0.473	1

Age 1.4						
	<i>FW1</i>	<i>SW1</i>	<i>SW2</i>	<i>SW3</i>	<i>SW4</i>	<i>TSS</i>
FW1	1					
SW1	0.076	1				
SW2	0.557	-0.100	1			
SW3	0.037	0.003	0.026	1		
SW4	-0.309	-0.110	-0.476	0.364	1	
TSS	0.411	0.388	0.326	0.704	0.378	1

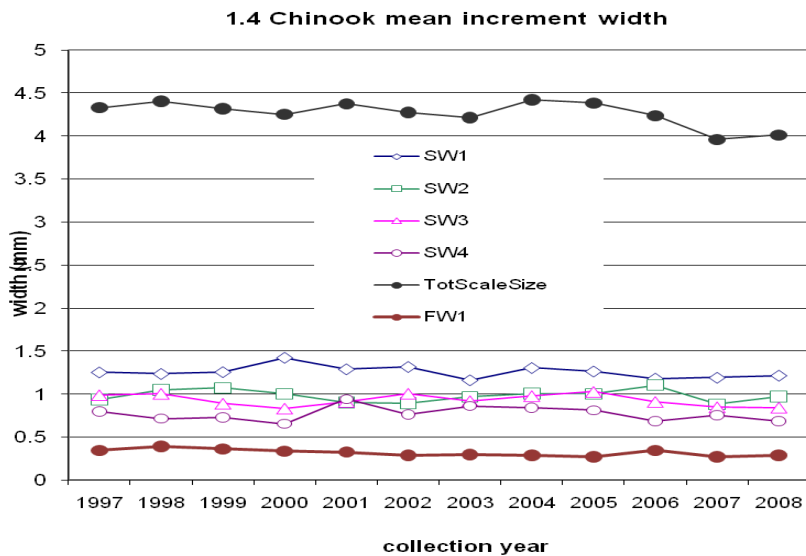
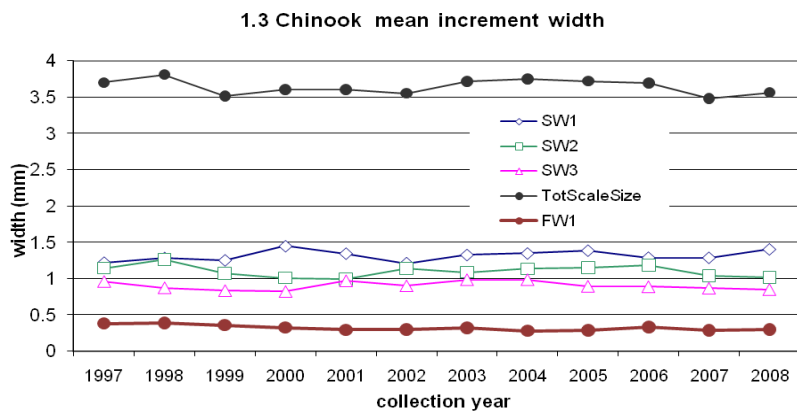
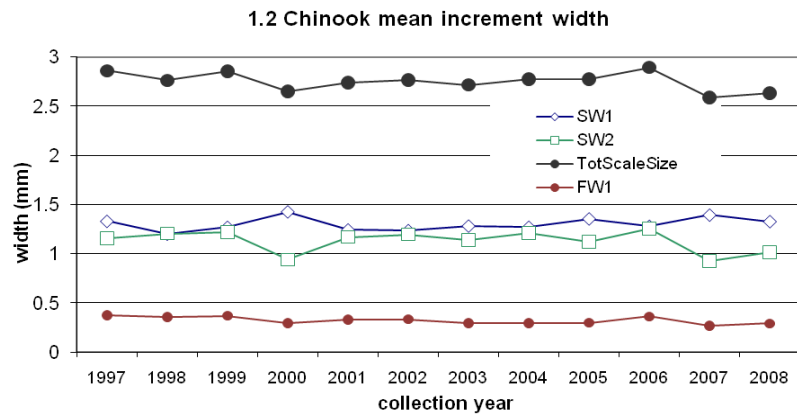


Figure 3- 18. Mean scale growth increment widths (in mm) by life stage for age 1.2, 1.3 and 1.4 OBS Chinook by collection year (values unlagged to actual year of growth, males and females combined). Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3) and 4th Ocean zones (SW4).

Table 3- 7. Correlations between scale growth by life stage and previous increment growth for each age group of OBS Chinook salmon all years combined (data lagged to actual year of growth). Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3), 4th ocean zones (SW4), Total Scale Size = TSS. Significant correlations are highlighted in yellow.

Age 1.2						
	<i>FW1</i>	<i>SW1</i>	<i>SW2</i>	<i>TSS</i>		
FW1	1					
SW1	0.037	1				
SW2	-0.112	0.314	1			
TSS	0.137	0.304	0.867	1		

Age 1.3					
	<i>FW1</i>	<i>SW1</i>	<i>SW2</i>	<i>SW3</i>	<i>TSS</i>
FW1	1				
SW1	-0.464	1			
SW2	0.161	-0.280	1		
SW3	0.026	0.017	0.769	1	
TSS	0.114	0.270	0.518	0.473	1

Age 1.4						
	<i>FW1</i>	<i>SW1</i>	<i>SW2</i>	<i>SW3</i>	<i>SW4</i>	<i>TSS</i>
FW1	1					
SW1	0.138	1				
SW2	0.086	0.257	1			
SW3	-0.014	0.022	0.690	1		
SW4	-0.313	0.103	0.347	0.728	1	
TSS	-0.135	0.231	0.252	0.479	0.378	1

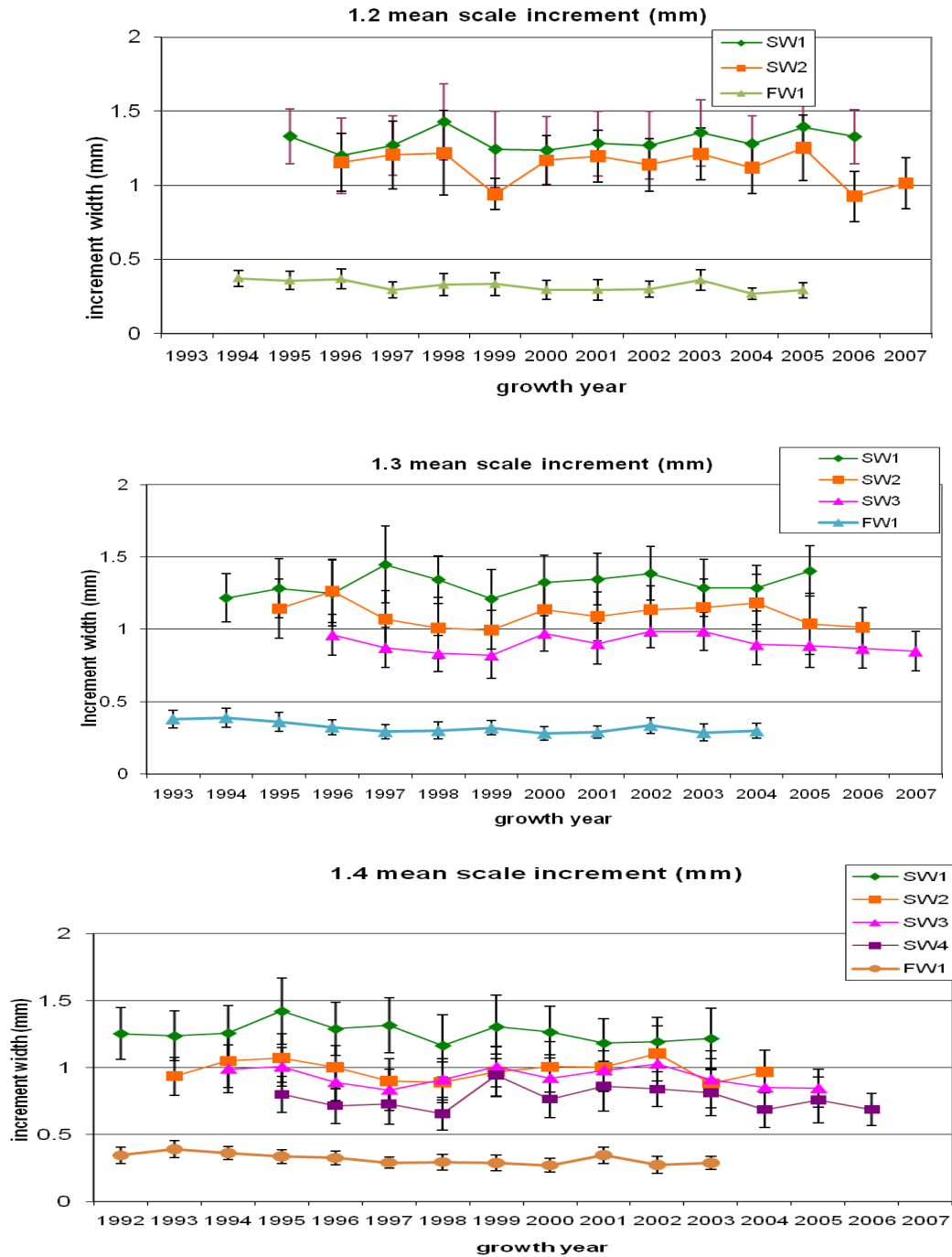


Figure 3- 19. Mean scale-growth increment widths (in mm) by life stage for age 1.2, 1.3 and 1.4 OBS Chinook lagged to actual growth year. Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3), 4th ocean zones (SW4), Total Scale Size = TSS.

We compared actual mean scale-growth increments across all life stages of age 1.3 and 1.4 female YUK adults with annual mean scale-growth increments of mixed-stock OBS females lagged to the year of growth. Correlations were then run on increment growth with the previous life-stage growth. High positive correlations were found between annual scale growth increments and growth in the previous year for all life stages of age 1.3 and 1.4 Yukon females (Table 3-8, corr. coefs. 0.31 to 0.90). This relationship was very different for mixed-stock age 1.3 and 1.4 OBS females; correlations between FW1 and SW1 and subsequent ocean life stages were weak, often negative or non-significant, and only the later/last ocean phases demonstrated significant positive relationships.

Table 3- 8. Correlations between scale growth by life stage and previous increment growth for age 1.3 and 1.4 Yukon and OBS female Chinook salmon (all years combined). Life stages: freshwater (FW1), 1st ocean (SW1), 2nd ocean (SW2), 3rd ocean (SW3), 4th ocean zones (SW4), and total scale size (TSS). Values in bold indicate significant correlations.

Age 1.3 Yukon Females						Age 1.3 OBS Females							
	FW1	SW1	SW2	SW3	TSS		FW1	SW1	SW2	SW3	TSS		
FW1	1					FW1	1						
SW1	0.3091	1				SW1	-0.4029	1					
SW2	0.6248	0.3368	1			SW2	0.0290	-0.2227	1				
SW3	0.7675	0.5304	0.5474	1		SW3	-0.0583	-0.1700	0.7721	1			
TSS	0.8310	0.1340	0.2681	0.7528	1	TSS	0.1150	0.1821	0.3979	0.1835	1		
TSS = Total Scale Size													
Age 1.4 Yukon Females						Age 1.4 OBS Females							
	FW1	SW1	SW2	SW3	SW4	TSS		FW1	SW1	SW2	SW3	SW4	TSS
FW1	1						FW1	1					
SW1	0.5475	1					SW1	0.2094	1				
SW2	0.4832	0.8704	1				SW2	-0.0717	-0.0604	1			
SW3	0.4692	0.9014	0.8992	1			SW3	-0.1684	-0.1483	0.6359	1		
SW4	0.3071	0.7722	0.9032	0.8510	1		SW4	-0.3042	-0.0650	0.4591	0.6166	1	
TSS	0.2912	0.7202	0.8527	0.8098	0.9629	1	TSS	-0.4567	0.0336	0.0569	0.5540	0.3865	1

Analyses of the relationship between SW2 versus SW1 incremental growth trends for age 1.2 immature WAK Chinook (1991-2007) and OBS Chinook (1997-2009) for both unlagged and lagged to actual year of growth, yielded the same patterns. For lagged data, scale increment growth in 2nd ocean (SW2) zone was in phase and positively correlated with growth in 1st ocean (SW1) for actual year of growth, implying dependence on ocean conditions (WAK, 0.481; OBS, 0.312), while for unlagged data SW2 was out of phase and negatively correlated with SW1 (WAK, -0.319; OBS, -0.837).

Sexually Dimorphic Growth

Data from the subset of OBS Chinook salmon scales used for measurement were grouped by fish age and sex (Figs. 3-20 – 3-22). Growth year and sex were statistically significant factors of OBS Chinook body length for ages 1.2, 1.3 and 1.4 fish. Generally for ages 1.2 and 1.3 OBS Chinook, immature and maturing females were significantly shorter than males overall (ANOVA, $p = 0.008$, and $p = 0.022$); by age 1.4 maturing OBS females were still not significantly larger than maturing males (ANOVA, $p = 0.1398$). The same results were found for age-, sex-, and year-group comparisons from the larger, original OBS data pool.

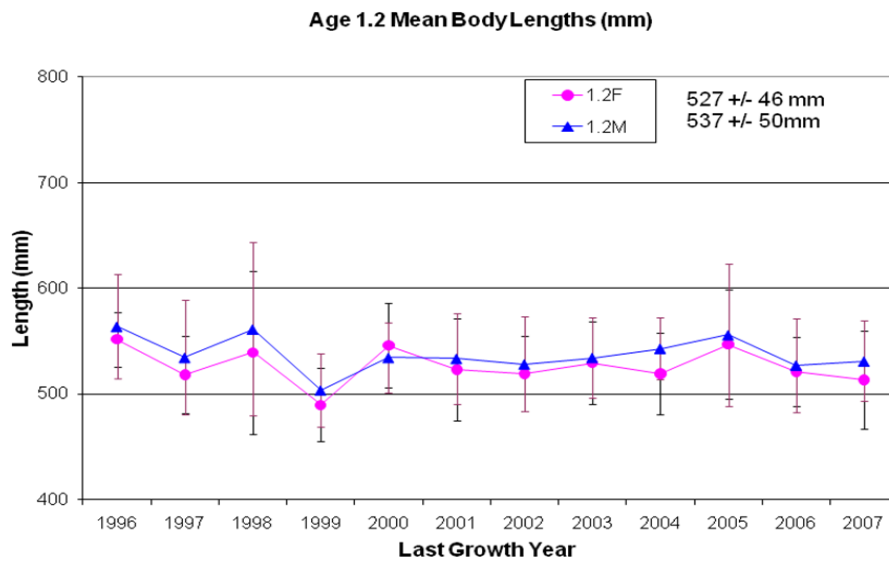


Figure 3- 20. Mean tip-of-snout-to-fork-of-tail lengths (mm) of age 1.2 male (M) and female (F) OBS Chinook salmon for growth years 1996 to 2007, sampled during late winter/early spring (n = 619).

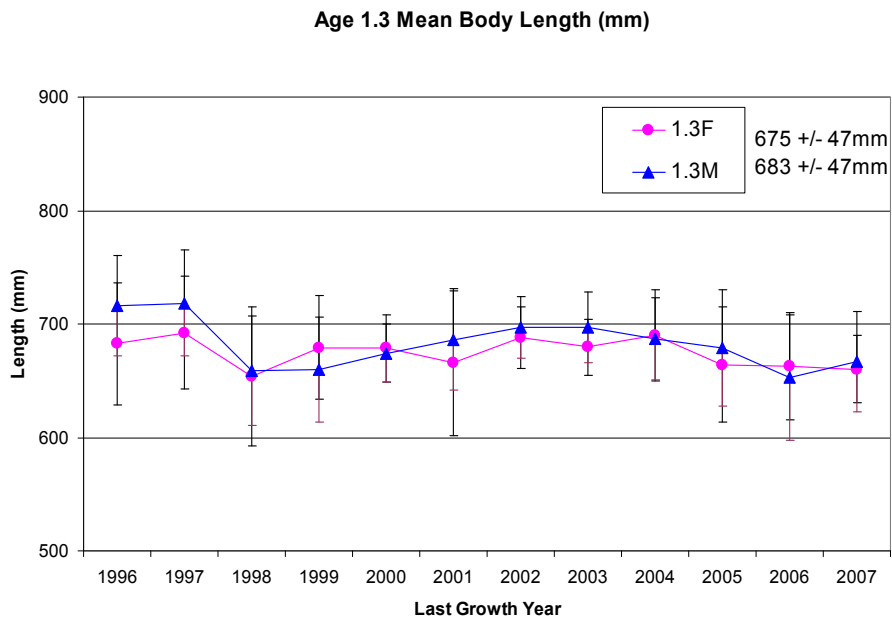


Figure 3- 21. Mean body lengths (mm, tip-of-snout-to-fork-of-tail) of age 1.3 male (M) and female (F) OBS Chinook salmon for growth years 1996 to 2007, sampled during late winter/early spring (n = 641).

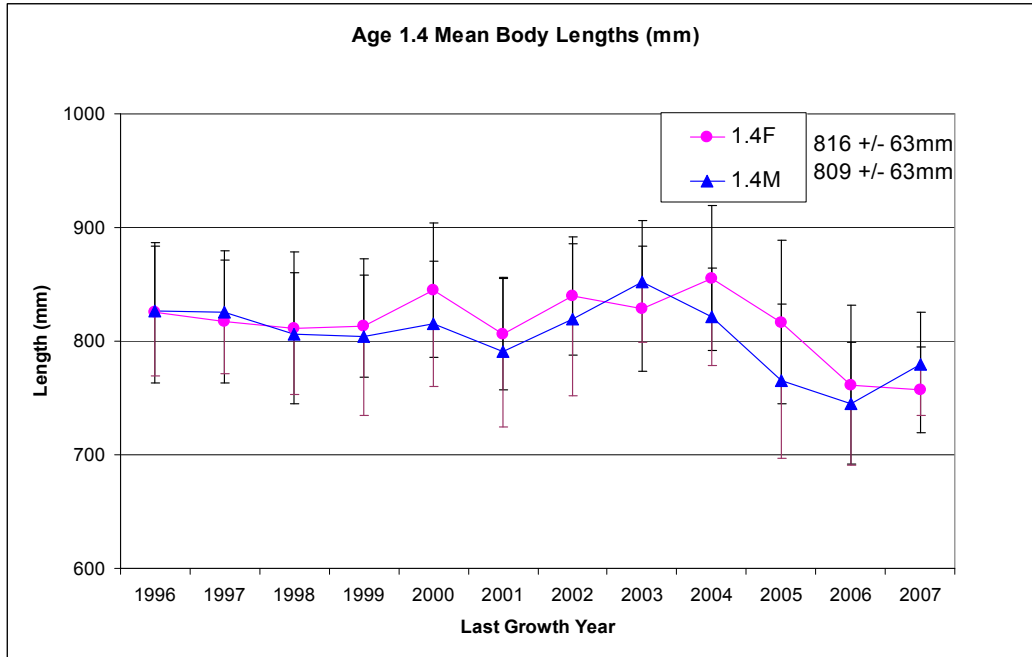


Figure 3- 22. Mean body lengths (mm, tip-of-snout-to-fork-of-tail) of age 1.4 male (M) and female (F) OBS Chinook salmon for growth years 1996 to 2007, sampled during late winter/early spring (n = 577).

Comparisons of age 1.2 OBS Chinook measured in late winter with a long-term data series (1971-2007) of age 1.2 Chinook salmon measured in the Bering Sea in July indicate that males are usually larger than females at this life stage (Figs. 3-20 and 3-23).

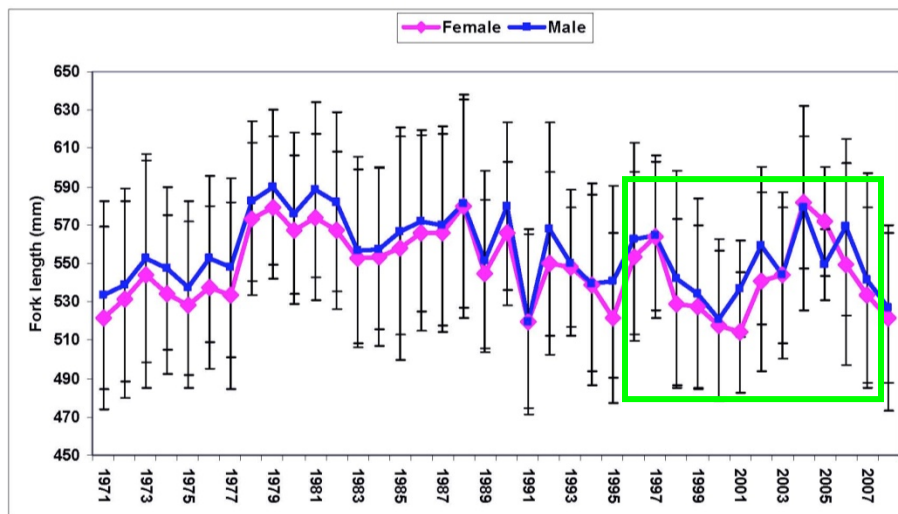


Figure 3- 23. Long-term trends in mean body lengths (mm, tip-of-snout-to-fork-of-tail) of immature ocean age-2 Chinook salmon measured in July during Japanese salmon research vessel surveys in the Bering Sea, 1971-2008. Green box delineates years of overlap with OBS Chinook samples and size range of 500-600 mm fork lengths. Data source: M. Fukuwaka, Hokkaido National Fisheries Research Institute, Fisheries Research Agency, Japan.

Alternating-Year Patterns in Abundance and Growth

For the period 1988 – 2008, we found significant positive correlations between the estimated abundances of adult eastern Kamchatka pink salmon and adult age 1.4 Canadian Yukon Chinook (lagged to ages 1.1 and 1.3; corr. coeffs. 0.375 and 0.289, $p < 0.0001$). Strong negative correlations were found when lagged to ages 1.0 (corr. coef. -0.468, $p < 0.001$), 1.2 (corr. coef. -0.678, $p < 0.0001$), and 1.4 (corr. coef. -0.535, $p < 0.0001$). These results indicate that the potential effects of Russian pink salmon on survival of AYK Chinook salmon are life-stage specific. We also evaluated brood-year specific correlations. For the period 1978-2004, the abundance of even-numbered brood years of age 1.4 Yukon Chinook were positively correlated at age 1.0 with low (corr. coef. 0.218, $p < 0.0001$) and negatively correlated with high (corr. coef. -0.104, $p < 0.0001$) abundance years of juvenile eastern Kamchatka pink salmon. The abundance of even-numbered brood years of age 1.4 YUK Chinook were negatively correlated at ages 1.1 and 1.2 with both low (corr. coef. -0.507, $p < 0.0001$) and high abundance (corr. coef. -0.365, $p < 0.0001$) years of eastern Kamchatka pink salmon. We did not investigate these relationships for WAK and OBS fish since we did not have reliable abundance estimates for Chinook salmon in the central and eastern Bering Sea. Negative correlations between pink salmon abundance and mean annual scale growth increments of YUK Chinook occurred at later life stages in age 1.3 fish (SW2 and SW3 corr. coeffs. -0.412 and -0.501, $p > 0.05$) and in both early and late stages in age 1.4 fish (SW1 and SW4 corr. coeffs. -0.341 and -0.759, $p > 0.05$) but these values were non-significant.

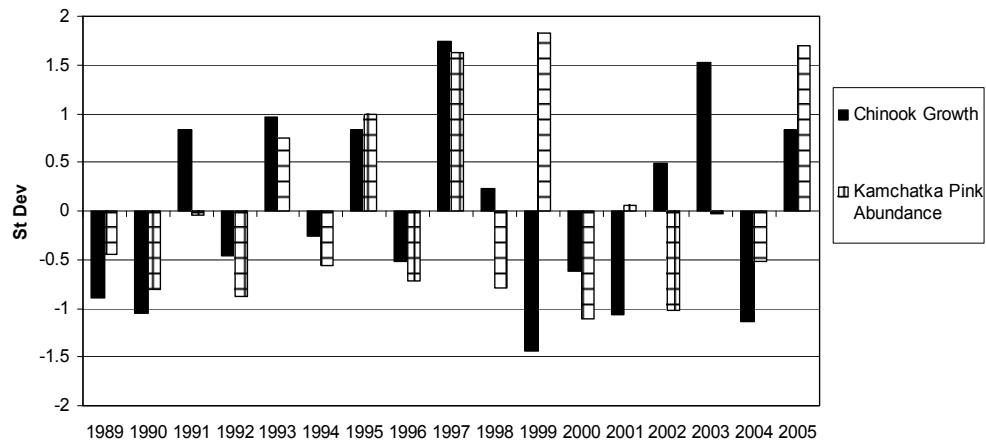
The normalized mean scale growth increments at each life stage of age 1.2 WAK female Chinook were not significantly correlated to the abundance of adult eastern Kamchatka pink salmon ($p > 0.10$). However, a graphical evaluation of these data indicated alternating-year growth patterns that varied by life stage (Fig. 3-24). During the first ocean year, growth anomalies of WAK Chinook salmon tended to be in phase with abundance anomalies of adult pink salmon (negative anomalies in even-numbered years and positive anomalies in odd-numbered years; Fig. 3-24a). Although Russian BASIS age 1.1 Chinook scale measurement data were limited to only three years, mean SW1 growth was also significantly greater in an odd-numbered year (2003) than in even-numbered years (2002 and 2004; ANOVA/Tukey's range test, $p < 0.01$).

In the 2nd ocean year, WAK Chinook growth anomalies exhibited patterns similar to those in the 1st ocean year during the early 1990s (in phase with pink salmon abundance), but growth anomalies were largely out of phase with adult eastern Kamchatka pink salmon abundance after 1995 (Fig. 3-24b). Chinook growth shifted to a negative phase in 1997, and shifted to a positive phase starting in 2002.

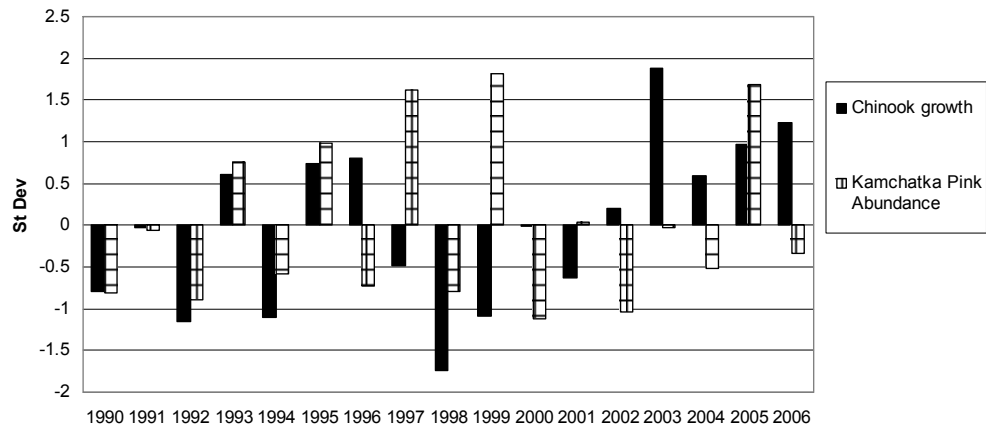
Results of high seas tagging experiments show direct overlap in distribution of age 1.2 AYK Chinook salmon and adult eastern Kamchatka pink salmon in WAK samples from the central Bering Sea in July (Objective 2). Because fish were sampled in July, only partial growth information for this life stage is available (3rd ocean plus growth, Fig. 3-24c). Chinook growth anomalies were frequently out of phase with pink salmon abundance, except during a 5-year period starting with the strong ENSO cycle (1997-2001) when Chinook growth and pink abundance anomalies were in phase.

Backward step-wise multi-linear regression, applied to 45 climate, biological and ocean condition indices (Appendix Table 6-1) with the growth period as the dependant variable, indicated that growth of age 1.2 WAK Chinook during the first year at sea was significantly correlated to multiple climate and biological indices including abundance of East Kamchatka pink salmon (Table 3-9). Eastern Kamchatka pink salmon abundance was not selected as a significant variable in regression models for other life stages. Further analyses of correlations between scale growth and climate variables were presented in Objective 9.

a. 1st ocean year



b. 2nd ocean year



c. 3rd ocean plus growth (January-July)

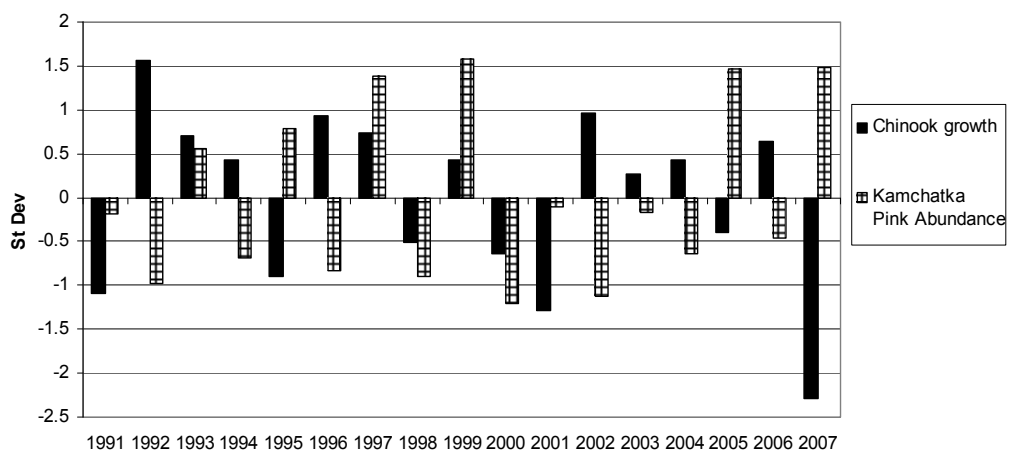


Figure 3- 24. Normalized annual growth anomalies, lagged to ocean growth year, of age 1.2 female WAK Chinook salmon and eastern Kamchatka pink salmon abundance anomalies.

Table 3- 9. Results of backward step-wise multi-linear regression, applied to 45 climate, biological and ocean condition indices (Appendix Table 6-1) with the normalized annual mean growth (see methods, equation 3-2) of age 1.2 WAK Chinook salmon (males and females) in the first ocean year (SW1) as the dependant variable. WSNA = Wind Stress across the North Alaska Peninsula - Annual, SWI = Shannon Werner Index of groundfish diversity , WPw = West Pacific Index - winter, UPI = upwelling index, SAI = Siberian/Alaska Index, pinks = Eastern Kamchatka pink salmon abundance. AIC = Akaike Information Criterion.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
WSNA	1	8.29	8.29	82.7454	3.76E-06
SWI	1	0.7748	0.7748	7.7337	0.019419
WPw	1	0.6116	0.6116	6.1042	0.033067
UPI	1	1.5873	1.5873	15.8433	0.002599
SAI	1	0.478	0.478	4.7713	0.053851
pinks	1	0.3273	0.3273	3.2671	0.100812
Residuals	10	1.0019	0.1002		
Residual standard error: 0.3165 on 10 degrees of freedom Multiple R-squared: 0.9234, Adjusted R-squared: 0.8774 F-statistic: 20.08 on 6 and 10 DF, p-value: 4.869e-05 AIC: 16.11090					

Seasonal Growth Patterns and Size-Selective Mortality

Ocean summer growth of YUK female Chinook salmon reflected total annual growth (Fig. 3-25). A pattern of lower growth in the second ocean summer (Oc2summer compared to Oc1summer and Oc3summer) is evident in age 1.3 fish, especially in 2006, 2008 and 2009 (growth years 2005, 2007 and 2008). Higher growth of age 1.3 fish occurred during the second ocean winter (Oc2winter) in 2007-2009, possibly in an attempt to compensate for lower summer growth. The annual ocean summer growth increments from the first ocean summer through the fourth ocean summer accounted for a slightly decreasing percentage (86% to 81%) of total (summer + winter) annual growth as Yukon females aged from age 1.1 (SW1) to age 1.4 (SW4). When ocean summer growth was plotted against ocean winter growth, the slope of the linear relationship was not significant.

Mixed-stock OBS males and females (all years combined) exhibited a pattern of seasonal growth opposite to that of Yukon female Chinook salmon. The percentage of each annual growth increment allocated to ocean summer growth increased as the fish aged (i.e., age 1.2 – 80%, age 1.3 – 82%, age 1.4 – 85%). Statistically significant differences between mean first ocean winter (Oc1winter) growth by age group were found in 6 of 10 years, during growth years 1995, 1997-2000, and 2004. Results for brood year 1993 (BY93) portray one of the years when ANOVA tests indicated significant size differences in Oc1winter growth by age group, although results were not dramatic (Fig. 3-26). Contrary to our expectations, the smallest size interval in older age fish was not present in age 1.2 fish. The reduced frequency of fish with large winter growth increments between age 1.2 and older age groups may reflect size-selective fishing mortality of large fish or their return to freshwater to spawn. These results coupled with the ANOVA results do not consistently support our hypothesis that smaller, slower growing fish experience size-selective mortality during their first ocean winter.

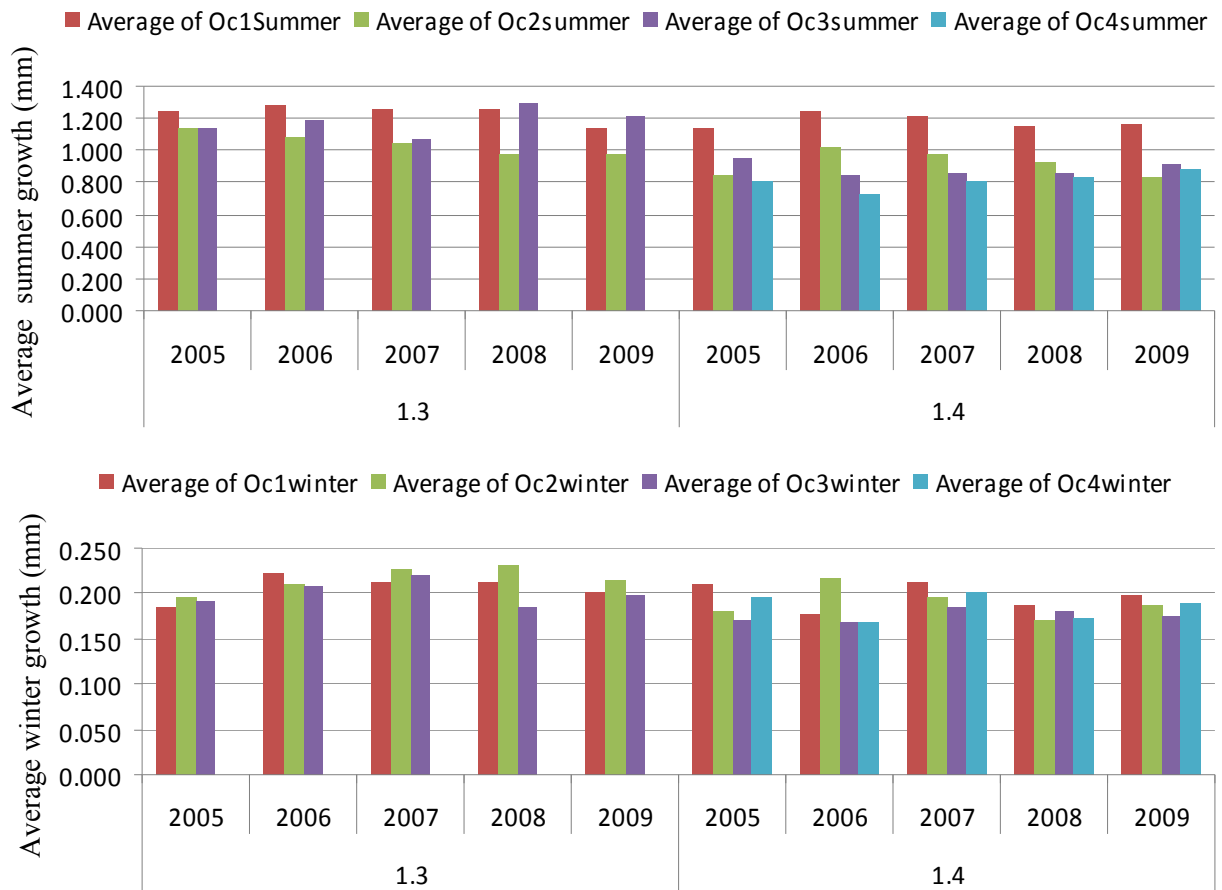


Figure 3- 25. Average size (mm) of seasonal scale growth increments by age group (1.3 and 1.4) and years (2005-2009) of Yukon female adults.

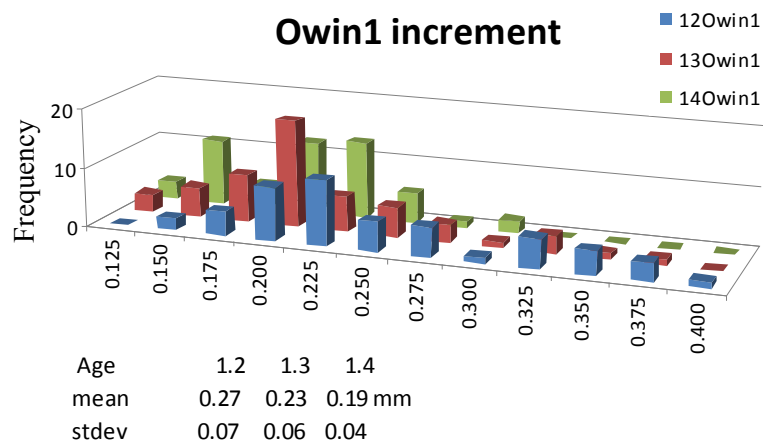


Figure 3- 26. Frequency distribution of first ocean winter (Owin1) scale growth increment size for Brood Year 1993 Chinook salmon in OBS bycatch samples by age group (1.2, 1.3, and 1.4).

Results Objective 4: Map Climate and Ocean Conditions in Regions Where AYK Salmon Migrate

This objective was largely methodological and results from mapping are provided in other sections of the report. Here we provide additional details on data sources and map products provided to AYK SSI.

For Objective 2, we mapped ocean location of temperature-depth tagged fish after release using data from several sources. MODIS satellite data provided images with estimates of sea surface temperatures (SST) throughout the year (oceancolor.gsfc.nasa.gov/cgi/l3). Surface temperature values were visually compared to images from corresponding dates (Aqua sea surface temperature sensor, 11 μ nighttime, eight-day composite, nine-km resolution). Data from Argo floats in and near the Bering Sea yielded temperature-depth profiles, primarily in the eastern basin (floats.pmel.noaa.gov). The Pacific Marine Environmental Laboratory (PMEL, National Oceanic and Atmospheric Administration) provided data collected from four moorings on the eastern Bering Sea shelf: M2 (56.9°N, 164.1°W), M4 (57.9°N, 168.9°W), M5 (59.9°N, 171.7°W) and M8 (62.2°N, 174.7°W) (P. Stabeno and D. Kachel, pers. comm. Phyllis.Stabeno@noaa.gov and Dave.Kachel@noaa.gov). Temperature-depth profiles were constructed from mooring sensor data for dates of interest, and these were compared to tag data.

For Objectives 6, 7, and 9, we used historical reconstructions of climate-ocean conditions in the Bering Sea and North Pacific Ocean available from the NOAA Earth System Research Laboratory (ESRL), Physical Sciences Division (PSD) website to map climate-ocean conditions for our analyses in Objectives 6 and 9 (<http://www.esrl.noaa.gov/psd/>). For spatially- and temporally-specific bioenergetics models (Objectives 6 and 7), we used the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis data (Kalnay et al. 1996) to define pre- and post- 1977 regime shift sea surface temperatures. The NCEP/NCAR reconstructions eliminate interannual shifts in parameters due to operational changes in the data collection system. Geographic coordinates for SST datasets corresponding to AYK Chinook salmon habitats in the Bering Sea and used in our bioenergetics models (Objective 6, see Fig. 6-1) were: (1) Northeastern Bering Sea (NEBS) shelf <30m depth: 65°-60°N, 168°W-161°W (or 192-199 degrees); (2) NEBS shelf >30m depth: area requested: 65°-60°N, 175°W-168°W (or 185-192 degrees); (3) Eastern Bering Sea (EBS) shelf break: area requested: 58°-54°N, 174°W-167°W (186-193 degrees); and (4) Central Bering Sea (CBS) basin: 62°-55°N, 172°E-175°W (172 to 185 degrees). Exploratory mapping of differences in climate and ocean conditions over the periods evaluated for correlations between climate and salmon growth indices (Objective 9) was done using monthly/seasonal composites available at the ESRL/PSD website. Gridded datasets and/or contour maps of SST and other climate-ocean variables can be downloaded or plotted online for any specified geographic coordinates, and so we do not provide maps here (for examples, see Figs. 9-1 and 9-2). For climate modeling and simulations of past climate scenarios (Objective 9), we used historical mean monthly SSTs from NOAA's Extended Reconstructed SST (ERSST) data, also available online from the ESRL/PSD website (Smith et al. 2008; NOAA_ERSST_V3 data). The ERSST data are based on the ICOADS dataset and interpolation procedures that reconstruct SST fields in regions with sparse data. Simulated SSTs (mean monthly skin temperature data, 1.4°x1.4° to 4°x5° - latitude by longitude) for the 'climate of the 20th century experiment (20c3m)', as well as for three warming scenarios of greenhouse gas emissions, were obtained online from the Program for Climate Model Diagnosis and Intercomparison (PCMDI) (<http://www.pcmdi.llnl.gov/>).

As a final product to AYK SSI (digital time-series atlas of ocean conditions), we provided a pre-mapped, gridded time-series of output data on ecosystem conditions in the Bering Sea and North Pacific Ocean from the North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO; Kishi et al. 2006), embedded in a 3-D circulation model (Aita et al 2006; M.N. Aita, pers. comm.). Model output data include seven physical/biological variables that characterize epipelagic salmon habitats (upper 50-m surface layer): sea surface temperature (SST), mixed layer depth (MLD), small phytoplankton (Phys), large phytoplankton (Phyl), small zooplankton (Zoos), large zooplankton (Zool), and predatory zooplankton (Zoop). The data consist of monthly maps (1 map per month, January-December) of gridded (1-degree latitude by 1-degree longitude) 3D-NEMURO Model output that covers the entire range of Pacific salmon in the North Pacific Ocean and Bering Sea (30N-73N latitude and

140E-124W longitude) from 1954 to 2002. The gridded data have a built in map (land is indicated by the number -999.0). Topography data for the model output are taken from ETOPO5 data set. The ocean circulation model tracer points are located in the center of 1-degree latitude by 1-degree longitude grid boxes. Data formats are in non-proprietary (ASCII, i.e., text) code. A source code for a Fortran program to read the data files was also provided (M.N. Aita, pers. comm.).

Additional results of mapping of climate and ocean conditions are presented in Objectives 2, 6, and 9.

Results Objective 5: Collect New Seasonal Food Habits Data; Evaluate Variation in Diets and Energetic Content of Somatic and Gonad Tissue

Food habits data were used to identify spatial and temporal patterns of marine resource utilization by Chinook salmon in the Bering Sea. New seasonal food habits and Chinook maturity samples were collected by a special project of US observers placed on pollock catcher-processors operating in the Bering Sea throughout the year in 2007-2008. Additional summer samples were collected by our research staff while on board a Japanese salmon research vessel (*Wakatake maru*) surveying the central Bering Sea basin in July 2007-2009. As a part of graduated student research, we evaluated seasonal trends in energetic condition and isotope ratios of Chinook salmon in the Bering Sea in 2009 using processing plant and NOAA research vessel samples. In collaboration with other BASIS researchers, we also reviewed the results of 2002-2006 BASIS food habits research on Chinook salmon and other salmon species in the Bering Sea.

Winter Food Habitats of Chinook Salmon in the Eastern Bering Sea in 2007

Results in this section were published in Davis et al. (2009a).

A total of 282 Chinook salmon stomach samples was collected by groundfish observers in winter (91%) and summer (9%) 2007 (Table 5-1). Samples were collected along the eastern Bering Sea slope in a northwesterly to southeasterly axis, with summer samples extending further to the northwest than winter samples (Fig. 5-1). Half the Chinook salmon collected in winter (50%) were ocean age-2 and most of the summer samples (64%) were ocean age-3 fish. Winter samples were collected from significantly (*t*-test, one tail, $P < 0.001$) deeper depths (mean 308 m, range 51–569 m) than summer samples (mean 138 m, range 95–272 m; Table 5-1; Fig. 5-2). Among winter samples, the age frequency in samples from each fishing depth and tow time period were not equal (both χ^2 , $df = 2$, $P < 0.001$). More young fish were collected from the deepest depth strata and more ocean age-3 fish were collected in afternoon tows than would be expected if the age composition were equal across tow time periods.

Twenty-one of 23 pairs of walleye pollock otoliths recovered from Chinook salmon stomach contents were collected from summer samples (Table 5-3). All pollock otoliths were recovered from whole fish consumed naturally by Chinook salmon. One pair of pollock subopercles was recovered from fish offal found in a winter Chinook salmon stomach sample. Most commonly, ocean age-3 Chinook salmon consumed age-1 pollock. The otoliths collected in the winter samples were found in two ocean age-4 Chinook salmon that consumed an age-1, and an age 3 or possibly age-4 pollock. The pollock subopercles were recovered from a Chinook salmon 77 cm long. The subopercle bones were likely from an age-5+ pollock, approximately 50 cm in size, a fish too large for the Chinook salmon to swallow whole.

Table 5- 1. Total number of Chinook salmon stomach samples, percent age composition, and body size at age for samples collected by groundfish observers in 2007. Winter is January–March and summer is June–August. Fishing depth is the depth where the tow was conducted. Fork length, body weight, and salmon maturity from data provided by observers. Tow time period indicates the six-hour time period of the day when at least 50% of the tow duration occurred.

Description	Winter	Summer
Total number of Chinook samples	257	25
mean fishing depth m (sd; min, max)	308 (177; 51, 569)	138 (56; 95, 272)
tow time period		
0001 to 0600 hours (% of seasonal samples)	28	16
0601 to 1200 hours (% of seasonal samples)	19	12
1201 to 1800 hours (% of seasonal samples)	30	52
1801 to 2400 hours (% of seasonal samples)	23	20
Ocean age-1		
number (% of seasonal total)	5 (2)	0
mean fishing depth m (sd)	155 (195)	
number immature (% of age group)	5 (100)	
mean fork length cm (sd)	28 (4.5)	
mean body weight kg (sd)	0.25 (0.11)	
proportion empty stomachs (for age group)	0.20	
Ocean age-2		
number (% of seasonal total)	128 (50)	9 (36)
mean fishing depth m (sd)	382 (144)	136 (60)
number immature (% of age group)	107 (84)	5 (56)
mean fork length cm (sd)	52 (5.0)	64 (6.6)
mean body weight kg (sd)	1.71 (0.61)	3.63 (1.08)
proportion empty stomachs (for age group)	0.52	0.00
Ocean age-3		
number (% of seasonal total)	89 (35)	16 (64)
mean fishing depth m (sd)	258 (176)	139 (56)
number immature (% of age group)	50 (56)	7 (44)
mean fork length cm (sd)	66 (5.1)	73 (5.9)
mean body weight kg (sd)	3.58 (1.14)	5.27 (1.30)
proportion empty stomachs (for age group)	0.54	0.19
Ocean age-4 or more		
number (% of seasonal total)	35 (14)	0
mean fishing depth m (sd)	191 (168)	
number immature (% of age group)	17 (49)	
mean fork length cm (sd)	76 (6.5)	
mean body weight kg (sd)	5.68 (1.90)	
proportion empty stomachs (for age group)	0.40	

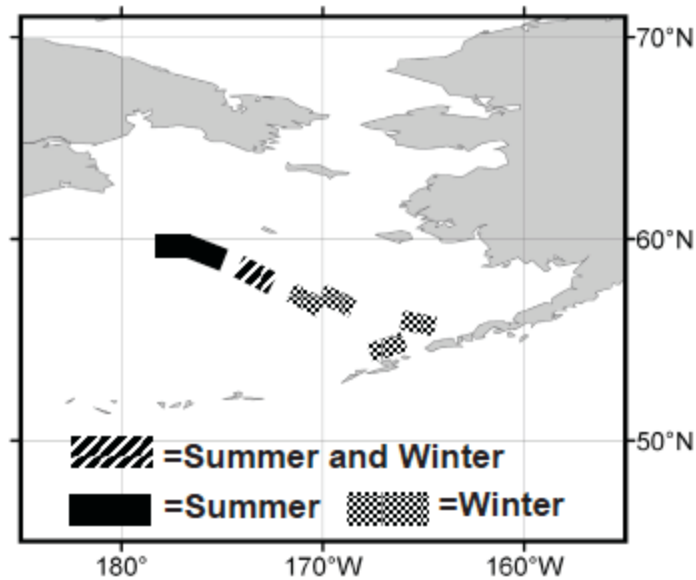


Figure 5- 1. Areas in the eastern Bering Sea where U.S. ground fish observers collected Chinook salmon stomach samples in winter and summer, 2007.

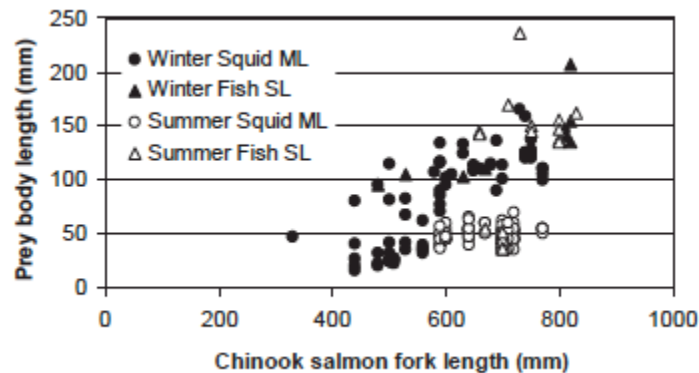


Figure 5- 2. Comparison of squid and fish prey size with Chinook salmon fork length of fish in which the prey were observed in winter and summer 2007.

Results showed qualitative differences in samples collected during winter and summer. In winter, Chinook salmon had a high percentage of empty stomachs (20–54%; Table 5-1). The squid species identified from stomach contents included a variety of species including *Berryteuthis magister*, *Gonatopsis (Go.) borealis*, and a mixture of other *Gonatus* species (Table 5-2). Fish offal was present in the diets of all age groups, ranging from 3.7% in ocean age-3 fish to 22.8% in ocean age-1 fish. By comparison, in summer Chinook salmon had a low percentage of empty stomachs (0–19%; Table 5-1). Two species of squid were identified from samples collected in summer, including *B. magister* and *Gonatus (G.) kamtschaticus*, the latter identified only in summer samples (Table 5-2). In the summer stomach samples, whole young pollock were common, but euphausiids, fish offal, and plastic debris were not found in these samples.

Table 5- 2. Percent prey composition of Chinook salmon stomach samples collected by groundfish observers in 2007. Percent prey composition calculated by adding prey weights in each category for each ocean age group and season, then dividing by the total prey weight in each stratum. Mean and range of prey weight calculated from among stomach samples that contain prey. Stomach index was the total prey weight (g) divided by fish body weight (g) times 100. Mean stomach index was averaged over the number of stomach samples containing prey. Fish offal and plastic material (n, mean wt) based on the number of stomachs and average weight among stomachs containing those materials.

Prey items	Percent prey composition by weight					
	Winter 2007				Summer 2007	
	Ocean age-1	Ocean age-2	Ocean age-3	Ocean age-4 & -5	Ocean age-2	Ocean age-3
Total Euphausiacea	22.8	4.9	13.2	0.9	0.0	0.0
Total Other/Unid Crustaceans	0.0	0.9	0.0	0.4	0.0	0.0
Total Cephalopods	47.4	73.9	80.7	81.6	45.2	26.7
<i>Beryteuthis magister</i>	47.4	49.8	29.3	38.2	14.0	10.7
<i>Gonatopsis borealis</i>	0.0	12.5	50.1	43.5	0.0	0.0
<i>Gonatus kamtschaticus</i>	0.0	0.0	0.0	0.0	31.2	15.9
<i>Gonatus pyros</i>	0.0	2.1	0.0	0.0	0.0	0.0
<i>Gonatus berryi</i>	0.0	1.2	0.3	0.0	0.0	0.0
Unidentified Cephalopods	0.0	8.2	1.0	0.0	0.0	0.1
Total Pisces	7.0	5.7	2.3	12.1	54.8	73.3
Bathymasteridae	0.0	0.0	0.0	0.0	0.0	0.1
<i>Mallotus villosus</i>	0.0	0.0	1.4	0.0	0.0	0.0
<i>Stenobrachius leucopsarus</i>	0.0	2.6	0.0	0.0	0.0	0.0
<i>Ammodytes hexapterus</i>	0.0	0.5	0.0	0.0	0.0	0.0
<i>Blepsias bilobus</i>	0.0	0.0	0.0	0.0	0.0	16.4
<i>Theragra chalcogramma</i>	0.0	1.3	0.0	1.5	50.3	56.3
<i>Leuroglossus schmidti</i>	0.0	0.0	0.1	0.0	0.0	0.0
Unidentified Pisces	7.0	1.2	0.8	10.6	4.5	0.5
Fish Offal	22.8	15.1	3.7	4.8	0.0	0.0
Plastic Debris	0.0	0.0	0.1	0.2	0.0	0.0
Number of stomachs	5	128	89	35	9	16
% empty stomachs	20	49	54	40	0	19
Mean prey weight (g) (sd)	1.43 (1.18)	16.20 (27.26)	29.42 (37.68)	56.39 (72.20)	28.33 (38.62)	72.24 (39.45)
Range prey weight (g)	0.4-3.1	0.1-155.1	0.1-165.9	0.1-244.0	1.6-127.30	1.1-145.8
Mean stomach index (sd)	0.547 (0.191)	0.781 (1.006)	0.803 (0.999)	1.049 (1.348)	0.721 (0.831)	1.465 (0.779)
Fish offal (n, mean wt)	1, 1.3 g	7, 21.0 g	5, 8.9 g	3, 18.8 g	0	0
Plastic debris (n, mean wt)	0	0	1, 1.1 g	1, 2.0 g	0	0

Table 5- 3. Estimated body length (SL, mm) and age of walleye pollock (year) based on pollock otoliths and subopercles collected from Chinook salmon stomach contents in the eastern Bering Sea, 2007. Pollock otoliths were recovered from whole fish consumed naturally by Chinook salmon and pollock subopercles were obtained from salmon consumption of pollock offal. Identical lengths listed for Chinook salmon indicate multiple otolith samples obtained from a single salmon stomach. Otolith length is the maximum dimension of the larger otolith of the pair. Conversion of otolith length and subopercle size to estimated pollock length and age from information provided by T. Buckley (Troy.Buckley@noaa.gov, pers. comm.).

Chinook salmon capture month	Chinook salmon fork length (cm)	Chinook salmon ocean age	Pollock otolith maximum length (mm)	Other pollock bone	Estimated pollock SL (mm)	Estimated pollock age (years)
Jan	82	4	7.12		143	1
Mar	79	4	14.90		348	3 or 4
Mar	77	4	n/a	subopercle	~500	5+
Aug	80	3	7.34		147	1
Aug	80	3	6.68		135	1
Aug	80	3	7.94		161	1
Aug	80	3	7.87		160	1
Aug	80	3	7.78		157	1
Aug	74	3	6.49		130	1
Aug	74	3	6.96		140	1
Aug	74	3	6.28		126	1
Aug	74	3	7.62		153	1
Aug	71	3	8.29		168	1
Aug	72	3	8.12		164	1
Aug	73	2	7.52		151	1
Aug	73	2	10.94		231	2
Aug	75	3	8.19		166	1
Aug	75	3	6.84		138	1
Aug	75	3	7.50		151	1
Aug	83	3	8.75		177	1
Aug	83	3	6.98		141	1
Aug	83	3	7.78		157	1
Aug	66	3	7.70		155	1
Aug	66	3	7.56		152	1

Comparison of Chinook salmon fork length to fish and squid prey size in winter showed a positive relation between predator size and maximum size of squid and fish consumed (Fig. 5-2). In summer, there is no relation between Chinook salmon size and either squid or fish prey size. In summer Chinook salmon might consume fish and squid that are smaller, or younger, than the size or age of those encountered in winter.

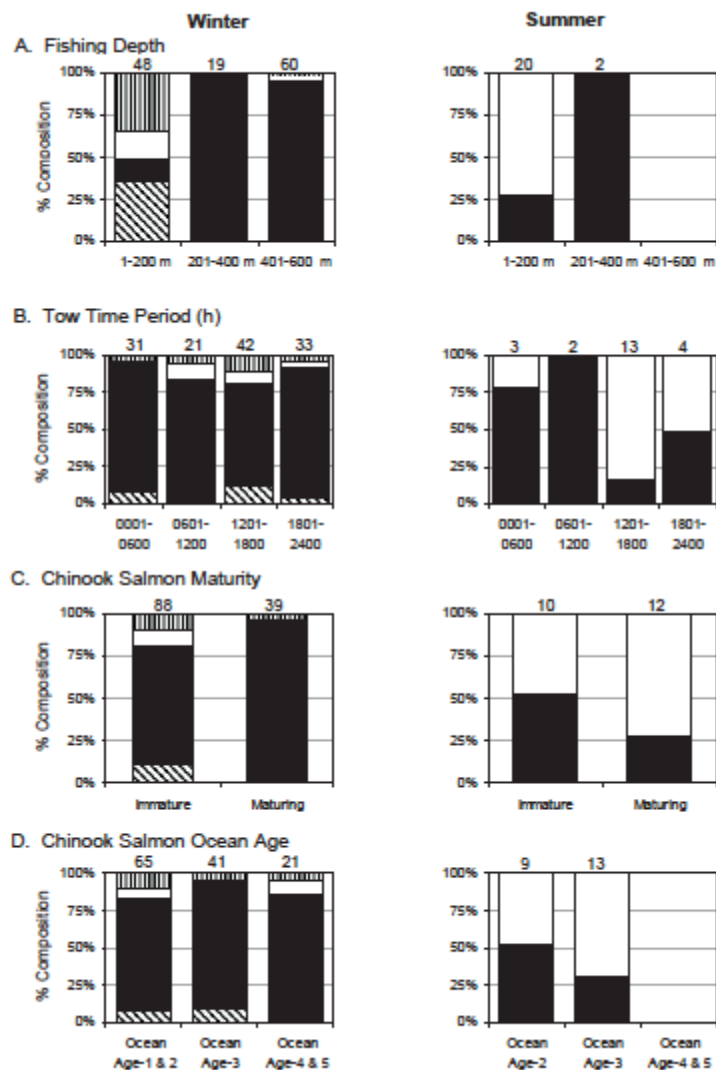


Figure 5- 3. Comparison of Chinook salmon diets for fish collected in winter (left panels) and summer (right panels) in the eastern Bering Sea, 2007. The percent composition is the mean prey index (PI = weight of prey category/fish body weight) among fish that contain prey. Sample size of fish that contain prey in each category is shown above each histogram. Histogram patterns include the major prey categories: Diagonal fill = euphausiids; solid fill = cephalopods; open fill = pisces; vertical fill = fish offal. A. Chinook salmon diet comparison among fishing depth zones (m). B. Chinook salmon diet comparison among tow time periods of the day (hr). C. Chinook salmon diet comparison between immature and maturing fish. D. Chinook salmon diet comparison among ocean age groups.

Table 5- 4. Results of nonparametric analysis for differences between prey category and fishing depth zones (1-200, 201-400, 401-600 m), tow time period of the day (0001–0600, 0601–1200, 1201–1800, 1801–2400 hr), maturity (immature, maturing), and Chinook salmon ocean age (age-1 and -2, age-3, and age-4 and -5) for the winter 2007 samples. Kruskal Wallis nonparametric chi-square test used to compare prey components with fishing depth zone, tow time period, and Chinook salmon ocean age. Wilcoxon rank sum test used to compare prey composition and maturity. Prey index (PI) = weight of prey component divided by fish body weight. Critical value of $P = 0.05$, ns = not significant.

Analysis	Prey components	Test statistic	df	P-value	Comparison of factors with significant P-values
Prey components and fishing depth zone		chi-square			
	Euphausiid PI	60.7602	2	< 0.001	1-200 > 201-400 and 401-600
	Squid PI	68.2755	2	< 0.001	1-200 < 201-400 and 401-600
	Fish PI	3.4103	2	ns	
	Fish offal PI	11.8835	2	< 0.01	1-200 > 401-600*
Prey components and tow time period		chi-square			
	Euphausiid PI	7.1513	3	ns	
	Squid PI	3.3642	3	ns	
	Fish PI	0.5559	3	ns	
	Fish offal PI	2.9347	3	ns	
Prey components by maturity		corrected-z			
	Euphausiid PI	2.5786	1	< 0.01	immature > maturing
	Squid PI	-1.9158	1	ns	
	Fish PI	0.9561	1	ns	
	Fish offal PI	-0.0045	1	ns	
Prey components and ocean age		chi-square			
	Euphausiid PI	2.217	2	ns	
	Squid PI	1.277	2	ns	
	Fish PI	0.6382	2	ns	
	Fish offal PI	0.0797	2	ns	

*Fish offal PI for the middle fishing depth range, 201–400 m, was not significantly different from fish offal PI in the shallow (1–200 m) or deep (401–600 m) depth range.

Among winter samples, results of nonparametric analysis indicated that prey composition was different among fishing depth zones and between maturity groups (Table 5-4). The PI of euphausiids in stomach contents of fish collected at depths < 200 m was significantly higher than observed in the diet of fish collected at depths from 201–600 m (Kruskal Wallis test, $df = 2$, $P < 0.001$). The opposite was true for the PI of squid (Table 5-4; Fig. 5-3). The PI of squid was significantly greater in Chinook caught at 201–600 m than at depths < 200 m (Kruskal Wallis test, $df = 2$, $P < 0.001$). The PI of fish offal in the diet was significantly higher in Chinook salmon caught at depths < 200 m than fish caught at 401–600 m (Kruskal Wallis test, $df = 2$, $P < 0.01$). The value of fish offal PI in stomach contents of fish sampled at 201–400 m was intermediate between shallow and deep samples and was not significantly different from either. Fish PI was not significantly different among depth strata. Euphausiid PI was significantly higher among immature Chinook salmon than maturing fish, but the PI of the other prey types were not different between maturity groups (Wilcoxon rank sum test, $df = 1$, $P < 0.01$). The PI of euphausiids, squid, fish, or fish offal were not significantly different among tow time periods or Chinook salmon ocean ages.

Patterns of Marine Resource Utilization (Food and Habitat) by Chinook Salmon in the Bering Sea, 2007-2009

In 2007-2009 a total of 830 samples were collected from Chinook salmon in the Bering Sea (Table 5-5). Most of the samples (81%) were collected in the southeast Bering Sea (SEBS) and 19% of the samples were collected from the central Bering Sea (CBS). A majority of the samples (74%) were collected in winter (Jan-Mar). In the summer (Jul-Sep), fewer samples were collected (23%) and the smallest number of samples (3%) was collected in fall (Oct-Dec). In the SEBS in all seasons most Chinook salmon were ocean age -2 and -3. Ocean age-1 fish were abundant in the samples collected in summer in the CBS, particularly in 2008 and 2009 when this was the most abundant age group. In both areas and all years, ocean age -3 and younger fish were generally immature and most ocean age -4 and -5 were maturing. Gonad samples collected in 2008 in the SEBS enabled comparison of maturity designation based on visual appearance and gonad weight determinations. Results showed differences in maturity determinations by observers and our staff of ocean age -2 and -3 fish in winter and fall samples. Maturity designations based on gonad weight produced a higher proportion of immature fish than maturity estimates based on visual examination.

In the SEBS (2007 and 2008) the percentage of empty stomachs in ocean age-2 and older fish was higher in winter than in summer and fall samples (Fig. 5-4). The highest proportion of stomachs with greater than 51% fullness was observed in ocean age -2 and -3 fish from the SEBS in 2007. In the CBS in summer the percentage of empty stomachs is highly variable among years and age groups.

Food habits analysis indicated squid and fish are the most common prey of Chinook salmon in both areas, all seasons and for all age groups (Fig. 5-5). Euphausiid prey were of secondary importance in summer and winter. Fish offal, determined by genetic procedures to be composed of pollock (Buser et al. 2009), was observed in Chinook salmon stomach contents in winter samples. In 2007 fish offal was present in all Chinook salmon age groups, however, fish offal was not common in 2008 winter samples. In winter, squid was the primary prey item in stomach contents. In summer, more fish was observed in stomach contents sampled from the SEBS and CBS.

Berryteuthis magister was the most frequently identified squid in Chinook salmon stomachs samples obtained in winter (Table 5-6). *Gonatopsis borealis* was consumed in the SEBS samples in winter and the CBS samples in summer. *Gonatus kamtschaticus* was present in samples from summer and fall samples from the SEBS. Fish prey including Atka mackerel (*Pleurogrammus monopterygius*), and Irish lords (*Hemilepidotus* spp.) were present in summer samples in the CBS. Pollock (not offal) were present in winter and summer diets in the SEBS, and myctophids (including *Stenobrachius leucopsarus*) were consumed in winter and summer in the SEBS and CBS.

Comparison of Chinook salmon fork length to fish and squid prey size shows there is a positive relation between Chinook body size and the maximum size of squid and fish prey consumed in the SEBS (Fig. 5-6). The range of squid and fish prey sizes consumed by Chinook salmon was similar in 2007 and 2008. The range in squid sizes consumed by Chinook salmon in summer is smaller than the range of squid sizes consumed during fall and winter. Summer samples collected in the CBS also indicated a positive relation between Chinook salmon fork length and maximum size of squid prey, however, samples showed no relation between fish prey size and Chinook salmon larger than approximately 38 cm fork (Fig. 5-7).

Table 5- 5. Chinook salmon age (percent at age) and maturity (proportion immature) composition determined for samples collected by area and season in the Bering Sea in 2007-2009 for food habits analysis. Samples obtained in area SEBS (southeast Bering Sea) were collected by US groundfish observers on pollock catcher-processing vessels. Samples obtained in area CBS (central Bering Sea) were collected for this study by researchers aboard the Japanese research vessel R/V *Wakatake maru*. Winter=Jan-Mar, summer=Jul-Sep, fall=Oct-Dec. No samples were collected in spring. Observer samples collected in 2008 included gonads, which allowed us to evaluate maturity based on gonad size.

Year	Area	Season	Total sample size	Ocean age-1		Ocean age-2		Ocean age-3		Ocean age-4		Ocean age-5	
				Age (%)	Immature (prop.)	Age (%)	Immature (prop.)	Age (%)	Immature (prop.)	Age (%)	Immature (prop.)	Age (%)	Immature (prop.)
2007	SEBS	winter ¹	257	1.9	1.00	49.8	0.84	34.6	0.56	12.5	0.50	1.2	0.33
		summer ¹	25	0.0	-	36.0	0.56	64.0	0.44	0.0	-	0.0	-
	CBS	summer ²	25	24.0	1.00	52.0	0.92	24.0	1.00	0.0	-	0.0	-
2008	SEBS	winter ³	357	0.3	1.00/1.00	20.7	0.83/1.00	58.5	0.77/0.85	16.8	0.32/0.30	3.6	0.15/0.16
		summer ³	9	0.0	-	11.1	1.00/1.00	88.9	1.00/1.00	0.0	-	0.0	-
		fall ³	22	4.5	1.00/1.00	63.6	1.00/1.00	31.8	0.57/1.00	0.0	-	0.0	-
	CBS	summer ²	63	42.9	1.00	27.0	0.94	28.6	1.00	1.6	0.00	0.0	-
2009	CBS	summer ²	72	62.5	1.00	31.9	1.00	5.6	1.00	0.0	-	0.0	-

¹Maturity determined by US groundfish observers based on the color, size (not weight), and texture of gonads.

²Maturity determined by criteria of Ito et al. (1974) using total (paired) gonad weight and sampling time period.

³Maturity determination includes two values separated by a backslash. First number is the maturity determination by observers using the same criteria in footnote 1. Second number is our maturity determination. Samples collected in summer follow the criteria of Ito et al. (1974). Fall samples are immature assuming maturing fish have already returned to freshwater. Maturity criteria for winter samples include gonad weight (males and females) and maximum gonad width (males).

Table 5- 6. Frequency of occurrence (%) of squid and fish prey identified in Chinook salmon stomach contents by sampling area, season, and year. SEBS = southeast Bering Sea and CBS = central Bering Sea. Winter=Jan-Mar, summer=Jul-Sep, fall=Oct-Dec.

Prey item	2007			2008				2009
	SEBS		CBS	SEBS			CBS	CBS
	Winter	Summer	Summer	Winter	Summer	Fall	Summer	Summer
Squid Total	140 (100)	95 (100)	151 (100)	207 (100)	14 (100)	61 (100)	67 (100)	41 (100)
<i>Berryteuthis anonychus</i>	0	0	0	0	0	0	17 (25)	0
<i>Berryteuthis magister</i>	59 (42)	29 (31)	0	109 (53)	0	9 (15)	0	0
<i>Berryteuthis</i> spp.	0	0	0	49 (24)	3 (21)	0	0	0
<i>Gonatopsis borealis</i>	30 (21)	0	3 (2)	11 (5)	0	0	2 (3)	2 (5)
<i>Gonatus kamtschaticus</i>	0	65 (68)	0	0	0	43 (70)	0	0
<i>Gonatus pyros</i>	14 (10)	0	0	2 (1)	0	1 (2)	0	0
<i>Gonatus berryi</i>	4 (3)	0	0	0	0	0	0	0
<i>Gonatus</i> spp.	0	0	0	0	0	0	4 (6)	4 (10)
unidentified Gonatidae	33 (24)	1 (1)	148 (98)	36 (17)	11 (79)	8 (13)	44 (66)	35 (85)
Fish Total	37 (100)	98 (100)	58 (100)	79 (100)	1 (100)	8 (100)	72 (100)	32(100)
<i>Theragra chalcogramma</i>	2 (9)	22 (22)	0	1 (1)	1 (100)	0	0	0
<i>Stenobranchius leucopsarus</i>	6 (16)	0	0	5 (6)	0	0	3 (4)	4 (13)
unidentified Myctophidae	3 (8)	0	0	1 (1)	0	0	2 (3)	1 (3)
<i>Pleurogrammus monopterygius</i>	0	0	5 (9)	0	0	0	38 (53)	6 (19)
<i>Mallotus villosus</i>	2 (5)	0	0	1 (1)	0	0	0	0
<i>Ammodytes hexapterus</i>	1 (3)	0	0	10 (13)	0	5 (63)	0	0
<i>Blepsias bilobus</i>	0	60 (61)	0	0	0	0	0	0
<i>Hemilepidotus</i> spp.	0	0	45 (78)	0	0	0	8 (11)	7 (22)
<i>Psychrolutes</i> spp.	0	0	1 (2)	0	0	0	0	0
<i>Leuroglossus schmidtii</i>	1 (3)	0	0	0	0	0	0	0
Bathymasteridae	0	1 (1)	0	0	0	0	15 (21)	1 (3)
Stichaeidae	0	0	3 (5)	0	0	0	0	0
unidentified fish	22 (59)	15 (15)	4 (7)	61 (77)	0	3 (37)	6 (8)	13 (41)

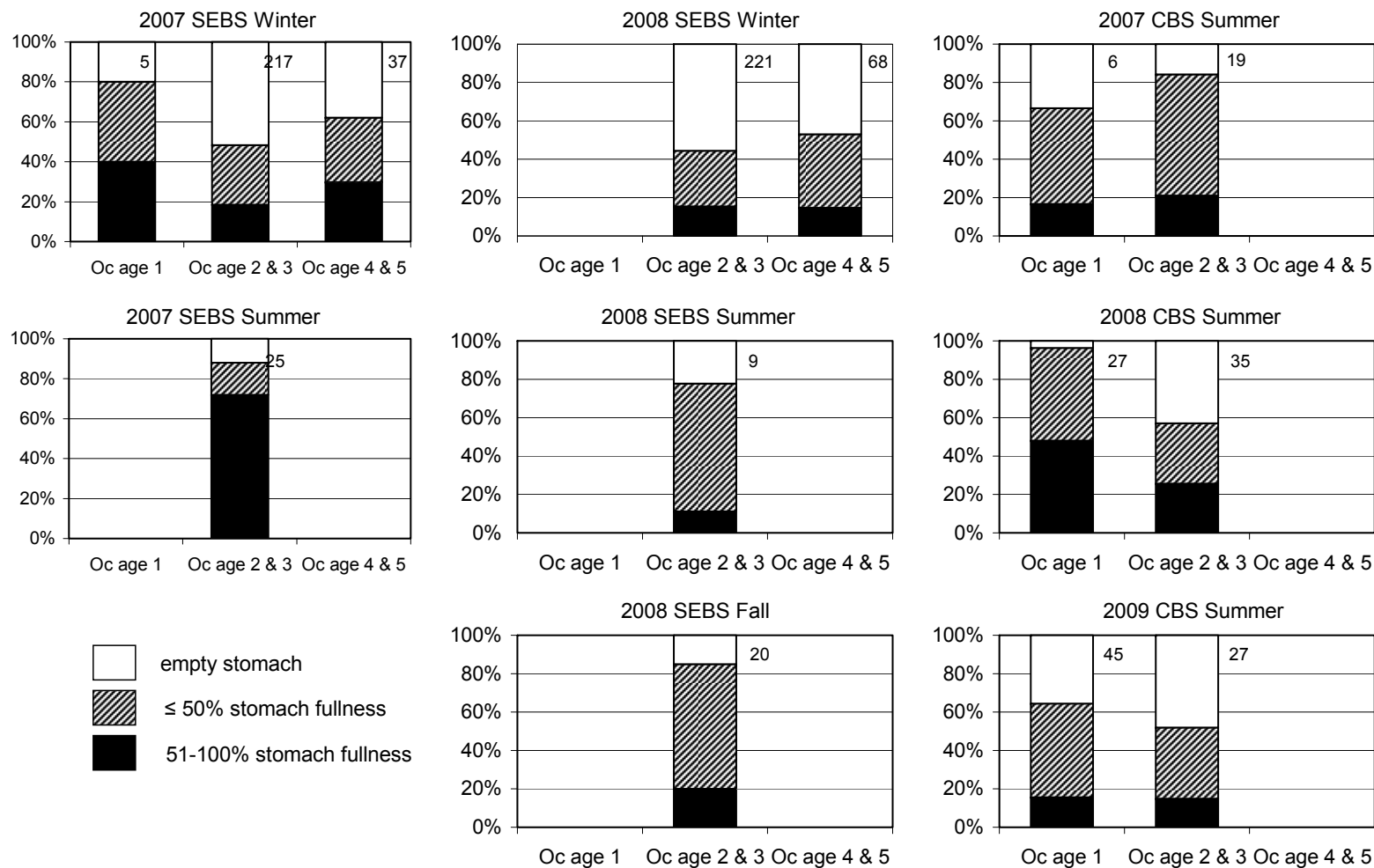


Figure 5- 4. Percent stomach fullness of Chinook salmon stomach samples by sampling area, season, and salmon age group in the Bering Sea. Samples were collected in the southeast Bering Sea (SEBS) in 2007 (left) and 2008 (center). Samples were collected in the central Bering Sea (CBS) in 2007-2009 (right side). Winter=Jan-Mar, summer=Jul-Sep, fall=Oct-Dec. No samples collected in spring. Numbers to the right of the bar indicate sample size. No bar shown for samples sizes <5.

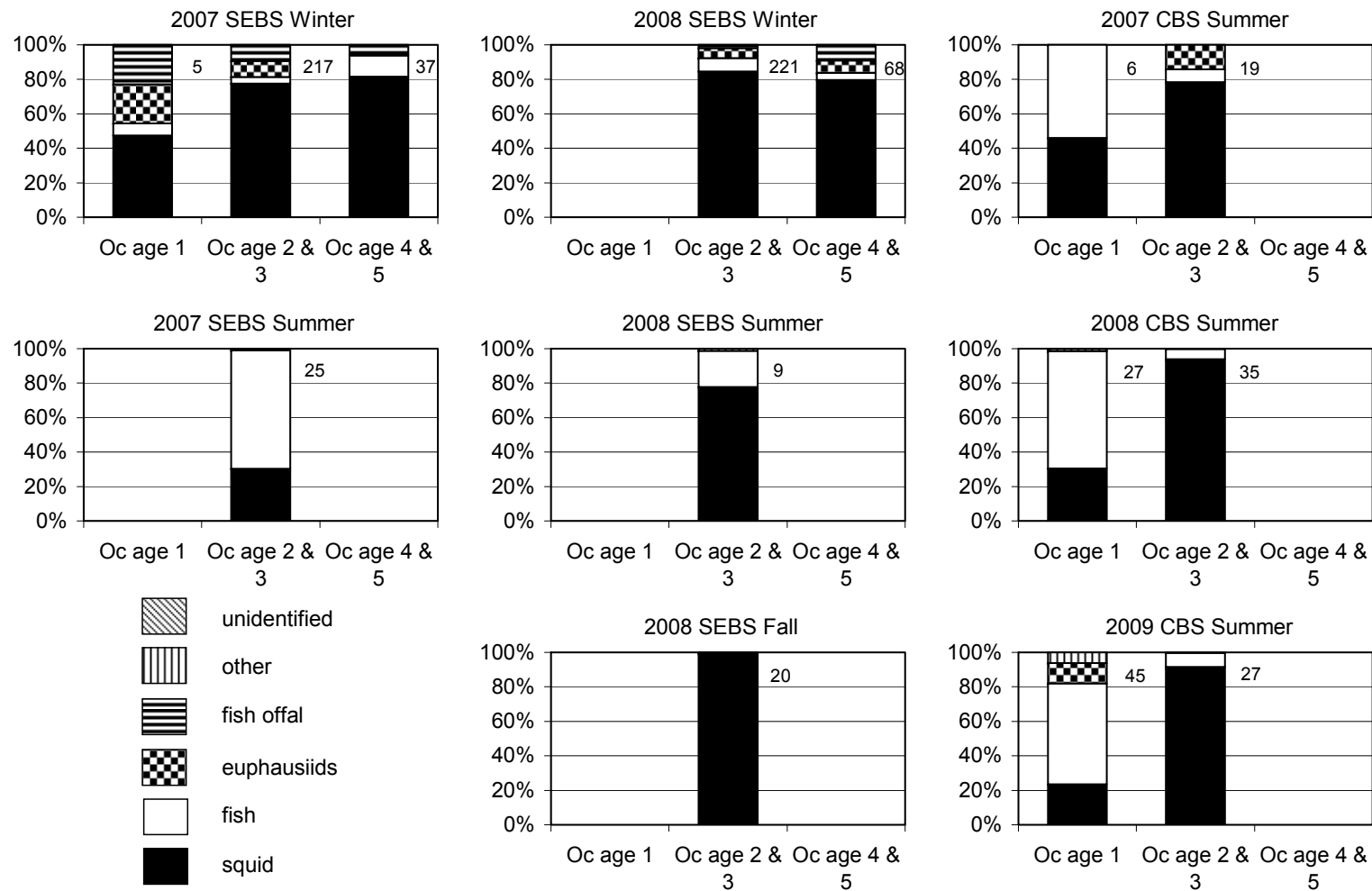


Figure 5- 5. Percent prey composition by weight of Chinook salmon stomach samples by sampling area, season, and salmon age group in the Bering Sea. Samples were collected in the southeast Bering Sea (SEBS) in 2007 (left) and 2008 (center). Samples were collected in the central Bering Sea (CBS) in 2007-2009 (right side). Winter=Jan-Mar, summer=Jul-Sep, fall=Oct-Dec. No samples collected in spring. Numbers to the right of the bar indicate sample size. No bar shown for samples sizes <5. Other prey group includes shrimp, amphipods, copepods, and worms.

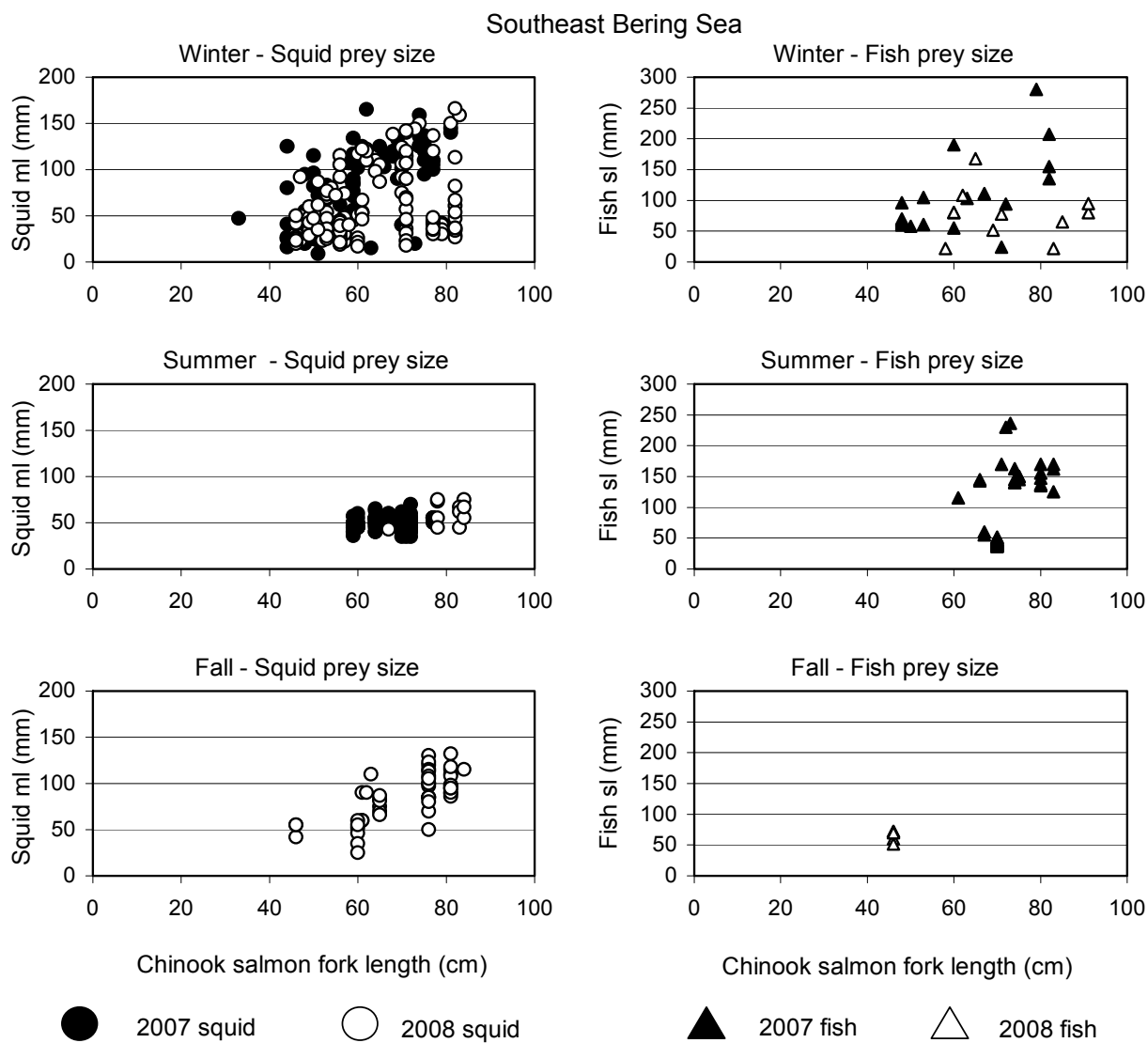


Figure 5- 6. Comparison of Chinook salmon fork length (cm) to squid and fish prey size by season in the southeast Bering Sea (SEBS) in 2007 and 2008. Size of squid prey (mantle length, mm) displayed on the left and size of fish (standard length, mm) displayed on the right. Winter=Jan-Mar, summer=Jul-Sep, fall=Oct-Dec. No fish prey were fresh enough to measure body size in summer 2008 samples. Fall samples only collected in 2008.

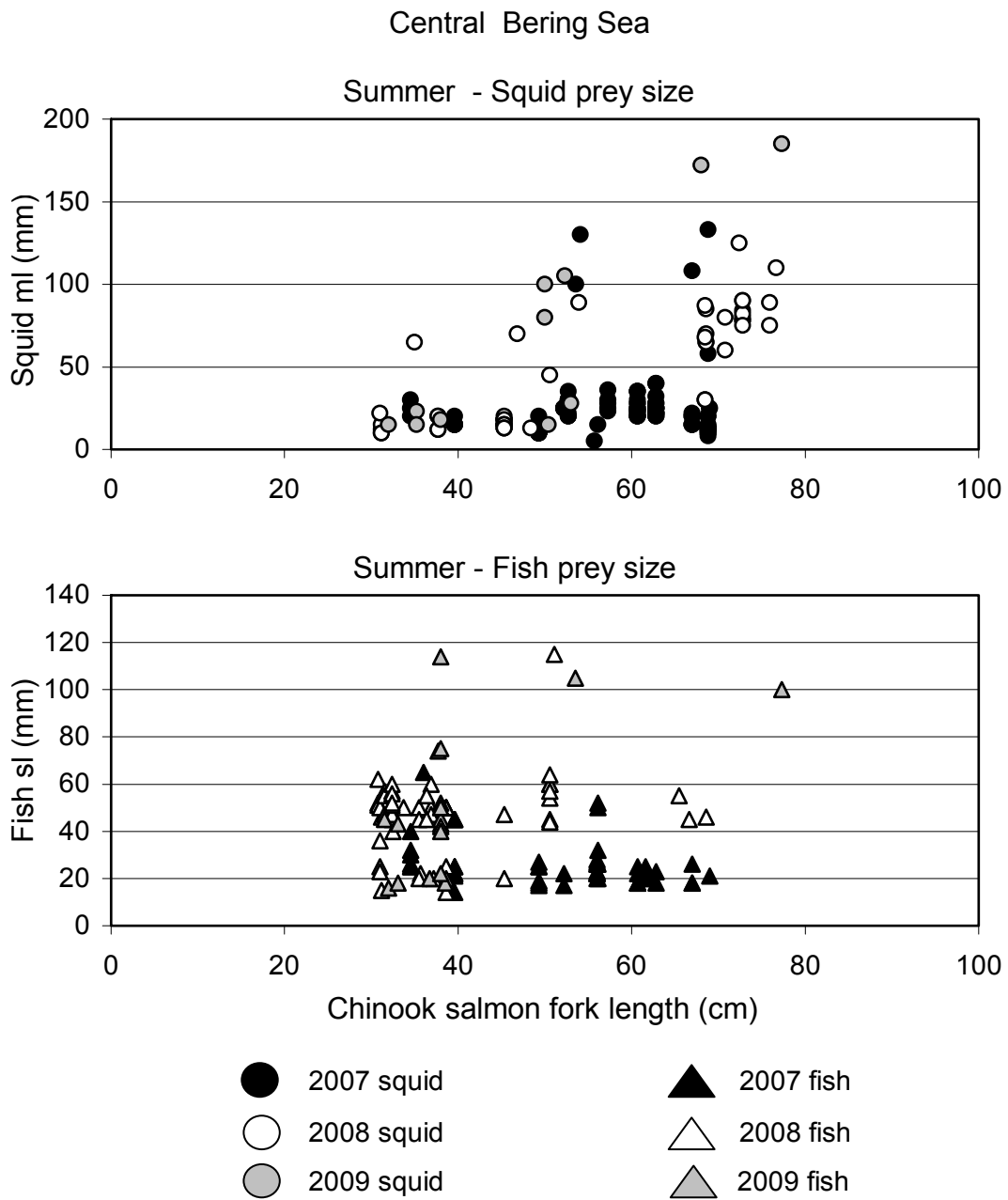


Figure 5- 7. Comparison of Chinook salmon fork length (cm) to squid and fish prey size in summer (July) in the central Bering Sea (CBS) in 2007-2009. Size of squid prey (mantle length, ml) displayed upper and size of fish (standard length, sl) displayed on lower.

Seasonal Trends in Energetic Condition and Isotope Ratios of Chinook Salmon

Analysis of energetic content of somatic and gonad tissue for sequential age groups and seasons showed that despite decreased growth in winter season, evident from scale growth, both male and female Chinook salmon were able to maintain their energetic density of somatic tissue (Figure 5-8). This seasonal trend may also be supported by the elevated carbon to nitrogen ratio of Chinook salmon muscle tissue during the winter (Table 5-7). Further investigation is required to explain the nitrogen enrichment in the winter indicative of elevated trophic level feeding during that season.

Energy allocation to gonads was higher for females than males in both energetic density and total energy allocated (Figure 5-9), resulting in a higher female gonadosomatic tissue index for all ages and seasons (Figure 5-10). Regression analysis for energy allocated to gonads (Tables 5-8 and 5-9) revealed only one significant (p -value <0.05) interaction term; Age:Sex (Table 5-9). This suggests that on a natural log scale, the relationship between energy allocated to gonads and total fish mass produced the same slope for all ages and both sexes but each age group within each sex had a unique y-intercept (Figure 5-9).

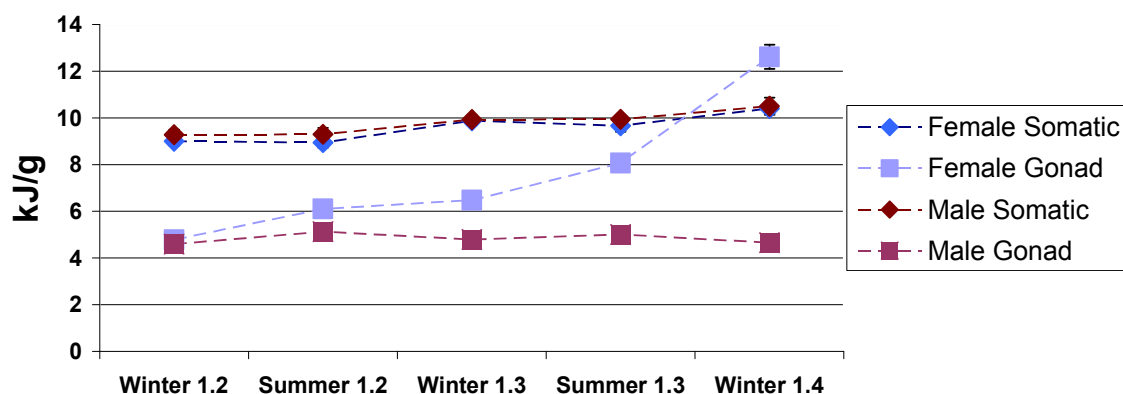


Figure 5- 8. Mean ($\pm$ SE) energetic density of somatic and gonad tissue (kJ/g) of ages 1.2, 1.3, and 1.4 Chinook salmon during winter and summer 2009 in the southeastern Bering Sea.

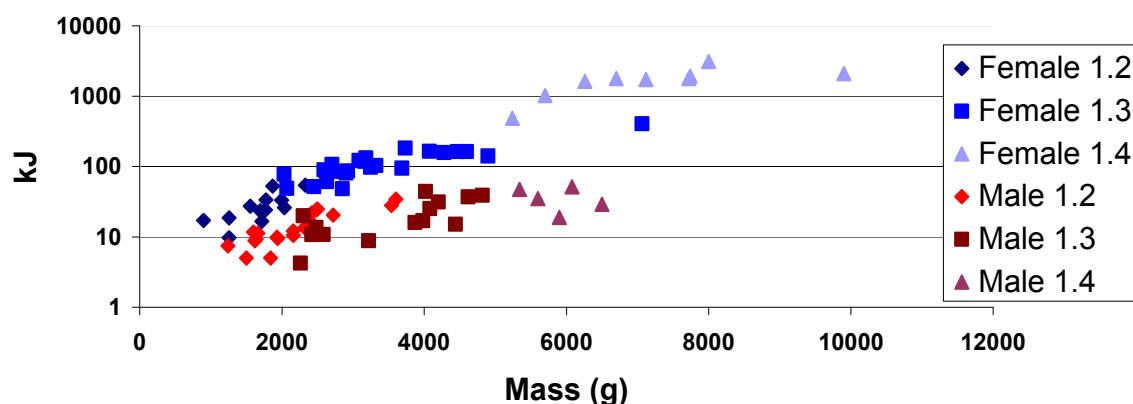


Figure 5- 9. Energy (kJ) allocated to gonads (mass, g) of male and female Chinook, ages 1.2, 1.3 and 1.4, during winter 2009 in the southeast Bering Sea.

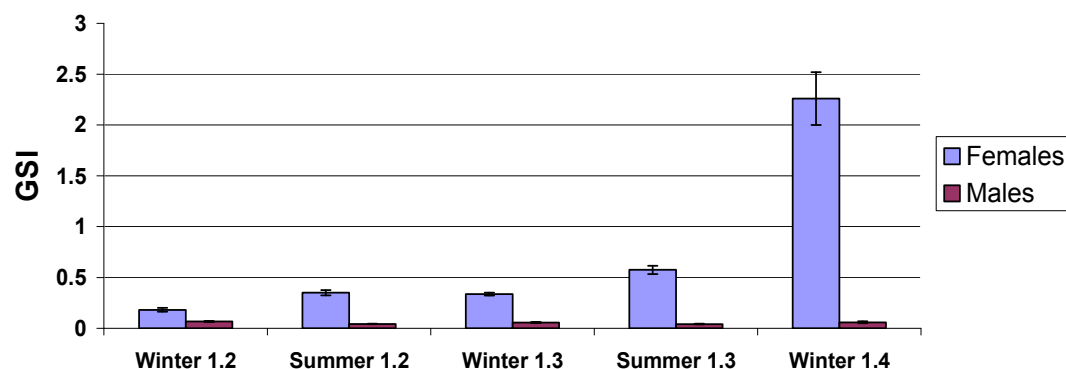


Figure 5- 10. Mean ($\pm$ SE) gonadosomatic index (GSI) of ages 1.2, 1.3, and 1.4 female and male Chinook salmon during winter and summer 2009 in the southeastern Bering Sea; ratio of energy allocated to gonads vs. whole body energetic content multiplied by 100.

Table 5- 7. Summary of stable isotope analysis for winter and summer 2009 Chinook salmon in the southeastern Bering Sea. The high C:N ratio required lipid fractionation correction (Post et al. 2007).

	Avg $\delta^{13}\text{C}$ (‰)	Avg $\delta^{15}\text{N}$ (‰)	C: N	n
Winter	-18.90	14.0	6.88	37
Summer	-20.51	12.7	5.21	37

Table 5- 8. Equation 1: Multi-linear regression model to predict energetic content of Chinook salmon in the Bering Sea (Equation 1). Input parameters include natural log transformed reactance, resistance, fish length and fish mass. Output is in kilojoules. $X_p = X_m + (R^2_m / X_m)$ $R_p = R_m + (X^2_m / R_m)$, where X_p = parallel resistance X_m = series reactance and R_p = parallel reactance R_m = series reactance.

Equation 1					
Model for Somatic Energetic Content Estimation					
$\ln(\text{kJ}) \sim \ln(\text{mass}) + \ln(\text{length}) + \ln(R_p) + \ln(X_p)$					
ANNOVA					
	Df	Sum sq	Mean sq	F-value	Pr(>F)
$\ln(\text{mass})$	1	28.11	28.11	3828.3	<2.2e-16
$\ln(\text{length})$	1	0.014	0.014	1.94	0.17
$\ln(R_p)$	1	0.32	0.32	4.3	0.04
$\ln(X_p)$	1	0.002	0.002	0.302	0.59
Residuals	42	0.31	0.0073		
Residual st error		0.0857		p-value	<2.2e-16
R-squared		0.9881		AIC	-226.23
F-stat		958.7	on 4 and 42 Df		

Table 5- 9. Equation 2: Multi-linear regression model to predict energetic content of Chinook salmon gonads in the Bering Sea. Input parameters include natural log transformed reactance, resistance, fish length, fish mass, and terms for age, sex and an age:sex interaction. Output is in kilojoules. $X_p = X_m + (R^2_m / X_m) R_p = R_m + (X^2_m / R_m)$, where X_p = parallel resistance X_m = series reactance and R_p = parallel reactance R_m = series reactance.

Equation 2					
Model for Gonad Energetic Content Estimation					
$\ln(\text{kJ}) \sim \ln(\text{somatic kJ}) + \ln(\text{length}) + \text{Age} + \text{Sex} + \text{Sex:Age}$					
ANNOVA					
	Df	Sum sq	Mean s	F-value	Pr(>F)
$\ln(\text{somatic kJ})$	1	22.74	22.74	157.2	1.1e-16
$\ln(\text{mass})$	1	41.68	41.68	288	<2.2e-16
$\ln(\text{length})$	1	2.57	2.57	17.78	1.5e-4
Age	2	3.61	1.8	12.46	7.73E-05
Sex	1	34.27	34.27	236.8	<2.2e-16
Age:Sex	2	6.25	3.12	21.58	6.9e-7
Residuals	36	5.21	0.15		
Residual st error		0.38		p-value	<2.2e-16
R-squared		0.95		AIC	-79.03
F-stat		95.98	on 8 and 36 Df		

Review of BASIS Salmon Food Habits Studies, 2002-2006

The results presented in this section were published in Davis et al. (2009b).

Regional differences in salmon food habits and zooplankton collections

BASIS 2002-2006 salmon food habits data showed regional differences in diets (Volkov et al. 2007b; Farley et al. 2009). Diets of salmon collected in the western Bering Sea contained more zooplankton, and those collected from the eastern Bering Sea contained more ichthyoplankton and nekton. In the western region, hyperiid amphipods, pteropods, and small squids were the basic prey of planktivorous salmonids, such as sockeye, pink, and chum salmon (Volkov et al. 2007a). Juvenile pink salmon most commonly consumed planktonic crustaceans including hyperiid amphipods (*The. pacifica*, *The. libellula*, and *P. macropa*), euphausiids (*Thy. longipes*), copepods (*Neocalanus plumchrus*), and pteropods (*L. helicina*; Naydenko et al. 2007). Juvenile Chinook salmon in the western Bering Sea consumed zooplankton (Naydenko et al. 2005). Salmon diets contained relatively few euphausiids because of their low abundance in surface waters during the day when salmon were actively feeding (Volkov and Kosenok 2007). Copepods and chaetognaths, while abundant in zooplankton collections, were not important in salmon diets suggesting the habitat provided a high abundance of more preferable food for salmon (Volkov et al. 2007b). Salmon selected prey that were heavily pigmented (e.g., *Themisto* spp. and *L. helicina*), large bodied (e.g., young squid, pollock, and Atka mackerel), or possessed luminous photophores (e.g., myctophids and euphausiids; A. Zavolokin, zavolokin@tinro.ru, pers. comm.). Eastern Bering Sea zooplankton collections were dominated by small-sized copepods, chaetognaths, and ichthyoplankton, primarily larval and juvenile pollock, and crab larvae. These same ichthyoplankton and

crab larvae also dominated the contents of salmon stomachs (Naydenko et al. 2007; Volkov et al. 2007b; Farley et al. 2009). The small-size fraction (< 1.3 mm) of zooplankton was most abundant in the eastern region, and the large-size fraction (> 3.3 mm) dominated throughout the year in other regions (Volkov et al. 2005a). The biomass of the zooplankton forage base, comprising organisms consumed by sockeye, chum, and pink salmon, was determined primarily from the abundance of organisms in the large-size fraction of zooplankton (Volkov et al. 2005a). In 2002–2006 differences in zooplankton size composition, taxonomic and trophic structure, and zooplankton production available for fish consumption led researchers to conclude that the eastern Bering Sea was approximately 30% less productive than the western Bering Sea (Volkov et al. 2007a). In 2006–2008 the large-size fraction of zooplankton increased in the eastern Bering Sea affecting salmon diet composition by increasing the proportion of zooplankton, particularly euphausiids, and decreasing nekton in sockeye, chum, pink, and Chinook salmon diets (Volkov et al. 2007b). Sockeye and chum salmon consumed juvenile rockfishes, age-0 pollock, capelin, sand lance, and sablefish (Davis et al. 2004; Naydenko et al. 2005; Volkov et al. 2007b; Farley et al. 2009), and Chinook salmon consumed young herring, capelin, pollock, rockfishes, and sablefish (Davis et al. 2004). In the central region the large-size fraction of zooplankton, which included hyperiid amphipods, pteropods, euphausiids and coelenterates (*Aglantha digitale*; Volkov et al. 2007a), were the common prey items found in the stomach contents of sockeye, chum, and pink salmon (Davis et al. 2004; Volkov et al. 2007b). Fish consumed by immature sockeye, chum, and Chinook salmon in the central Bering Sea differed from fish observed in stomachs collected in the eastern region. In the central region, salmon consumed *S. leucopsarus* and juvenile fish including Atka mackerel, sculpins, and flatfish (Davis et al. 2004; Naydenko et al. 2005). Squid predominated in the diets of Chinook salmon collected from the central basin and fish were the primary prey of Chinook salmon collected on the eastern shelf (Davis et al. 2004). If salmon consumption of zooplankton does not significantly affect the salmon's forage base, then recent increases in salmon abundance are unlikely to change the trophic relationships in the Bering Sea (Naydenko 2009). Patterns in food habits characteristics may represent adaptive strategies intended to lessen density-dependent interactions and maximize utilization of available feeding grounds (Sviridov et al. 2004).

Differences in major prey taxa by species and body size of salmon in the Bering Sea

Particular taxa of zooplankton, squid, and fish were important prey ($\geq 10\%$ of the prey composition by weight) of sockeye, chum, pink, and Chinook salmon in the Bering Sea in late summer-fall (Figs. 5-11 and 5-12). Zooplankton prey, including euphausiids (*Thysanoessa longipes* and *Thy. raschii*) and crab megalopa and zoea, were identified as important prey for all four salmon species (Fig. 5-11). The hyperiid amphipod, *Themisto pacifica*, was an important component in the diet of sockeye, chum, and pink salmon from the smallest sizes (10 cm FL) to fish up to 60 cm in length. The shelled pteropod, *Limacina helicina*, was also an important component of the diet for a wide size range of sockeye, chum, and pink salmon. Prey items such as medusae and comb jellies, the hyperiid amphipod, *Primno abyssalis*, the unshelled pteropod, *Clione limacina*, and chaetognaths (*Sagitta* spp.) were important in chum salmon diets, exclusively. The euphausiid, *Thy. longipes*, was an important component of stomach contents observed from a wide range of Chinook salmon body sizes (20–70 cm FL). Squid, Atka mackerel (*Pleurogrammus monopterygius*), lampfishes (*Stenobranchius* spp.), Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), and walleye pollock (*Theragra chalcogramma*) were important nekton ($\geq 10\%$ of the prey composition by weight) in sockeye, chum, pink, and Chinook salmon diets (Fig. 3). Other species of fish identified as significant components ($\geq 10\%$ of the prey composition by weight) of Chinook salmon diets included herring (*Clupea pallasii*), whitespotted greenling (*Hexagrammos stelleri*), prowfish (*Zaprora silenus*), sablefish (*Anoplopoma fimbria*), and rockfishes (*Sebastes* spp.).

Patterns in food habits were associated with variations in salmon body size, age, or maturity. For example, as chum salmon grew they preyed more intensively on lampfish, pollock, Atka mackerel, sand lance, or capelin, depending on the geographic area (Naydenko et al. 2005). In the western Bering Sea, small chum salmon (< 20 cm FL) fed mostly on hyperiid amphipods (*The. pacifica*) and large chum

salmon (> 50 cm FL) fed mostly on fish (Atka mackerel; Temnykh et al. 2003). In the western region and more southerly waters off Kamchatka, medusae consumption was a distinctive feature of chum > 51 cm. This might reflect adaptations by maturing chum, which could require more easily digested prey (Dulepova and Dulepov 2003). Sockeye salmon < 50 cm FL preyed on hyperiid amphipods, euphausiids, pteropods, and juvenile squid, while larger fish preyed more intensively on nekton (Naydenko et al. 2005). Chinook salmon juveniles consumed mostly plankton, including large crab larvae and euphausiids, and larger fish consumed few zooplankton (Naydenko et al. 2005). The diurnal feeding activity of immature salmon (< 30 cm FL) had similar feeding rhythms, regardless of whether they were nekton or zooplankton consumers, with most activity occurring between mid-day and dusk (Volkov and Kosenok 2007). Older immature and maturing individuals had less defined diurnal patterns (Volkov and Kosenok 2007). Juvenile sockeye, chum, and pink salmon in the eastern region preyed on nektonic animals including, larvae and age-0 walleye pollock, sand lance, capelin, and bottom fish larvae. All sizes of chum salmon consumed larval and age-0 pollock, crab larvae, and coelenterates (Naydenko et al. 2005; Volkov et al. 2007a). Prevalence of fish in the diet of juvenile sockeye, chum, and pink salmon was associated with the high concentration of juvenile fish prey, especially age-0 pollock (Kuznetsova 2006). Small Chinook (≤ 40 cm FL) salmon preyed predominately upon fish (sand lance, juvenile pollock, larval fishes) and large individuals (≥ 60 cm FL) preyed almost exclusively on squid (Naydenko et al. 2005). In the eastern region, pteropods often dominated the diets of ocean age-1 and older sockeye and chum salmon (NPAFC2004). In Bristol Bay juvenile sockeye up to 10 cm FL fed mostly on copepods. Larger juveniles (10–30 cm FL) consumed mainly juvenile pollock, pteropods, copepods, hyperiid amphipods, euphausiids, and crab megalopa (Kuznetsova 2006), whereas large sockeye salmon (50 to 60 cm FL) consumed mostly euphausiids. The proportion of fish (juvenile pollock and capelin) in the diet of pink salmon increased with pink salmon body size (Kuznetsova 2006). Examining Chinook salmon winter diets, investigators found that the ratio of euphausiids to fish body weight was significantly higher in immature than maturing fish (Davis et al. 2009a).

Shifts in salmon food habits associated with relatively warm and cool years

BASIS research in 2002–2006 captured variation in environmental conditions in the Bering Sea including relatively warm and cool years. Oceanographic indices formulated from eastern Bering Sea shelf conditions show that 2002 to 2005 were relatively warm years, and 2006 was a relatively cool year (Fig. 5-13). These indices show levels of water column stability, nutrient conditioning, and the influence of thermal conditions on distributions of fishes. The period provided a natural experiment to measure effects on salmon food habits in response to climate and ecosystem change. Warmer spring sea surface temperatures on the eastern Bering Sea shelf were associated with increased marine growth and survival of juvenile western Alaska sockeye salmon and changes in primary prey composition of juvenile sockeye salmon during relatively warm years (2002–2003), as compared to cool years (2000–2001; Farley et al. 2007b). When cool springtime conditions prevailed in the eastern region, Pacific sand lance was an important component (by weight) of juvenile salmon diets. However, when warm springtime conditions prevailed, age-0 pollock were the primary prey and sockeye salmon had an improved body condition (Farley et al. 2007b). Similarly, later comparisons of juvenile salmon collected in the southeast and northeast Bering Sea shelf showed a shift in diets for all species across the shelf in a cool year (2006; Farley et al. 2009). Under cool conditions, the importance of sand lance dramatically increased in the diets of juvenile salmon in both areas, while the importance of age-0 pollock (southeast and northeast areas) and euphausiids and other zooplankton (northeast area) was reduced. Authors concluded cold spring sea surface temperatures on the eastern Bering Sea shelf contribute to lower growth and survival for western Alaska juvenile salmon (Farley et al. 2009). Environmental changes are likely to have complex effects on different salmon species from inter-specific interactions, prey availability, and bioenergetics (Beauchamp et al. 2007). For example, abundance of several species of large medusae, which consume some of the same prey as chum salmon, was higher in relatively warm years (2004, 2005) than in relatively cool years (2006, 2007) suggesting possible increased food competition between jellyfish and chum salmon in warming climate conditions (Cieciel et al. 2009). Using average total lipid

content as a measure of chum body condition, researchers showed a significant negative correlation between sea surface temperature and lipid content of chum salmon muscle (T. Kaga, tkaga@fra.affrc.go.jp, pers. comm.). Increased water column stability and observed shifts to increased abundance and biomass of smaller-sized zooplankton taxa in relatively warm years might affect the feeding conditions of higher trophic levels in the eastern Bering Sea (Coyle et al. 2008).

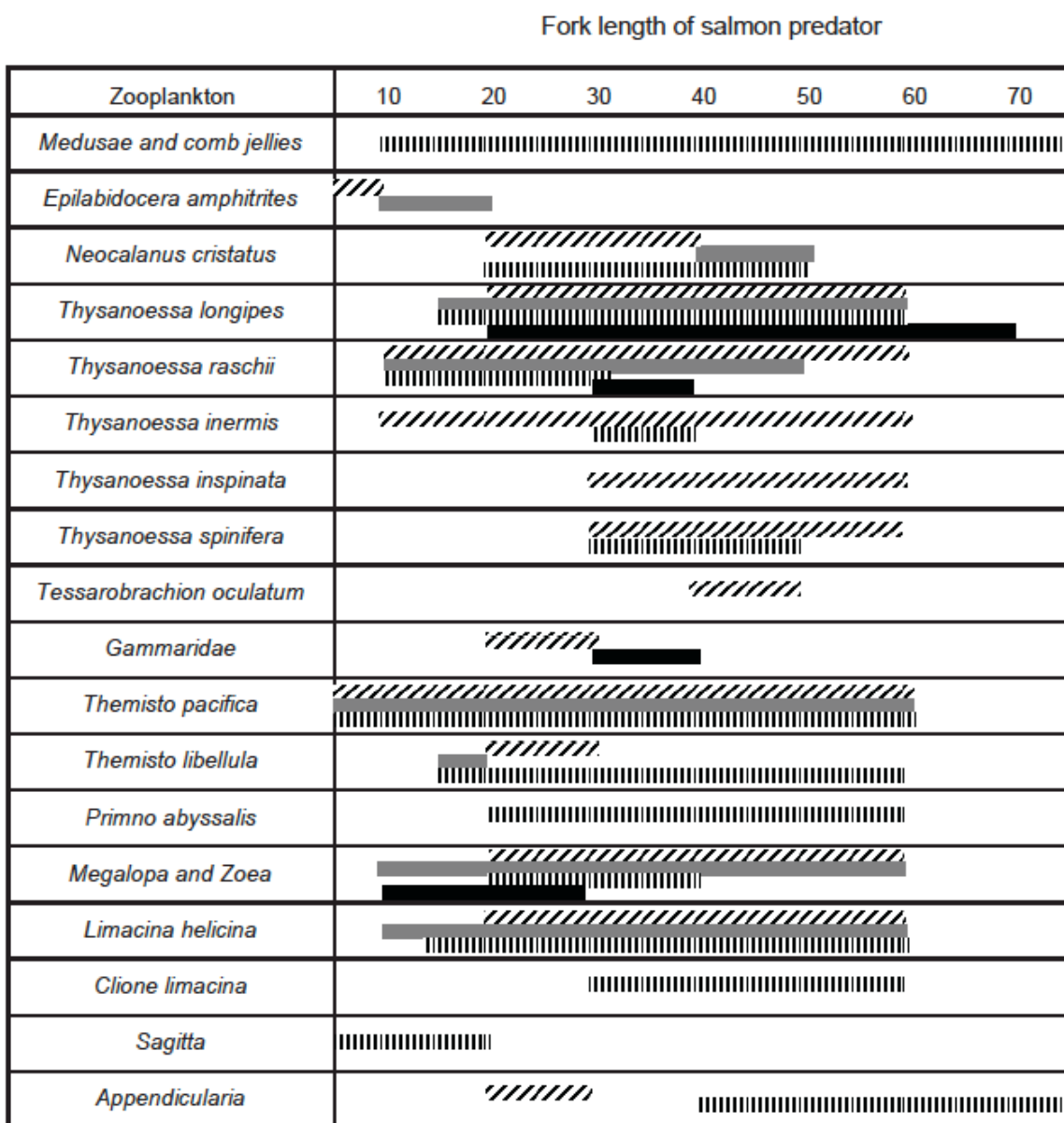


Figure 5- 11. List of the major zooplankton prey items consumed by salmon in the Bering Sea by fork length (cm) of the salmon predator. A prey item is considered major if it comprises at least 10% of the diet by weight for a region and size group. Diagonal pattern = sockeye salmon, gray = pink salmon, vertical pattern = chum salmon, black = Chinook salmon.

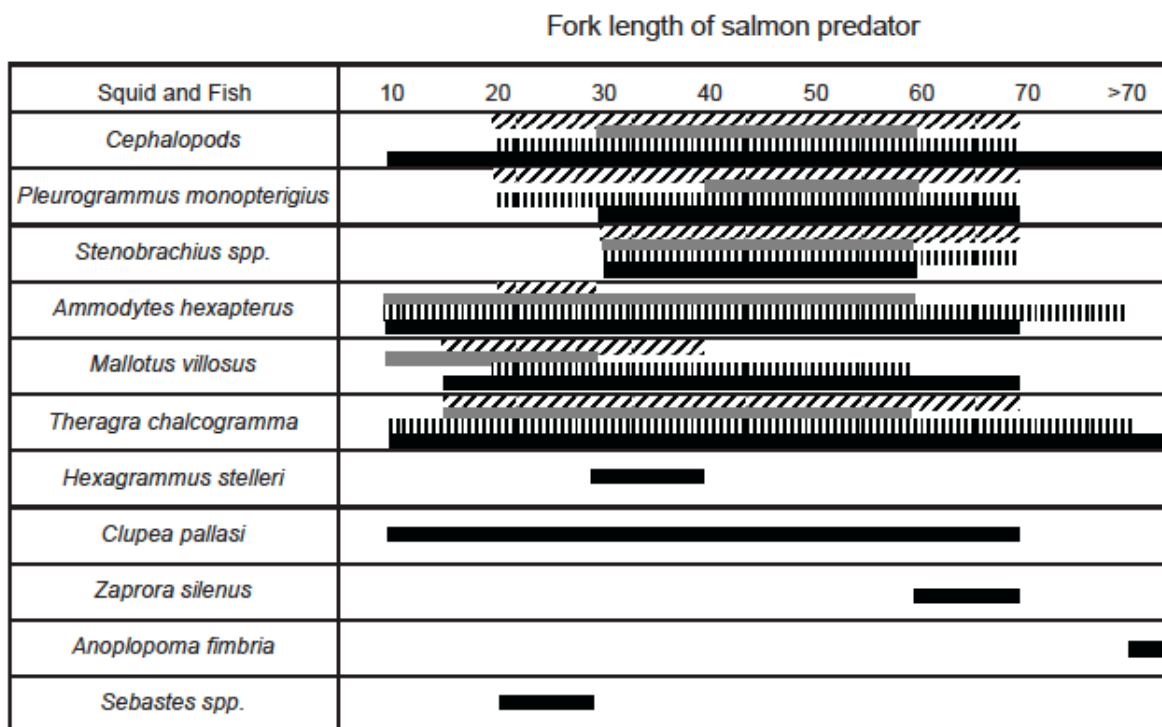


Figure 5- 12. List of the squid and major fish prey items consumed by salmon in the Bering Sea by fork length (cm) of the salmon predator. A prey item is considered major if it comprises at least 10% of the diet by weight for a region and size group. Diagonal pattern = sockeye salmon, gray = pink salmon, vertical pattern = chum salmon, black = Chinook salmon.

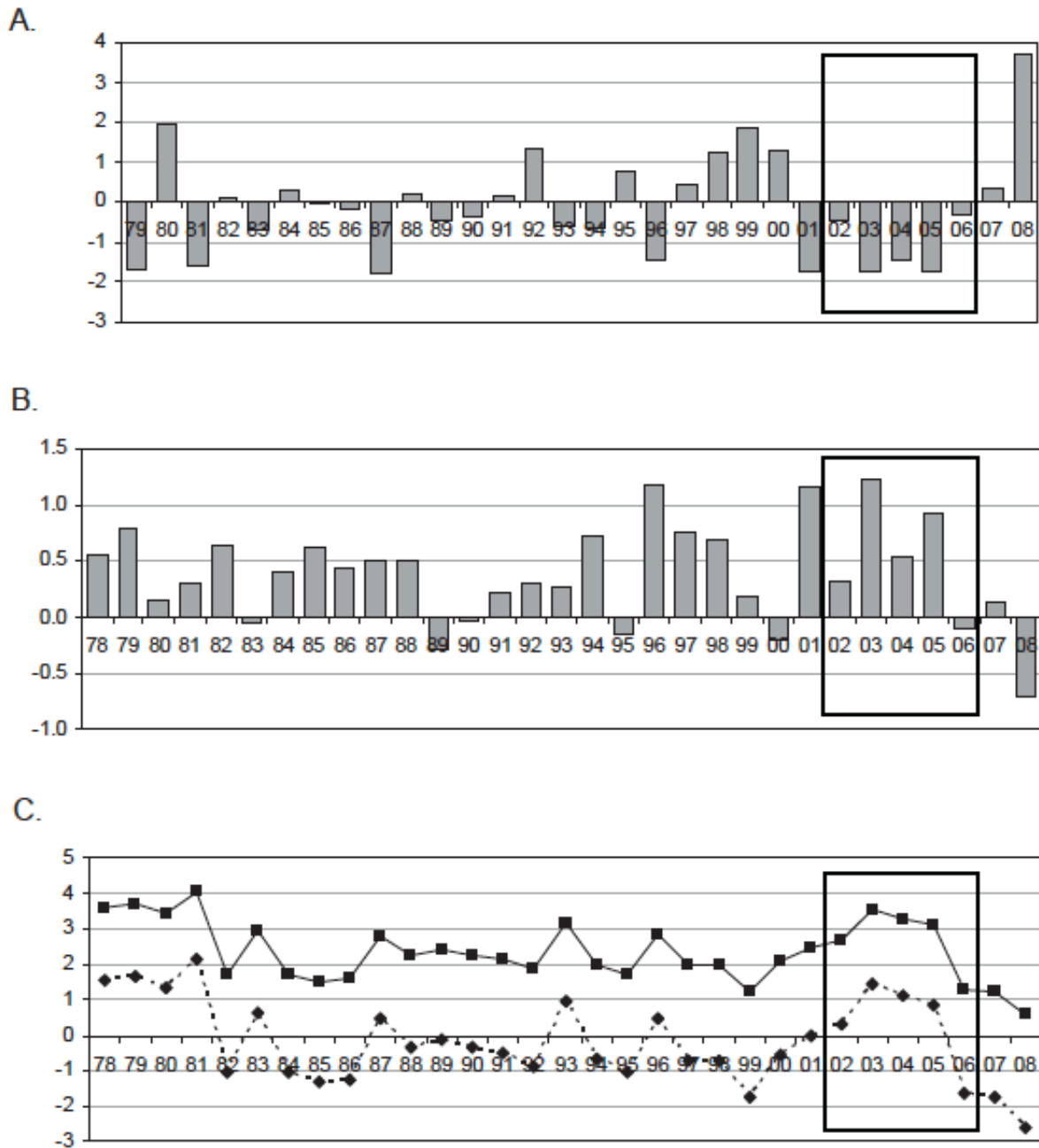


Figure 5- 13. Several eastern Bering Sea shelf climate indices show that 2002–2005 were characterized as relatively warm years, and 2006 was a cool year. Rectangular boxes highlight the BASIS years 2002–2006. Data source for indices: <http://www.beringclimate.noaa.gov>. A. Ice cover index shows the average ice concentration anomalies from January 1 to May 31 at locations between 56° to 58°N, 163° to 165°W, normalized relative to values from 1981 to 2000. B. Winter (January to March) sea surface temperature anomalies in the 5° by 5° grid centered at 55°N, 170°W, normalized relative to values from 1950 to 2000. C. May sea surface temperatures (solid line) and anomalies (dotted line) in the area 54° to 60°N, 161° to 172°W. Anomalies normalized relative to values from 1961 to 2000.

Results Objective 6: Estimate Consumption and Growth Efficiencies Modeled Under Different Climate Scenarios

Conversion Efficiency and Prey Consumption Estimates

Conversion efficiency (net production/total prey consumption) were similar between the periods before (1972-76) and after (1977-81) the 1977 regime shift except for young Chinook salmon during their first winter at sea on the SEBS shelf break (Table 6-3 and Figs. 6-3 and 6-4). In the cooler period before the 1977, conversion efficiency of fast- and slow growing fish ranged from 8.8% to 9.8%, however, the conversion efficiency of young fish was 23.2- 22.6% in the warmer later period (Table 6-3). The highest conversion efficiencies were estimated for juvenile fish on the NEBS shelf in summer (NEBS shelf <30m ~40%) and fall (NEBS shelf >30m ~34%). For immature fish, conversion efficiencies were higher in summer (CBS basin 20-29%) than in winter (SEBS shelf break 9-20%). Fast-growing maturing ocean age-3 Chinook salmon had a higher efficiency (31-34%) than slower-growing maturing at ocean age-4 (29%) fish.

Growth Rate by Period, Season, and Habitat

In summer the growth rate of juvenile and immature fast- and slow-growing fish during the cool period (1972-76) was somewhat higher than the growth rate of fish in the warmer climate period (Figure 6-5). During the fall, the growth rate of juvenile and immature age groups was the same during both climate periods. In the winter in the SEBS shelf break habitat, immature fish of all ocean-ages grew slower in the cooler than the warmer period. For maturing fish during their final month in marine waters (NEBS shelf <30m), fast-growing fish in the warmer period grew faster than the fast-growing fish in the cooler period and slow-growing fish in both climate periods grew at the same rate.

Table 6- 3. Net production (g), conversion efficiency (%; net production/total prey consumption), and prey consumption (g and kJ) estimated from bioenergetics models for juvenile, immature, and maturing female Yukon River Chinook salmon before (1972-76) and after (1977-81) the 1977 regime shift in the Bering Sea. Fast-growing fish mature and return to freshwater as ocean age-3 fish. Slow-growing fish mature and return as ocean age-4 fish. Maturity groups include juv=juvenile, imm=immature, mat=maturing fish. Cmax is a measure of feeding rate. Proportion of Cmax=1.00 at the physiological maximum for a particular fish size and temperature. Prey categories include: Am=amphipods, Co=copepods, Cr=crab megalopa, Eu=euphausiids, Fi=fish, In=Insects, Sh=Shrimp, and Sq=squid.

Ocean age	Ma- tur- ity	Area	Period	Month	Grow- th rate	Pro- por- tion of Cmax	Ini- tial body weight (g)	Net pro- duc- tion (g)	Con- ver- sion effic- iency (%)	Prey Consumption (g)									Total (kJ)
										Am	Co	Cr	Eu	Fi	In	Sh	Sq	Total	
0	juv	NEBS Shelf <30m	1972-76	Jun-Aug	fast	1.165	40	317	40.8	0	0	0	0	738	39	0	0	777	2925
			1977-81		fast	0.924	22	193	40.7	0	0	0	0	450	24	0	0	473	1783
			1972-76		slow	1.132	21	230	41.7	0	0	0	0	525	28	0	0	552	2079
			1977-81		slow	0.871	20	163	40.5	0	0	0	0	383	20	0	0	403	1516
0	juv	NEBS Shelf >30m	1972-76	Sep-Oct	fast	1.165	363	277	33.4	0	0	91	0	712	0	0	25	828	3184
			1977-81		fast	0.924	219	184	34.7	0	0	58	0	455	0	0	16	529	2035
			1972-76		slow	1.132	256	218	34.3	0	0	70	0	548	0	0	19	637	2449
			1977-81		slow	0.871	186	152	34.4	0	0	49	0	380	0	0	13	442	1698
0 to 1	juv to imm	SEBS Shelf break	1972-76	Nov- May	fast	1.165	639	128	8.8	0	0	0	436	131	0	0	887	1454	6438
			1977-81		fast	0.924	402	345	23.3	0	0	0	444	133	0	0	904	1481	6560
			1972-76		slow	1.132	474	114	9.8	0	0	0	346	104	0	0	704	1154	5110
			1977-81		slow	0.871	338	276	22.6	0	0	0	366	110	0	0	745	1221	5405
1	imm	CBS basin	1972-76	Jun-Sep	fast	1.216	762	1217	27.7	44	44	44	439	2151	0	0	1668	4390	20814
			1977-81		fast	0.954	744	1003	27.4	37	37	37	366	1795	0	0	1392	3663	17367
			1972-76		slow	1.048	583	894	29.0	31	31	31	308	1508	0	0	1170	3078	14595
			1977-81		slow	0.805	611	704	27.3	26	26	26	258	1263	0	0	979	2577	12219

Table. 6-3. Continued.

Ocean age	Maturity	Area	Period	Month	Growth rate	Proportion of Cmax	Initial body weight (g)	Net production (g)	Conversion efficiency (%)	Prey Consumption (g)									Total (kJ)
										Am	Co	Cr	Eu	Fi	In	Sh	Sq	Total	
1 to 2	imm	SEBS Shelf break	1972-76	Oct-May	fast	1.216	1997	858	15.8	0	0	0	271	217	0	54	4886	5429	30809
			1977-81		fast	0.954	1761	1189	20.4	0	0	0	291	233	0	58	5239	5821	33037
			1972-76		slow	1.048	1490	612	16.2	0	0	0	189	151	0	38	3396	3774	21417
			1977-81		slow	0.805	1325	786	20.1	0	0	0	196	157	0	39	3529	3921	22251
2	imm	CBS basin	1972-76	Jun-Sep	fast	1.012	2837	3284	26.7	0	0	0	2335	1598	0	0	8357	12290	67470
			1977-81		fast	0.753	2936	2410	24.5	0	0	0	1872	1281	0	0	6701	9854	54097
			1972-76		slow	0.834	2089	2118	26.9	0	0	0	1494	1022	0	0	5348	7864	43173
			1977-81		slow	0.685	2101	1833	25.8	0	0	0	1351	924	0	0	4835	7110	39034
2 to 3	imm	SEBS Shelf break	1972-76	Oct-May	fast	1.012	6158	1932	14.3	0	0	0	1219	948	0	0	11375	13542	78348
			1977-81		fast	0.753	5373	2136	16.1	0	0	0	1193	928	0	0	11134	13255	76688
			1972-76		slow	0.834	4231	1178	14.0	0	0	0	758	590	0	0	7076	8424	48739
			1977-81		slow	0.685	3955	1637	16.9	0	0	0	875	680	0	0	8163	9718	56223
3	imm	CBS basin	1972-76	Jun-Sep	slow	0.910	5385	3331	21.3	0	0	0	781	781	0	0	14054	15616	86027
			1977-81		slow	0.727	5572	2797	20.0	0	0	0	701	701	0	0	12610	14012	77189
3 to 4	imm	SEBS Shelf break	1972-76	Oct-May	slow	0.910	8751	1592	10.6	0	0	0	599	1049	0	0	13331	14979	86623
			1977-81		slow	0.727	8398	2127	12.6	0	0	0	676	1183	0	0	15039	16898	97719
3	mat	NEBS Shelf <30m	1972-76	Jun-Jun	fast	1.068	7777	1054	30.7	0	0	0	0	3428	0	0	0	3428	27452
			1977-81		fast	1.083	6946	1488	34.0	0	0	0	0	4373	0	0	0	4373	35022
4	mat	NEBS Shelf <30m	1972-76	Jun-Jun	slow	1.138	9031	1609	29.3	0	0	0	0	5499	0	0	0	5499	44032
			1977-81		slow	1.154	10059	1751	29.1	0	0	0	0	6022	0	0	0	6022	48221

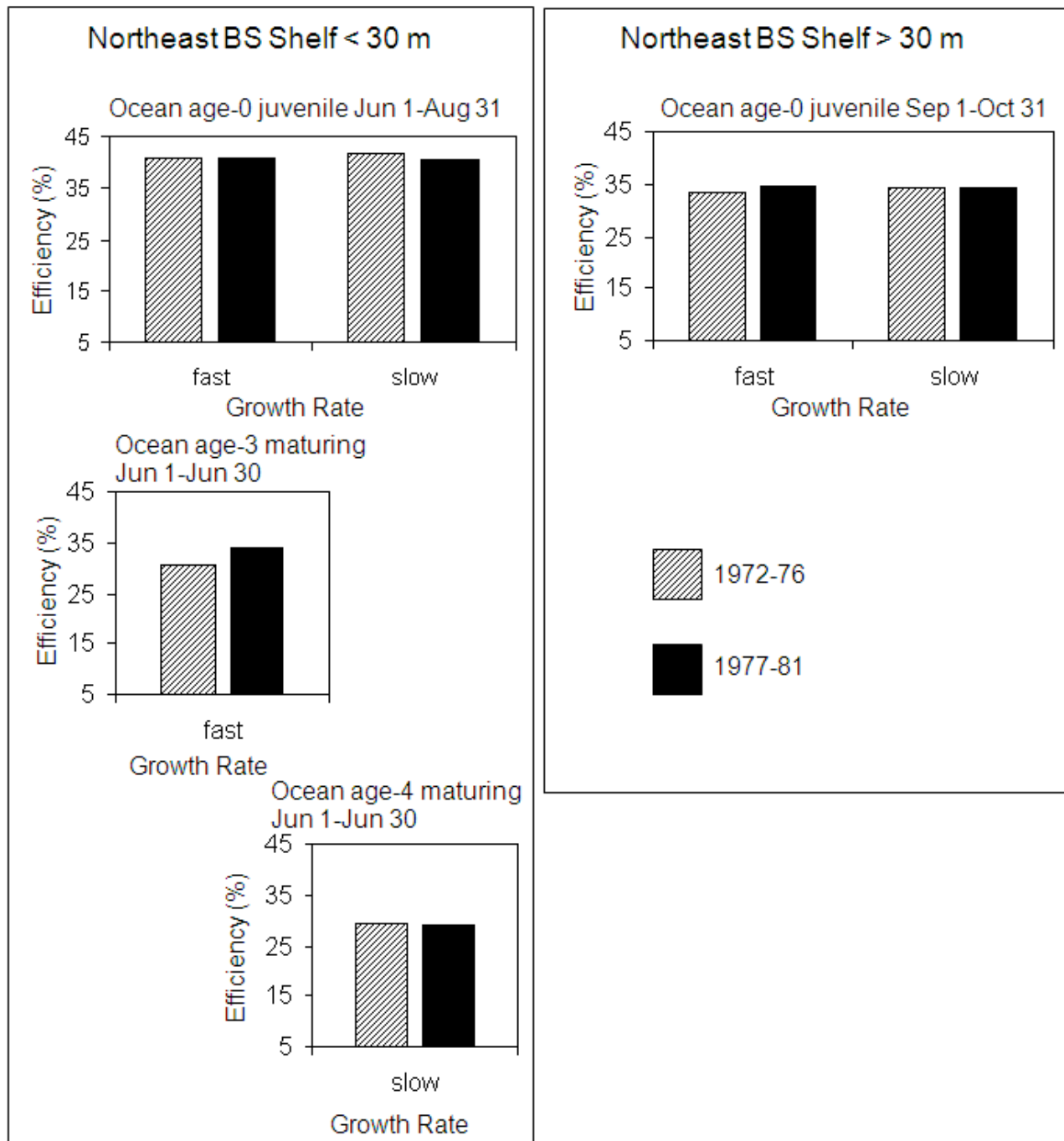


Figure 6- 3. Estimated conversion efficiency (%; net production/total prey consumption) for juvenile and maturing female Yukon Chinook salmon before (1972-1976) and after (1977-1981) the 1977 regime shift. Left panel shows estimates for the northeast Bering Sea shelf (<30 m) habitat in summer for juvenile and maturing Chinook salmon. Right panel shows conversion efficiency of juvenile fish in the northeast Bering Sea shelf (>30 m) habitat in fall. Fast growing fish mature and return to the river at ocean age-3 and slow-growing fish mature and return at ocean age-4. Conversion efficiency estimates based on a bioenergetics model.

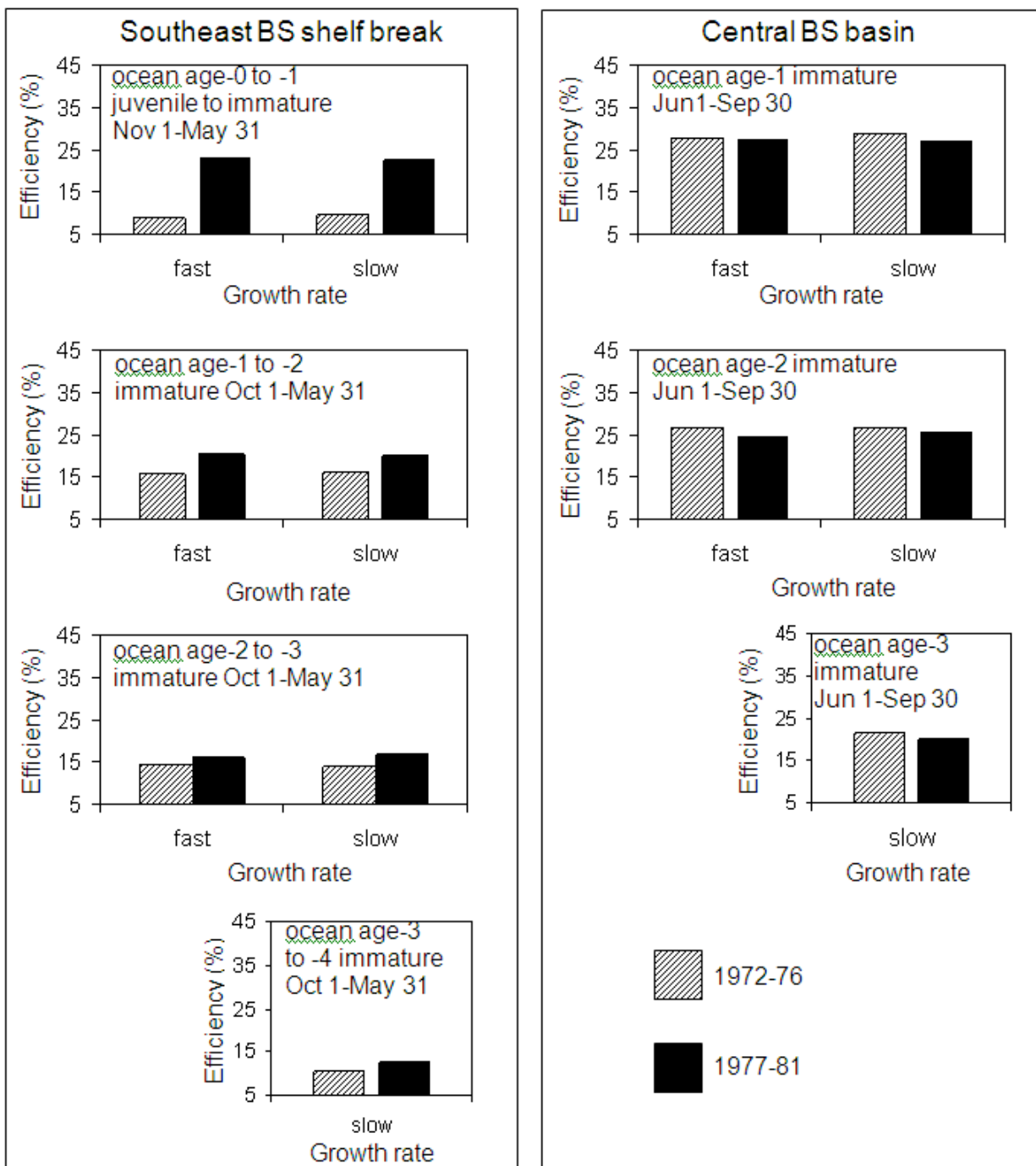


Figure 6- 4. Estimated conversion efficiency (%; net production/total prey consumption) for juvenile and immature female Yukon Chinooks salmon before (1972-1976) and after (1977-1981) the 1977 regime shift. Left panel shows estimates for the southeast Bering Sea shelf break habitat in winter for juvenile and immature Chinook salmon. Right panel shows conversion efficiency of immature fish in the central Bering Sea basin in summer. Fast growing fish mature and return to the river at ocean age-3 and slow-growing fish mature and return at ocean age-4. Conversion efficiency estimates based on a bioenergetics model.

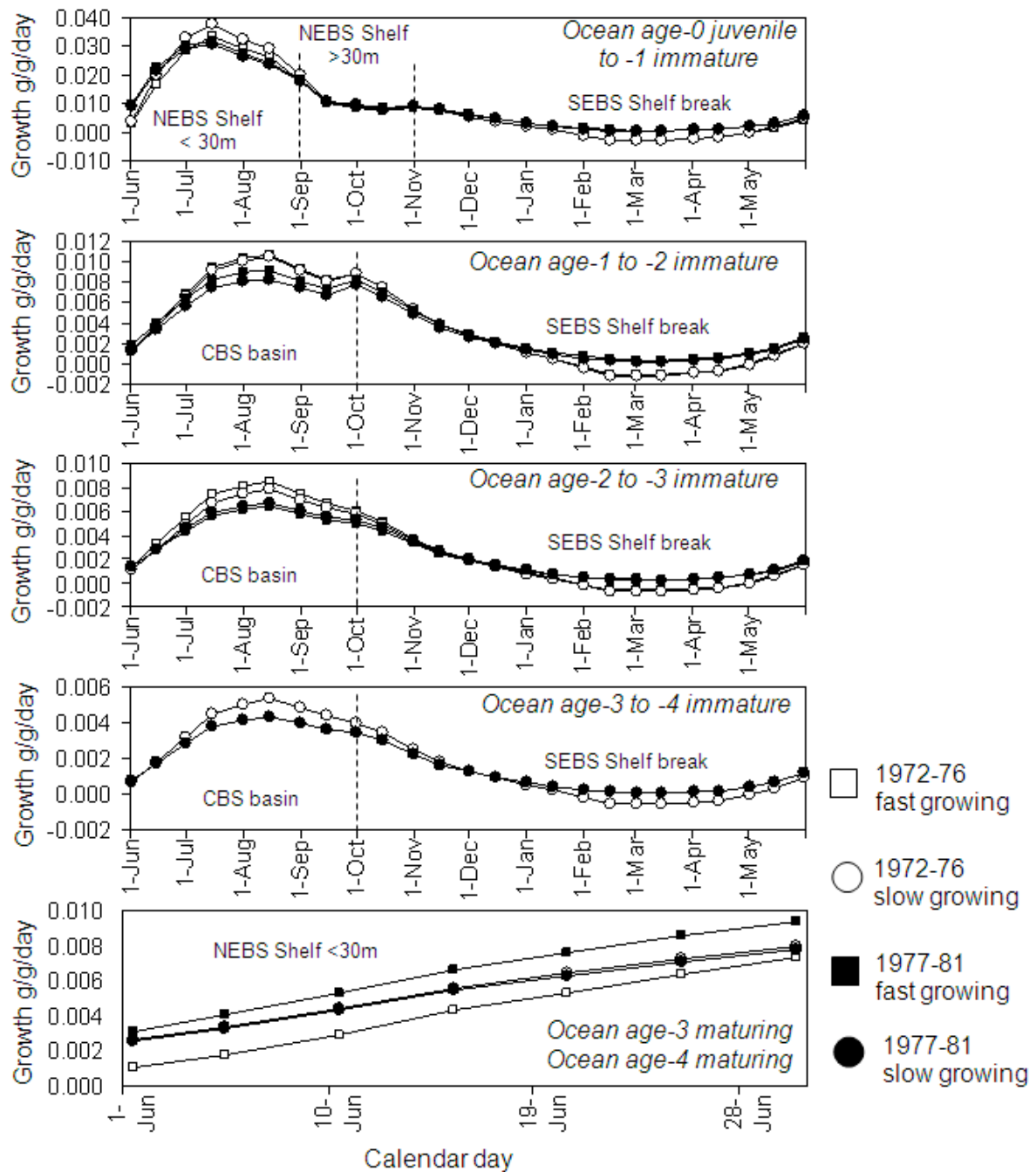


Figure 6- 5. Change in female Chinook salmon growth rate (g/g/day) by habitat for ocean age-0 juveniles, ocean age-1, -2, -and -3 immature, and ocean age -3 and -4 maturing fish before (1972-76) and after (1977-81) the 1977 regime shift. Growth rates estimated from bioenergetics models based on yearly body weight increments determined from back calculation of female Yukon River Chinook salmon scales and conversion from fish length to weight data. Fast-growing fish mature and return to freshwater at ocean age-3 and slow-growing fish mature and return at ocean age-4. Note there are different scales on the Y-axis among different age-maturity groups of Chinook salmon.

Results Objective 7: Map Spatial and Temporal Variability in Ocean Growth Potential

Our bioenergetics model results provide ocean age-specific daily growth rates with respect to sea surface temperature for mapping ocean growth potential of AYK Chinook salmon in the Bering Sea (minimum winter temperature 2.5°C; maximum summer temperature 13°C). Improved diet quality enabled growth at lower feeding rates and enabled growth to occur at a wider range of temperatures than the lower quality diet (Figs. 7-1 and 7-2). Juvenile (ocean age-0) Chinook salmon had substantially higher growth rates (g/g/day) than older fish. Specific growth rates of juvenile Chinook salmon were approximately three times higher than the growth rate immature ocean age-1 fish and approximately 10 times higher than immature ocean age-4 fish consuming the same quality diet. Juvenile Chinook salmon showed a high growth rate over a broader range of temperatures than older fish. The minimum temperature required for Chinook salmon to grow was about 2-3°C. The optimal temperature for growth occurred at 11° to 14°C. Fish with an improved diet grew at higher temperatures than fish consuming a lower quality diet. The optimal temperature for growth declined with consumption rate in all age-maturity groups.

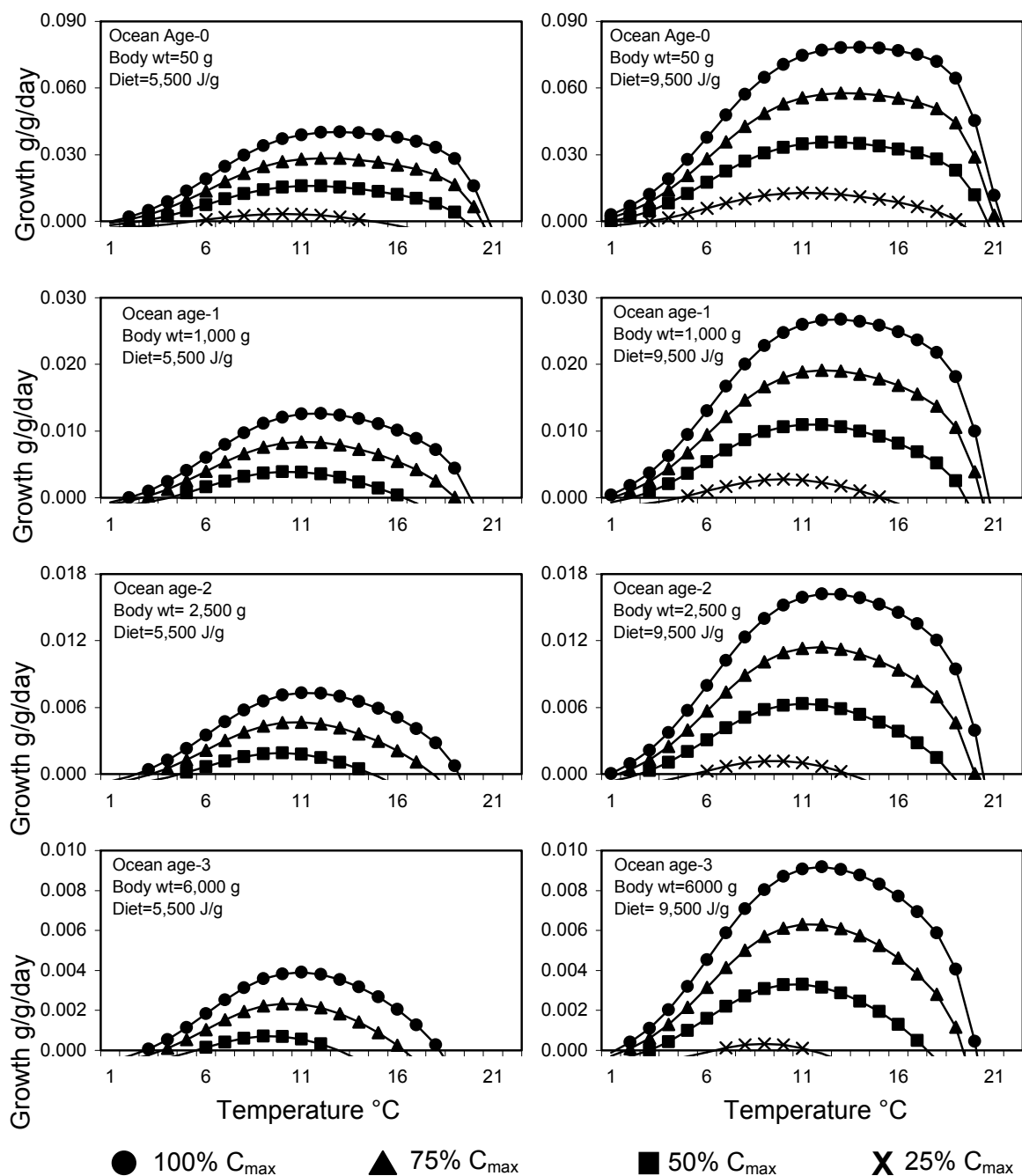


Figure 7- 1. Change in daily growth rate (g/g/day) compared with sea surface temperature (°C) and different feeding rates (25% to 100% C_{max} ; maximum prey consumption rate) for the body weight (g) of Chinook salmon typical for juvenile (ocean age-0) and immature (ocean age-1, -2, -3) fish. Scenarios depict differences in growth rates between a Chinook salmon consuming an energy density diet of 5,500 J/g wet weight (left side) and a 9,500 J/g wet weight diet (right side) based on a bioenergetics model. Note there are different scales on the Y-axis among different ages of Chinook salmon.

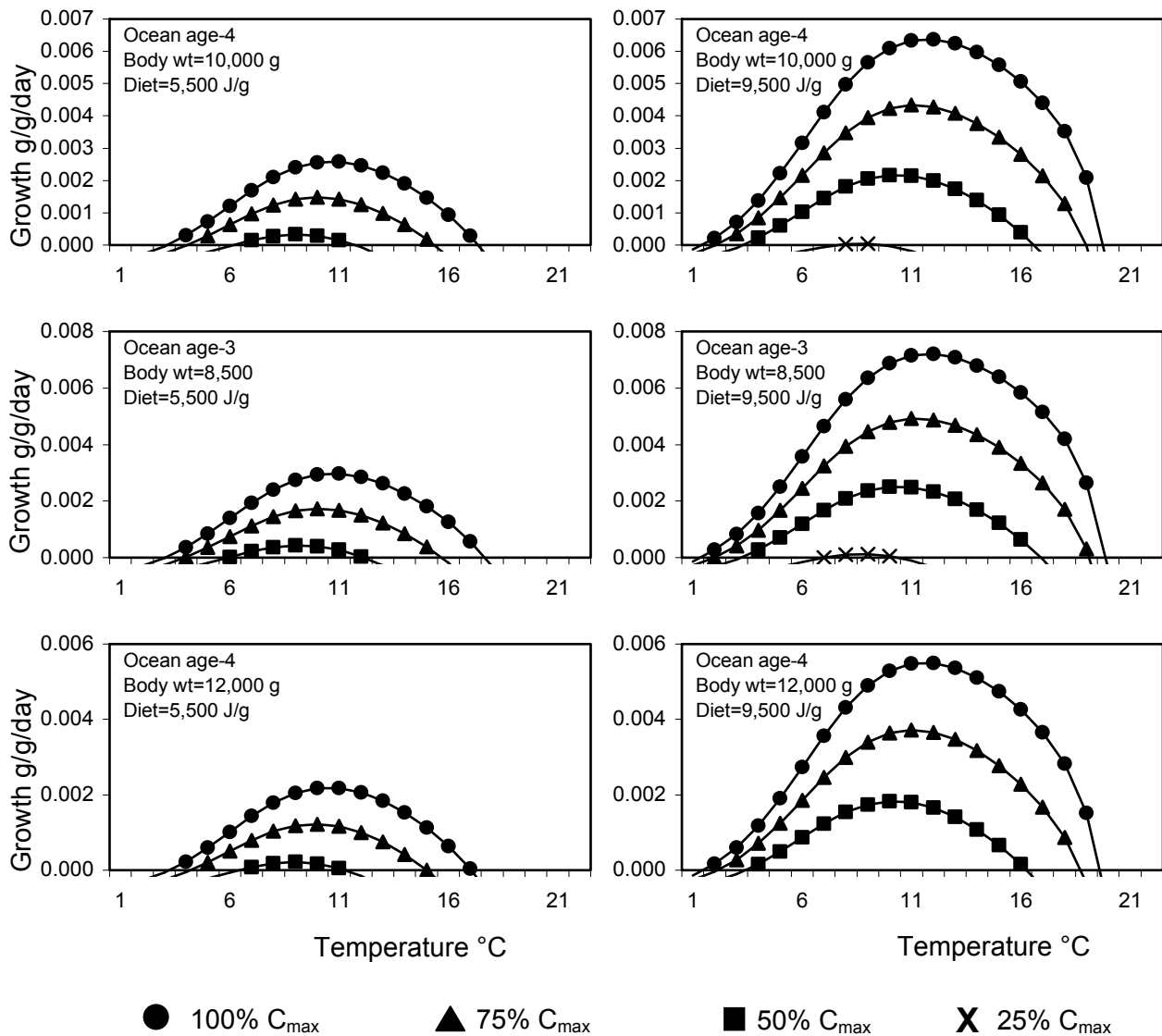


Figure 7- 2. Change in daily growth rate (g/g/day) compared with sea surface temperature (°C) and different feeding rates (25% to 100% C_{max} ; maximum prey consumption rate) for the body weight (g) of Chinook salmon typical for immature (ocean age-4) and maturing (ocean age-3 and -4) fish. Scenarios depict differences in growth rates between a Chinook salmon consuming an energy density diet of 5,500 J/g wet weight (left side) and a 9,500 J/g wet weight diet (right side) based on a bioenergetics model. Note there are different scales on the Y-axis among different age-maturity groups of Chinook salmon.

Results Objective 8: Simulate Climate Effects on Age and Growth

Adult female Chinook salmon in test gillnet fishery samples from the mouth of the Yukon River were predominantly age 1.4 fish. However, in some years (e.g., 1998, Table 8-2) proportions of age 1.3 fish were relatively high. Previous analyses of scale samples from Chinook salmon caught by U.S. commercial groundfish fisheries in the Bering Sea in winter show that annuli are present at the outer edge of the scale in January (K. Myers and J. Armstrong, unpublished data). We assumed, therefore, that back-calculated lengths from the Ruggerone et al. (2007; 2009a,b) annual scale growth increment data represent size of fish on January 1 of each year. The back-calculated MEFT lengths of maturing ages 1.3 and 1.4 females in 1997-2004 test fishery samples (brood years 1992-1998) ranged from 67 to 101 cm in January (n=273 fish).

Logistic regression analysis identified significant effects of length on the probability of maturing at age 1.3 (Fig. 8-1, Table 8-3). An earlier iteration of the model that included brood year as a variable indicated that brood year effects were not statistically significant. The results were robust to assumptions about mortality, and threshold size at maturity was relatively insensitive to changes in mortality.

The optimal rule of size and age at maturity for female Chinook salmon was predicted for different growth rates and assumptions about mortality (M) (Fig. 2). Fish with low growth rates initiated maturation at an older age and smaller size than fish with high growth rates. The results were sensitive to changes in mortality. There was a good fit between the observed length threshold value (50% probability of maturing) for age 1.3 female Yukon River Chinook salmon and the model at relatively high mortality rates (between 0.4 and 0.6) and growth rates ($k=0.4$).

The estimated optimal ocean growth rates (k^*) for female BY1992-1998 Yukon River Chinook salmon was low, 0.12 ($R^2 = 0.98$, $t_0 = 0.633$, $L_\infty = 227$ cm), for fish that matured at age 1.3 and only slightly lower, 0.10 ($R^2 = 0.98$, $t_0 = 0.546$, $L_\infty = 229$ cm) for fish that matured at age 1.4.

The simulation of average age and size at maturity indicated that at low growth rates ($k = 0.2$ or less) no female Chinook salmon would mature at age 1.3 and at high growth rates (0.5 or greater) all female Chinook salmon would mature at age 1.3 (Table 4). Size of age 1.3 fish at maturation (in January) increased with growth rate. Observed (back-calculated) average sizes of maturing age 1.3 female Yukon River Chinook salmon in January were comparable to simulated sizes at growth less than 0.5 and greater than 0.2. Observed average sizes of age 1.3 female Chinook salmon in January samples from the bycatch of the Bering Sea commercial groundfish fishery were not comparable to simulated sizes.

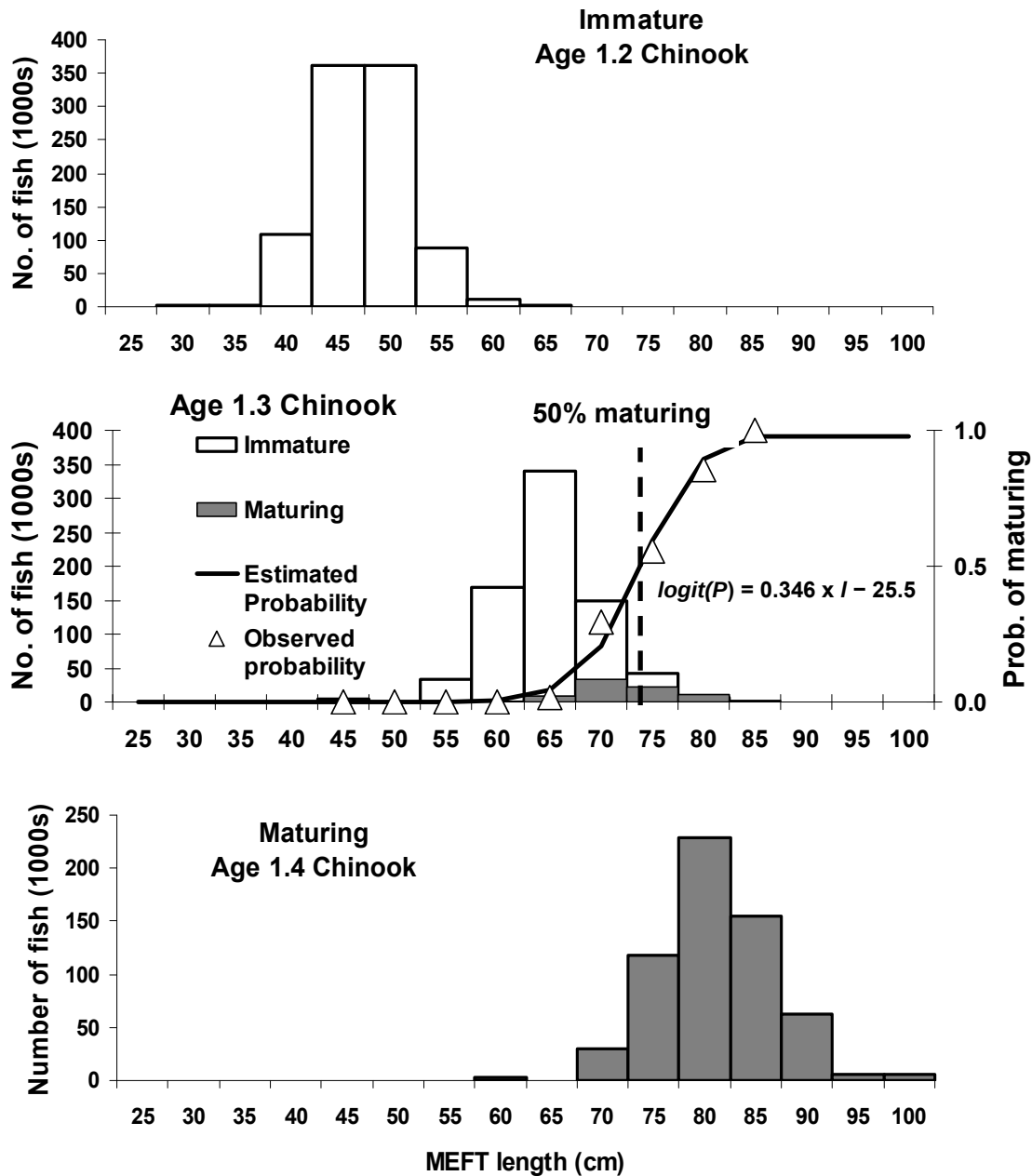


Figure 8- 1. Winter (January) ocean length-frequency distributions for combined brood years (1992-1997) of ages 1.2, 1.3, and 1.4 female Chinook salmon from the Yukon River, assuming a baseline annual mortality rate of 0.2 (Ricker 1976); open bars, immature; shaded bars, maturing; MEFT is mid-eye-to-fork-of-tail length. The estimated logistic regression of the probability of maturing (P) at age 1.3 is plotted on fork length (curved solid line, center panel; triangles, observed probability of maturing; broken line, threshold (50% probability) size at maturing).

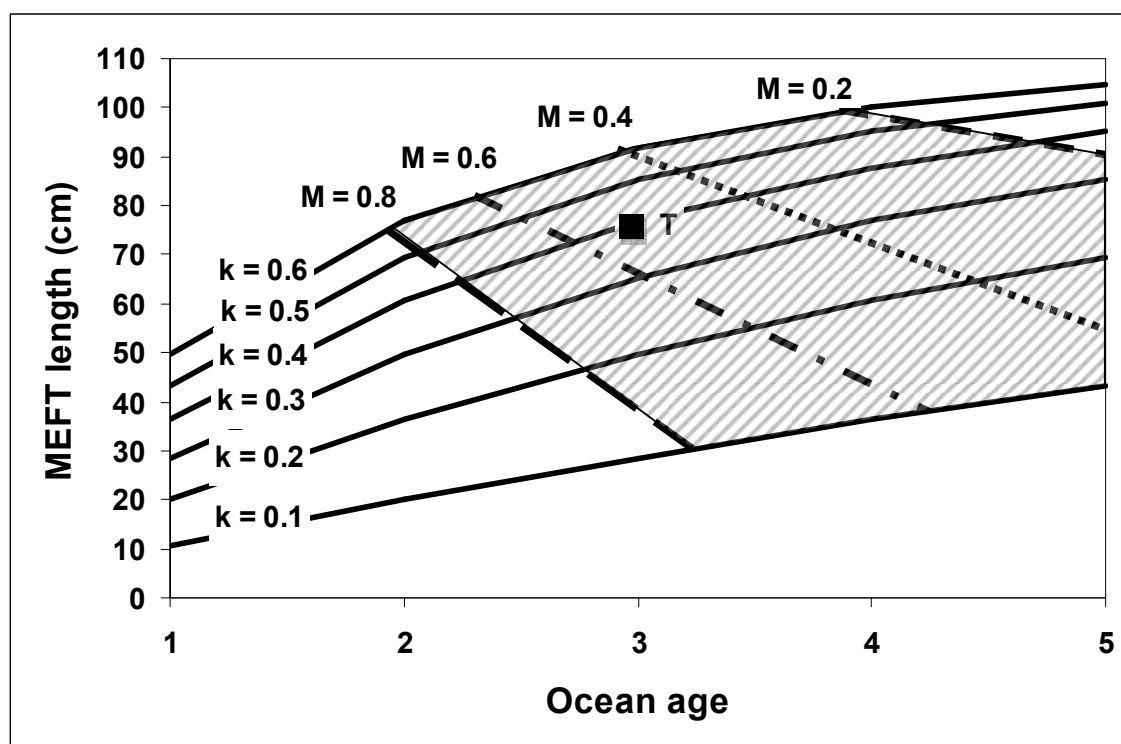


Figure 8- 2. Female Chinook salmon growth trajectories and optimal age at maturation with different growth rates (k). The hatched area indicates the optimal age and size at maturation (in January) that maximizes fitness at different mortality rates (M). Observed (back-calculated) threshold (T, 50% probability of maturing) size for age 1.3 female Yukon River Chinook salmon in January is indicated by a closed square. Ocean age is the number of winters the fish spent in the ocean. MEFT = mid-eye-to-fork-of-tail length.

Table 8- 3. Logistic regression models of size at maturity of age 1.3 female Yukon River Chinook salmon and estimated threshold size at maturity (50% probability of maturing) for three different mortality assumptions. MEFT = mid-eye-to-fork-of-tail length; SNF=tip-of-snout-to-fork-of-tail length.

Mortality rate	Coefficients	Value	Std. Error	t value	P	Threshold size (cm)	
						MEFT	SNF
0.20	Intercept	-25.549	7.533	-3.3917	0.0006		
	Length	0.346	0.102	3.379	0.0007	75.3	83.9
0.445	Intercept	-26.371	7.864	-3.353	0.0007		
	Length	0.355	0.106	3.341	0.0008	75.6	84.2
0.69	Intercept	-27.319	8.247	-3.313	0.0009		
	Length	0.366	0.111	3.302	0.0009	75.9	84.6

Table 8- 4. Simulated and observed mean size (MEFT length, cm) and ocean age (number of ocean annuli) at maturity of female Yukon River Chinook salmon in January at four different growth rates ($k = 0.2, 0.3, 0.4$, and 0.5). Observed sizes of Yukon River fish in January were back-calculated from scale data. Bering Sea observations are from mixed-stock samples of female Chinook salmon in the bycatch of commercial groundfish trawl fisheries in winter. MEFT = mid-eye-to-fork-of-tail length.

Population	Mean (SD, N) MEFT Length (cm)	Mean ocean age
<u>Simultated</u>		
$k=0.2$, age 1.3 female (January)	no maturing age 1.3 fish	4.0
$k=0.3$, age 1.3 female (January)	76.9	3.9
$k=0.4$, age 1.3 female (January)	79.9	3.3
$k=0.5$, age 1.3 female (January)	86.3	3.0
<u>Observed female (January)</u>		
Yukon River, 1972-1976 (Pre-regime shift)	78.6 (5.9, 93)	
Yukon River, 1977-1981 (Post-regime shift)	76.8 (5.7, 102)	
Yukon River, 1997-2004	75.9 (4.8, 94)	
Bering Sea bycatch, 1978-81 (maturity unknown)	63.0 (5.4, 129)	
Bering Sea bycatch, 1997 (maturity unknown)	63.2 (5.3, 110)	
Bering Sea bycatch, 2007-2008 (maturing)	60.5 (4.2, 24)	

Results Objective 9: Synthesize Information on the Ocean Life History and Climate-Ocean Effects on Chinook Salmon

Long-Term Trends and Shifts in Size of Immature Chinook Salmon in the Bering Sea

A sequential t-test analysis of regime shifts (STARS; Rodionov 2005) detected statistically significant ($p < 0.05$) shifts in mean fork length of immature age 1.2 female Chinook salmon in Japanese research vessel samples from the central Bering Sea in July, 1974-2008 (Fig. 9-1). A significant increase in mean lengths occurred in 1978 and a significant decrease occurred in 1991. The first shift occurred one year after the 1977 regime shift, and the second shift occurred two years after the 1989 regime shift, indicating that growth effects likely occurred when fish were age 1.1 or 1.0, respectively. A third shift in 2004 was not statistically significant. Although not tested with STARS, mean fork lengths of immature age 1.2 male Chinook salmon were usually larger than females, but showed long-term trends and shifts in mean fork lengths similar to females (Fig. 3-23).

Correlations Between Annual Scale Growth Increments and Climate Indices

Relationships between mixed-stock *Wakatake maru* (WAK) and NOAA Observer Program (OBS) Chinook scale growth increments by age and life stage and numerous climate indices were investigated (Tables 9-1 and 9-2; Appendix Table 6-1). All final best-fit model results for WAK age 1.2 Chinook salmon were highly significant with high p-values (Table 9-3, from 0.6 to 0.8). Models each incorporated measures of wind stress and temperature. High winds had a negative effect in either winter for SW1 or in spring for freshwater (FW1) and 2nd-year (SW2) ocean growth, and temperature had a positive effect for FW1 and SW2 growth. Opposite effects were noted for the final growth stage of maturing fish (SWPlus), when wind had a positive effect, as did the PDO.

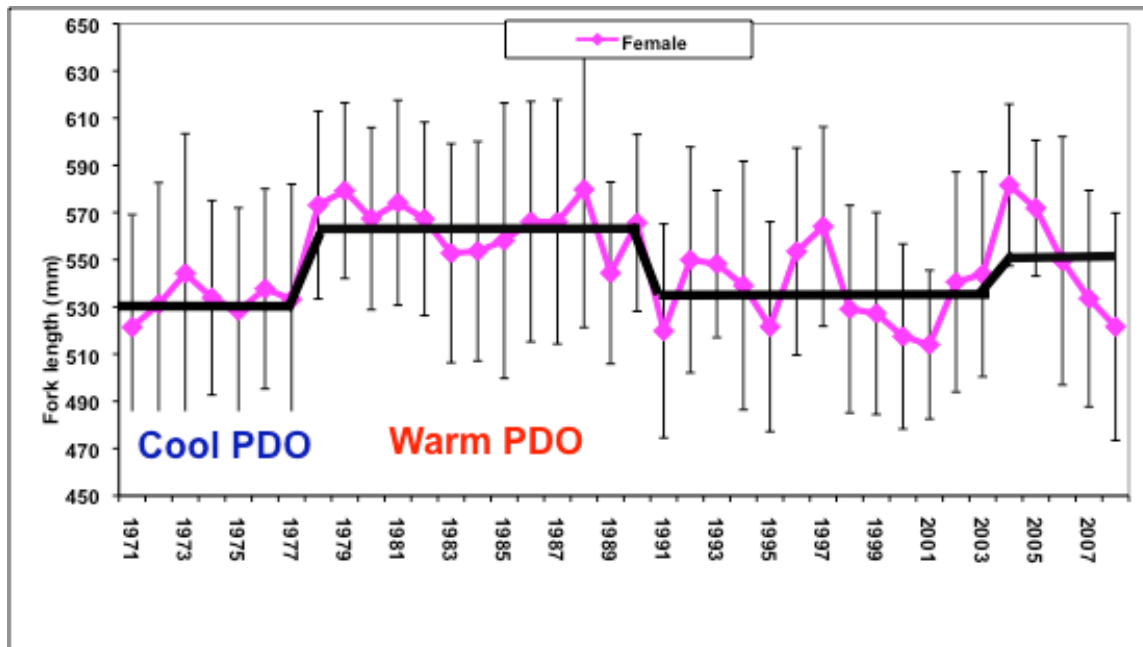


Figure 9- 1. Sequential t-test analysis of regime shifts (STARS; Rodionov 2005) in mean fork lengths (mm) of immature age 1.2 female Chinook salmon in Japanese research vessel samples from the eastern Bering Sea in July 1974-2008. Mean fork lengths by period are: 1971-1977 = 533 mm, 1978-1990 = 565 mm; 1991-2003 = 535.5 mm; 2004-2008 = 551 mm. The early period (1974-1976) corresponds to a negative (cool) phase of the Pacific Decadal Oscillation (PDO), and the second period (1977-1989) corresponds to a positive (warm) phase of the PDO. Data source: M. Fukuwaka, Hokkaido National Fisheries Research Institute, Fisheries Research Agency, Japan.

For ages 1.2, 1.3 and 1.4 OBS Chinook, the influence of temperature on FW1 growth was evident in high positive correlations with average summer and spring/summer air temperatures at Fairbanks, Alaska, and negative correlations with fall and winter temperatures (Table 9-2). Significant negative correlations with the Aleutian Low Pressure Index (ALPI) and positive correlations with the Arctic Oscillation (AO), North Pacific Index (NPI), and Bering Sea Pressure Index (BSPI) in winter indicated the strong influence of pressure systems over the western North American continent on freshwater growth. Lower pressure (stronger AO, NPI, and BSPIwinter) brought more storms from the south and warmer temperatures to the Alaskan land mass. Thus, during that first year of freshwater residence, warmer temperatures throughout the year encouraged greater growth.

First-year ocean growth (SW1) of OBS Chinook was positively correlated with warm El Niño events and Fairbanks average temperatures especially in fall and winter, and negatively correlated with NPI, BSPIspring, spring/summer wind mixing, and fall-winter wind stress across the Alaska Peninsula (Table 9-2). The strength of spring/summer wind mixing may disrupt or delay conditions conducive for primary and secondary production as shelf waters are unable to stratify, reducing food resources for smolts entering the coastal marine environment.

Second-year ocean growth (SW2) of OBS Chinook was highly positively correlated with the Pacific Decadal Oscillation (PDO), Alaskan Index, all seasons surface air temperature (SAT), and sea surface temperature (SST) measures for the eastern Bering Sea (EBS), and winter average temperature in Fairbanks (Table 9-2). Negative correlations were associated with sea ice cover and longevity, and wind stress along the Alaska Peninsula, especially in May and June. Again, higher temperatures promoted greater growth.

Growth of OBS Chinook in later ocean years (SW3 and SW4) was less correlated with pressure indices but continued to reflect strong relationships with temperature, including high positive correlations with all-seasons surface air temperature (SAT) in the Pribilofs and SST in the EBS, winter air temperatures in Fairbanks and summer mixing (Table 9-2). Negative correlations persisted with sea ice cover and longevity, winter air temperatures in Fairbanks, May mixing, and wind stress along the Alaska Peninsula in May and June.

Similar to mixed-stock WAK Chinook, final best-fit regression models for OBS Chinook consistently selected climate indices of atmospheric pressure and temperature (Table 9-4). For all ages of OBS Chinook, the relationships between climate indices and FW1 growth were not very strong (r -squared ≤ 0.35) and p -values just barely significant for wind stress and pressure (NPI and ALPI). SW1 growth was more highly related to measures of El Niño, temperature, and wind mixing for ages 1.2 and 1.3 Chinook (r -squared values 0.67 – 0.93, p -values < 0.0001). Growth at SW2, SW3, and SW4 stages was reflected in measures of temperature and wind stress for all age groups (r -squared values 0.41 – 0.76, p -values < 0.05 to 0.01 for SW2 and r -squared values 0.52 – 0.85, p -values < 0.01 for SW3 and SW4).

For female YUK Chinook salmon, correlations between climate variables and annual ocean growth were positive for those variables associated with temperatures and negative for those associated with more sea ice cover and later ice retreat (Table 9-5). Some wind stress variables were also negatively associated with ocean growth. Marine growth of age 1.4 fish showed a negative correlation with ice cover and positive correlations with warmer sea temperatures (Table 9-5). Few linear regressions of age 1.4 fish showed significant ($p < 0.05$) relations with indices (Table 9-6). Few climate indices correlated with the marine growth of the faster-growing age 1.3 females (only five Pearson r values over 0.45, Table 9-5), and only two linear regressions with indices were significant (Table 9-7).

Potential Climate Change Impacts on Thermal Habitats of Chinook Salmon

The following results were extracted from a manuscript submitted to a peer-reviewed scientific journal (Abdul-Aziz, O.I., N.J. Mantua, and K.W. Myers. Potential climate change impacts of thermal habitats of Pacific salmon in the North Pacific Ocean and adjacent seas. Submitted to the Canadian Journal of Fisheries and Aquatic Sciences, November 3, 2010).

Non-dimensional sensitivity coefficients and percent changes (in parentheses) in 1980s reference habitat areas for a 1°C increase in respective reference limits were: July (cold limit) -0.01 (-0.87); July (warm) 1.95 (19.47); December (cold) -0.10 (-6.61); December (warm) 1.05 (8.76). These sensitivity coefficients can be used to calculate the percent changes in thermal habitat areas for any reference thermal limit (T_{ref}), e.g., 1°C, 2°C, 3°C,..... changes in the thermal limits can be obtained by multiplying the respective sensitivity coefficients by the factors of $100/T_{ref}$, $200/T_{ref}$, $300/T_{ref}$,, respectively, where T_{ref} is a non-zero reference thermal limit.

Both the July and December reference isotherms showed very small displacements between the warm and cool PDO phases in the 20th century (Fig. 9-2).

The Global Climate Model (GCM) scenarios show SST warming by up to ~3°C by the 2080s, with the western N. Pacific and western and northern Bering Sea (1.4-1.6°C by 2040s and 2.6-3.0°C by 2080s) warming more than other parts of the study domain (Fig. 9-3).

Based on median of SST increases over the entire study area, mean July and December temperatures were projected to increase by around 0.5°C by 2020s and 1.0°C by 2040s within the North Pacific and adjacent Arctic Basins under all three emission scenarios (Bering Sea, Fig. 9-4). The A1B scenario showed average increases of around 2.0°C both in July and December SSTs by 2080s. Increases in temperatures were around 12% higher for A2 and 31% lower for B1 scenarios, respectively, compared to those for A1B.

Changes in the high-seas thermal habitat of Chinook salmon due to natural climatic variation (PDO) in the 20th Century were small relative to potential changes under scenarios of anthropogenic climate change for the mid to late 21st Century. Under a multi-model ensemble average of climate model outputs

using the A1B (medium) emissions scenario, projected summer habitat in the North Pacific Ocean and Bering Sea decreased by 86% for Chinook salmon. Projected decreases were 25% lower for B1 (lower) emissions and 7% higher for A2 (higher) emissions scenarios. Projected habitat losses in both winter and summer were largest in the Gulf of Alaska and subarctic North Pacific.

July 1980s habitat of Chinook salmon (Fig. 9-5) encompassed a much smaller geographic range and area compared to that for other species. It included a small portion from the Gulf of Alaska in the east and extended through much of the Okhotsk Sea in the west. In the north-south dimension, it extended from the edge of Subarctic through the Beaufort, Chukchi, and Laptev Seas in the Arctic Ocean. The drastic northward movement and east-west contraction of the warmest boundary caused a complete elimination of the Gulf of Alaska habitat, substantial reductions of the Okhotsk Sea and Subarctic habitats, and a large reduction of the Bering Sea habitat by the 2040s. The 2080s SST changes resulted in complete eliminations of the Okhotsk Sea and Subarctic habitats, as well as a substantial reduction of the Bering Sea habitat. The coldest boundary also moved slightly northward to contribute only a small increase in total habitat by opening new areas in the Arctic Ocean. The overall reductions in the total reference habitat area under different emission scenarios for the 2020s were 24-29%, which were much larger than the CV of 13% of the historical areas. The 2040s habitat area reductions were 41-48% and the 2080s reductions were 88% (A2), 86% (A1B), and 66% (B1), which by far exceeded the three standard deviations (39%) of the 1970-1999 potential habitat areas.

The December 1980s habitat range for Chinook salmon (Fig. 9-5) exhibited a wider east-west band than that for other species. It excluded the Arctic Ocean while including the Gulf of Alaska, the Subarctic, most of the Bering Sea, and parts of the Okhotsk Sea. Climatic warming shifted both the warmest and coldest boundaries northward, which led to habitat losses in the Gulf of Alaska and Subarctic while opening new areas in the Bering and Okhotsk Seas. Although the total habitat area remained unchanged for the 2020s, it was reduced by 2-6% by the 2040s. The reductions of 7-12% by the 2080s were greater than the CV of 4%. However, only the reductions of 10-12% under the medium (A1B) and higher (A2) emissions scenarios exceeded the equivalent two standard deviations (8%) of the potential historical areas.

The reference July 1980s range provided suitable thermal habitat areas of around 2.49 million km² for Chinook salmon throughout the entire Bering Sea area, and was reduced by 0.13-2.22 million km² for the 2020s through 2080s. The Arctic Ocean provided July 1980s thermal habitat areas of 0.31 million km² for Chinook salmon, and climatic warming led to an increase in July reference habitat areas of 0.01-0.20 million km². However, historical December reference habitats in the Arctic Ocean were eliminated under all emission scenarios for these periods. In the Gulf of Alaska there was complete (i.e., 100%) elimination of the July reference area (0.41 million km²) for Chinook salmon under each of the three emission scenarios. In the subarctic North Pacific, the reference July habitat of Chinook salmon (4.43 million km²) was completely eliminated by the 2080s under each of the three emission scenarios.

Table 9- 1. Correlation coefficients for age 1.2 *Wakatake* (WAK) Chinook salmon scale growth increments by life stage and various regional/local climate indices for the eastern Bering Sea (EBS). Peach highlight = indices tested in initial models (some later omitted). Bold font = correlation coefficients ≥ 0.45 or ≤ -0.45 . Yellow highlight = factors selected in final regression models (see Table 9-4). FW1 = 1st year in freshwater; SW1 = 1st ocean year; SW2 = 2nd ocean year; SWPI = plus growth in 3rd ocean summer. See Appendix Table 6-1 for description of indices.

Climate Indices	Chinook salmon life history (growth) stage			
	Freshwater FW1	1 st Ocean- SW1	2 nd Ocean- SW2	3 rd Ocean SWPI
PDO	0.003	0.584	0.417	0.633
AO	-0.536	0.001	-0.067	-0.079
ALPI	0.312	0.065	-0.005	0.118
NPI	-0.547	-0.139	-0.173	-0.130
BSPIw	-0.338	0.332	0.143	0.164
BSPIsp	-0.082	-0.277	-0.069	0.209
AlaskaIdx	-0.155	0.425	0.621	0.204
SibAlaskaIdx	0.045	-0.237	-0.285	-0.068
SibIdx	-0.141	0.178	0.284	-0.210
NINO3.4AnnAvg	0.158	0.500	0.122	0.431
MEI	0.151	0.495	-0.072	0.444
MElw	0.116	0.231		0.015
Sea Ice Cover	-0.012	-0.138	-0.589	-0.142
Ice Retreat (post 3/15 M2)	-0.056	-0.488	-0.336	-0.094
StPaulSATw	0.125	-0.159	0.372	0.176
StPaulSATa	-0.149	0.195	0.705	0.223
MaySSTSEBC	-0.076	0.251	0.681	0.243
SST JFMA M2	0.479	0.157	0.566	0.029
SST JFM Prib	0.556	0.165	0.231	0.042
JFM	0.315	0.546	0.334	0.016
AMJ	-0.337	0.198	0.126	-0.311
JAS	-0.279	0.051	-0.088	-0.274
OND	-0.071	0.303	0.333	0.044
NDJFM	0.170	0.505	0.323	0.014
MJJAS	-0.383	0.114	0.071	-0.256
ANNUAL	-0.050	0.560	0.394	-0.135
OptWindDays M2	0.158	-0.083	0.264	-0.148
JJ Mix M2	-0.198	0.180	0.238	0.609
HiWind M2 spring	-0.600	0.071	0.165	0.528
NSw Wind Prib	0.499	0.363	-0.017	0.086
MayMix Prib	-0.107	0.269	-0.104	0.096
WindStress AKPen NDJFMA	-0.259	-0.781	-0.408	0.169
WindStress AKPen MJ	-0.333	-0.190	-0.605	0.031

Table 9- 2. Correlation coefficients for ages 1.2, 1.3, and 1.4 Observer (OBS) Chinook scale growth increments by life stage and various regional/local climate indices for the eastern Bering Sea (EBS). Yellow highlights = factors selected in final regression models (see Table 9-5). FW1 = 1st year in freshwater; SW1 = 1st ocean year; SW2 = 2nd ocean year; SWPI = plus growth in 3rd ocean summer. See Appendix Table 6-1 for description of indices.

	Climate Indices	Freshwater Phase			First Ocean			Second Ocean			Third Ocean		Fourth Ocean
		12FW1	13FW1	14FW1	12SW1	13SW1	14SW1	12SW2	13SW2	14SW2	13SW3	14SW3	14SW4
Large - scale Climate Indices	PDO	0.089	0.184	0.280	0.245	0.437	0.222	0.474	0.324	0.524	0.262	0.066	0.057
	AO	-0.070	0.415	0.132	-0.153	0.069	-0.250	-0.243	-0.147	-0.072	-0.026	0.270	0.008
	ALPI	-0.175	-0.354	-0.503	0.334	0.301	-0.168	0.389	0.133	0.049	0.319	0.095	0.341
	NPI	-0.092	0.580	0.162	-0.473	-0.183	-0.221	-0.703	-0.141	-0.351	-0.262	-0.162	-0.198
	NINO3.4AnnAvg	-0.216	0.161	0.171	0.238	0.561	-0.152	0.375	0.055	0.164	0.190	-0.183	0.071
	MEI	-0.105	0.248	0.290	0.466	0.548	-0.022	0.453	-0.109	0.042	-0.001	-0.332	-0.025
	MEIw	0.284	0.196	0.241	0.820	0.045	-0.046	0.303	-0.089	0.015	-0.190	-0.167	-0.183
	SibAlaskaIdx	-0.236	-0.166	-0.292	0.111	-0.085	-0.238	-0.512	-0.408	-0.442	-0.326	-0.178	-0.017
	AlaskaIdx	0.190	0.225	0.278	0.007	0.232	0.316	0.612	0.487	0.703	0.547	0.269	0.180
	SibIdx	-0.128	-0.005	-0.140	0.161	0.128	-0.015	-0.064	-0.046	0.133	0.139	0.027	0.179
Smaller Scale Temp/Ice Fairbanks Air Temps Means	Sea Ice Cover	0.060	-0.004	-0.302	-0.063	-0.093	-0.053	-0.393	-0.446	-0.394	-0.452	-0.111	-0.295
	Ice Retreat (post Mar 15 M2)	0.076	0.130	-0.002	-0.246	-0.389	-0.414	-0.674	-0.295	-0.393	-0.640	-0.146	-0.588
	StPaulSATw	-0.024	-0.307	0.196	-0.053	-0.003	0.258	0.340	0.222	0.277	0.164	-0.066	-0.123
	StPaulSATa	-0.237	-0.265	-0.103	-0.013	0.277	0.337	0.661	0.642	0.395	0.698	0.314	0.486
	MaySSTSEBC	-0.203	-0.103	0.147	0.090	0.196	0.003	0.704	0.585	0.354	0.653	0.331	0.443
	SST JFMA M2	-0.057	-0.301	0.131	0.175	0.109	0.063	0.639	0.348	0.407	0.447	0.160	0.277
	SST JFM Prib	0.145	-0.272	0.078	0.120	0.107	0.236	0.668	0.242	0.323	0.234	0.022	0.034
	JFM	-0.188	-0.139	0.122	0.212	0.513	0.122	0.811	0.202	0.410	0.612	0.257	0.478
	AMJ	-0.023	0.375	0.393	0.344	-0.038	0.097	0.161	0.053	-0.233	-0.515	-0.252	-0.345
	JAS	-0.019	0.444	0.205	0.183	0.194	-0.235	-0.228	-0.277	-0.082	-0.609	-0.383	-0.632
	OND	-0.488	-0.023	-0.227	0.245	0.504	-0.406	0.207	0.059	-0.018	0.387	0.106	0.587
	NDJFM	-0.408	-0.125	-0.064	0.140	0.636	-0.055	0.711	0.212	0.244	0.639	0.260	0.626
	MJJAS	-0.168	0.468	0.252	0.241	0.199	-0.218	-0.092	-0.129	-0.186	-0.536	-0.385	-0.547
	ANNUAL	-0.449	0.118	0.097	0.421	0.677	-0.216	0.650	0.110	0.147	0.367	0.061	0.431
Local Pressure/ Wind/Mixing	OptWindDays M2	0.223	0.057	0.092	-0.213	-0.453	0.166	0.191	0.469	0.090	0.388	0.528	0.497
	BSPlw	0.405	0.551	0.067	-0.259	-0.064	0.041	-0.191	0.223	0.314	0.068	0.238	-0.225
	BSPisp	-0.174	0.159	0.121	-0.545	0.064	-0.009	-0.303	0.098	0.144	0.284	0.173	0.146
	NSw Wind Prib	0.182	-0.037	-0.296	0.493	0.259	-0.329	0.189	-0.135	0.210	0.045	0.050	-0.020
	HiWind M2 spring	-0.060	-0.019	0.048	-0.435	0.083	0.443	-0.078	0.417	0.240	0.375	0.051	0.249
	MayMix Prib	-0.472	-0.271	-0.311	0.203	0.787	0.076	0.367	-0.380	-0.126	-0.272	-0.560	-0.387
	JJ Mix M2	0.593	0.268	0.311	-0.369	-0.507	0.464	-0.114	0.527	0.449	0.505	0.423	0.249
	WindStress AKPen NDJFMA	0.084	0.175	-0.007	-0.437	-0.550	-0.294	-0.553	-0.053	-0.321	-0.085	0.017	-0.092
	WindStress AKPen MJ	-0.309	-0.144	-0.146	0.289	0.352	0.217	-0.020	-0.435	-0.548	-0.627	-0.720	-0.337

Table 9- 3. Backward stepwise multiple linear regression models of growth on climate-ocean indices for age 1.2 Chinook salmon (males and females combined) sampled during *Wakatake maru* (WAK) research surveys in the central Bering Sea in summer, 1991-2007. Bold font and asterisks indicate statistical significance (* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.0001$). See Appendix Table 6-1 for description of indices.

WAK1.2FW1

Start Model: $W12FW1 \sim NPI + HiWindM2sp + SSTJFMPrib$

Final Model: **$W12FW1 \sim -0.0021 HiWindM2sp + 0.0074 SSTJFMPrib + 0.3599$**

Multiple R-Squared: **0.8243**

p-value = **5.16e-006 *****

WAK1.2SW1

Start Model: $W12SW1 \sim PDO + MEIa + FairSATann + WindStressNDJFMA$

Final Model: **$W12SW1 \sim -0.9714 WindStressNDJFMA + 1.4322$**

Multiple R-Squared: **0.6103**

p-value = **0.0002132 *****

WAK1.2SW2

Start Model: $W12SW2 \sim PDO + AKIndx + SeaIceCover + MAYSSTSEBS + WindStressMJ$

Final Model: **$W12SW2 \sim 0.0815 MAYSSTSEBS -0.5677 WindStressMJ + 0.9248$**

Multiple R-Squared: **0.6151**

p-value = **0.001252 *****

WAK1.2SWPlus

Start Model: $W12SWPl \sim PDO + HiWindM2sp + JJMixM2$

Final Model: **$W12SWPL \sim 0.0309 PDO + 3.9579 JJMixM2 + 0.1302$**

Multiple R-Squared: **0.6426**

p-value = **0.000746 *****

Table 9- 4. Backward stepwise multiple linear regression models of growth on climate-ocean indices for ages 1.2, 1.3, and 1.4 Observer (OBS) Chinook salmon (males and females combined) sampled by NOAA Fisheries Observer Program research surveys in the central Bering Sea in summer. Bold font and asterisks indicate statistical significance (* = $p < 0.05$, **= $p < 0.01$, ***= $p < 0.0001$). See Appendix Table 6-1 for description of indices.

Freshwater Growth

OBS1.2FW1

Start Model: $12\text{OBSFW1} \sim \text{FairSATfall} + \text{JJ.Mix.M2}$

Final Model: $12\text{OBSFW1} \sim 55.8165 \text{ JJ.Mix.M2} - 0.7493$

R-squared = 0.3514, P value = **0.04222***

OBS1.3FW1

Start Model: $13\text{OBSFW1} \sim \text{NPI} + \text{BSPIw} + \text{FairSATsummer}$

Final Model: $13\text{OBSFW1} \sim 0.4772 \text{ NPI} + 0.1172$

R-squared = 0.3366, P value = **0.04798 ***

OBS1.4FW1

Start Model: $14\text{OBSFW1} \sim \text{ALPI}$

Final Model: $14\text{OBSFW1} \sim -0.1441 \text{ ALPI} + 0.1630$

R-squared = 0.2526, P value = 0.09587

First Ocean Growth

OBS1.2SW1

Start Model: $12\text{OBSSW1} \sim \text{BSPIsp} + \text{NPI} + \text{MEIw} + \text{NSw.Wind.Prib}$

Final Model: $12\text{OBSSW1} \sim 0.2363 \text{ MEIw} - 0.0285$

R-squared = 0.6729, P value = **0.001082****

OBS1.3SW1

Start Model: $13\text{OBSSW1} \sim \text{MEIann} + \text{FairSATann} + \text{MayMix.Prib} + \text{WindStress.AKPen.NDJFMA}$

Final Model: $13\text{OBSSW1} \sim -0.2675 \text{ MEIann} + 0.1322 \text{ FairSATann} + 21.2246 \text{ MayMix.Prib} - 4.2505$

R-squared = 0.9271, P value = **0.00006731 *****

OBS1.4SW1

Start Model: $14\text{OBSSW1} \sim \text{JJ.Mix.M2}$

Final Model: $14\text{OBSSW1} \sim 26.8973 \text{ JJ.Mix.M2} - 0.4169$

R-squared = 0.2153, P value = 0.1287

Second Ocean Growth

OBS1.2SW2

Start Model: $12\text{OBSSW2} \sim \text{PDO} + \text{NPI} + \text{MEIann} + \text{AlaskaIndx} + \text{MaySSTSEBS} + \text{FairSATw} + \text{Ice.Retreat(post.Mar.15.Mooring.2)} + \text{WindStress.AKPen.NDJFMA}$

Final Model: $12\text{OBSSW2} \sim 0.0677 \text{ FairSATw} - 3.2288 \text{ WindStress.AKPen.NDJFMA} + 0.0236$

R-squared = 0.7621, P value = **0.001562 ****

OBS1.3SW2

Start Model: $13\text{OBSSW2} \sim \text{AlaskaIndx} + \text{Sea.Ice.Cover} + \text{StPaulSATa} + \text{JJ.Mix.M2}$

Final Model: $13\text{OBSSW2} \sim 0.3014 \text{ StPaulSATa} - 0.6851$

R-squared = 0.4125, P value = **0.02432 ***

OBS1.4SW2

Start Model: $14\text{OBSSW2} \sim \text{PDO} + \text{AlaskaIndx} + \text{JJ.Mix.M2} + \text{WindStress.AKPen.MJ}$

Final Model: $14\text{OBSSW2} \sim 0.3699 \text{ PDO} - 3.3832 \text{ WindStress.AKPen.MJ} - 0.0436$

R-squared = 0.7445, P value = **0.002155 ****

Table 9-4. (continued)

Third Ocean Growth

OBS1.3SW3

Start Model: 13OBSSW3 ~ AlaskaIndx + Ice.Retreat(post.Mar.15.M2) + StPaulSATa + FairSATwinter + FairSATsummer + WindStress.AKPen.MJ

Final Model: 13OBSSW3 ~ 0.1923 StPaulSATa + 0.0304 FairSATwinter -0.0709 FairSATsummer – 1.4326 WindStress.AKPen.MJ + 3.4823

R-squared = 0.8464, P value = **0.00563 ****

OBS1.4SW3

Start Model: 14OBSSW3 ~ WindStress.AKPen.MJ + OptWindDays.M2 + MayMix.Prib

Final Model: 14OBSSW3 ~ – 3.5844 WindStress.AKPen.MJ + 0.0531

R-squared = 0.5189, P value = **0.008232 ****

Fourth Ocean Growth

OBS1.4SW4

Start Model: 14OBSSW4 ~ OptWindDays.M2 + FairSATfall + FairSATJAS + StPaulSATa + Ice.Retreat(post.Mar.15.M2)

Final Model: 14OBSSW4 ~ 0.0534 FairSATfall – 0.1869 FairSATJAS + 9.7785

R-squared = 0.7156, P value = **0.003488 ****

Table 9- 5. Correlations (r values) between climate-ocean indices and annual scale growth of adult Yukon River female age 1.4 Chinook, 1996-2008. Shaded cells are r values greater than 0.4, bold font are values greater than 0.3. FW1=freshwater year; SW1=first ocean year; SW2=second ocean year; SW3=third ocean year; SW4=fourth ocean year. See Appendix Table 6-1 for description of indices.

Yukon 1.4 F 1996-2008						Yukon 1.3 F 1996-2008			
	1.4FW1	1.4SW1	1.4SW2	1.4SW3	1.4SW4	Y1.3 FW1	1.3 SW1	1.3 SW2	1.3 SW3
Climate Indices									
PDO	-0.642	-0.043	0.175	-0.024	-0.139	-0.216	0.011	0.049	-0.260
AO	-0.034	-0.145	-0.247	0.070	0.063	-0.038	-0.391	0.287	0.197
ALPI	0.098	0.463	0.226	0.183	-0.277	0.275	0.482	0.143	-0.287
NPI	0.068	-0.338	-0.169	0.029	0.237	-0.327	-0.338	0.175	0.165
NINO3.4AnnAvg	-0.457	0.199	0.330	0.191	0.006	-0.045	0.215	0.281	-0.174
MEI	-0.630	-0.047	0.077	-0.008	-0.196	-0.179	0.241	0.058	-0.283
MEIw	-0.507	-0.036	0.038	0.218	0.043	-0.085	0.533	-0.013	0.220
SibAlaskaIndx	0.323	0.019	-0.104	0.139	0.196	0.277	-0.185	0.237	0.362
SibIndx	0.124	0.203	0.139	0.230	0.314	0.338	-0.332	0.387	0.446
AlaskaIndx	-0.327	0.163	0.279	0.027	0.013	-0.049	-0.073	0.042	-0.091
Ice Cover and Sea Temperatures									
Sea Ice Cover	0.050	-0.505	-0.664	-0.443	-0.090	-0.348	-0.337	-0.276	-0.061
Ice Retreat (post	0.226	-0.423	-0.194	-0.210	0.151	-0.448	-0.175	-0.011	0.052
StPaulSATw	0.127	0.283	0.424	0.022	-0.064	0.206	0.234	-0.112	-0.109
StPaulSATa	-0.011	0.558	0.516	0.276	0.268	0.513	0.208	0.292	0.246
MaySSTSEBC	-0.012	0.632	0.655	0.324	-0.037	0.546	0.442	0.370	-0.055
SST JFMA Moor 2	0.089	0.548	0.595	0.204	-0.087	0.462	0.284	0.170	-0.087
SST JFM Prib	-0.075	0.234	0.248	0.005	-0.299	0.065	0.425	-0.192	-0.278
Fairbanks Air Temperatures									
FairbanksSATw	-0.187	0.495	0.202	0.092	-0.164	0.511	0.057	0.075	-0.127
FairbanksSATsp	-0.281	-0.346	-0.065	-0.176	0.088	-0.237	0.034	-0.117	0.262
FairbanksSATsm	-0.181	-0.324	-0.087	-0.075	0.090	-0.502	-0.122	-0.064	0.082
FairbanksSATf	0.074	0.610	0.485	0.624	0.129	0.553	0.315	0.673	0.150
FairbanksSATfw	-0.115	0.582	0.274	0.290	-0.113	0.570	0.119	0.308	-0.065
FairbanksSATspsr	-0.180	-0.207	0.082	0.008	0.221	-0.324	0.016	0.090	0.261
FairbanksSATan	-0.181	0.475	0.398	0.388	0.029	0.437	0.217	0.430	0.107
Wind and Pressure									
OptWindDays M2	0.024	-0.002	0.002	0.103	-0.032	0.191	-0.165	0.234	0.148
BSPIw	-0.369	-0.486	-0.270	-0.166	0.120	-0.704	-0.391	0.056	-0.063
BSPIsp	0.075	0.172	0.024	0.154	0.191	0.130	-0.424	0.168	0.145
NSw Wind Prib	-0.221	0.066	0.105	0.257	0.240	-0.154	0.133	0.365	0.138
HiWind M2sp	-0.129	0.064	0.097	-0.053	-0.123	-0.041	0.031	-0.171	-0.333
MayMix Prib	-0.093	0.084	0.011	-0.202	-0.417	-0.052	0.125	-0.115	-0.421
JJ Mix M2	-0.281	-0.225	-0.071	-0.033	0.169	-0.216	-0.061	-0.137	-0.031
WindStress AKPe	0.478	-0.085	-0.082	-0.099	-0.135	-0.120	0.038	-0.058	-0.241
WindStress AKPe	-0.275	-0.357	-0.377	-0.482	-0.422	-0.297	0.070	-0.453	-0.391

Table 9- 6. Results of single linear regressions of annual scale growth of Yukon female age 1.4 (YF1.4) Chinook, 1996-2008, with selected climate-ocean indices and final best-fit multiple regression models. Shaded cells indicate significant p-values ($p < 0.05$). FW1=freshwater year; SW1=first ocean year; SW2=second ocean year; SW3=third ocean year. See Appendix Table 6-1 for description of climate-ocean indices.

	Y1.4 FW1		Y1.4 SW1		Y1.4 SW2		Y1.4 SW3	
	R Square	P-value	R Square	P-value	R Square	P-value	R Square	P-value
PDO	0.4123	0.0180						
BSP1w	0.1360	0.2150						
MEI	0.3973	0.0209						
ALPI			0.2140	0.1114				
Sea Ice Cover			0.2551	0.0783	0.4413	0.0133	0.1960	0.1298
MaySSTSEBC	0.0001	0.9695	0.3988	0.0206	0.4287	0.0152	0.1052	0.2796
FairbSATsummer	0.0327	0.5542						
FairbSATfall	0.0055	0.8104	0.3718	0.0269	0.2353	0.0929	0.3892	0.0227
FairbSATannual			0.2257	0.1009				
WindStress AKPen MJ					0.1420	0.2044	0.2321	0.0955

YF 1.4 FW1 Final Model: $YF1.4FW1 \sim -0.0899 \text{ MEI} + 0.0063 \text{ FairbSATf} + 0.2867$
Multiple r^2 : 0.533 $p = 0.02221^*$

YF 1.4 SW1 Final Model: $YF1.4SW1 \sim 0.0172 \text{ Fairbanks.SAT.OND} - 0.0542 \text{ Sea.Ice.Cover} + 1.0519$
Multiple r^2 : 0.5741 $p = 0.01402^*$

YF 1.4 SW2 Final Model: $YF1.4SW2 \sim -0.0784 \text{ Sea.Ice.Cover} + 0.0142 \text{ FairbSATf} + 0.8048$
Multiple r^2 : 0.6283 $p = 0.0071^{**}$

YF 1.4 SW3 Final Model: $YF1.4.SW3 \sim -0.0632 \text{ Sea.Ice.Cover} - 0.0839 \text{ MaySSTSEBC} + 0.0194$
 $\text{FairbSATf} - 0.6905 \text{ WindStress.AKPen.MJ} + 0.9885$
Multiple r^2 : 0.7471 $p = 0.01632^*$

Table 9- 7. Results of single linear regressions of annual scale growth of adult Yukon River female age 1.3 Yukon (YF1.3) Chinook, 1996-2008, with selected climate data and final best-fit multiple regression models. Shaded cells indicate p-values less than 0.05. FW1=freshwater year; SW1=first ocean year; SW2=second ocean year; SW3=third ocean year. See Appendix Table 6-1 for description of indices.

	Y1.3 FW1		Y1.3 SW1		Y1.3 SW2		Y1.3 SW3	
	R Square	P-value	R Square	P-value	R Square	P-value	R Square	P-value
PDO	0.0465	0.4791						
BSPIw	0.4962	0.0072						
MEI	0.0322	0.5577						
ALPI			0.2326	0.0951				
Sea Ice Cover			0.1132	0.2609	0.0763	0.3610	0.0037	0.8440
MaySSTSEBC	0.2984	0.0535	0.1955	0.1303	0.1368	0.2136	0.0030	0.8591
FairbSATsummer	0.2520	0.0805						
FairbSATfall	0.2520	0.0501	0.0995	0.2938	0.4531	0.0117	0.0226	0.6240
FairbSATannual			0.0472	0.4759				
WindStress AKPen MJ					0.2055	0.1197	0.1528	0.1866
SibIndx							0.1993	0.1262

YF 1.3 FW1 Final Model: $YF1.3.FW1 \sim -0.0310 \text{ BSPIw} - 0.0331 \text{ MEI} + 0.0249 \text{ MaySSTSEBC} + 0.0058 \text{ FairbSATf} + 0.2133$
Multiple r^2 : 0.8374 $p = 0.003041^{**}$

YF 1.3 SW1 Final Model: $YF1.3.SW1 \sim 0.0302 \text{ ALPI} + 1.3147$
Multiple r^2 : 0.2326 $p = 0.09512$

YF 1.3 SW2 Final Model: $YF1.3.SW2 \sim 0.0139 \text{ FairbSATf} - 0.5868 \text{ WindStress.AKPen.MJ} + 1.0899$
Multiple r^2 : 0.649 $p = 0.005328^{**}$

YF 1.3 SW3 Final Model: $YF1.3.SW3 \sim 0.0872 \text{ SiberianIndex} + 1.2006$
Multiple r^2 : 0.1993 $p = 0.1262$

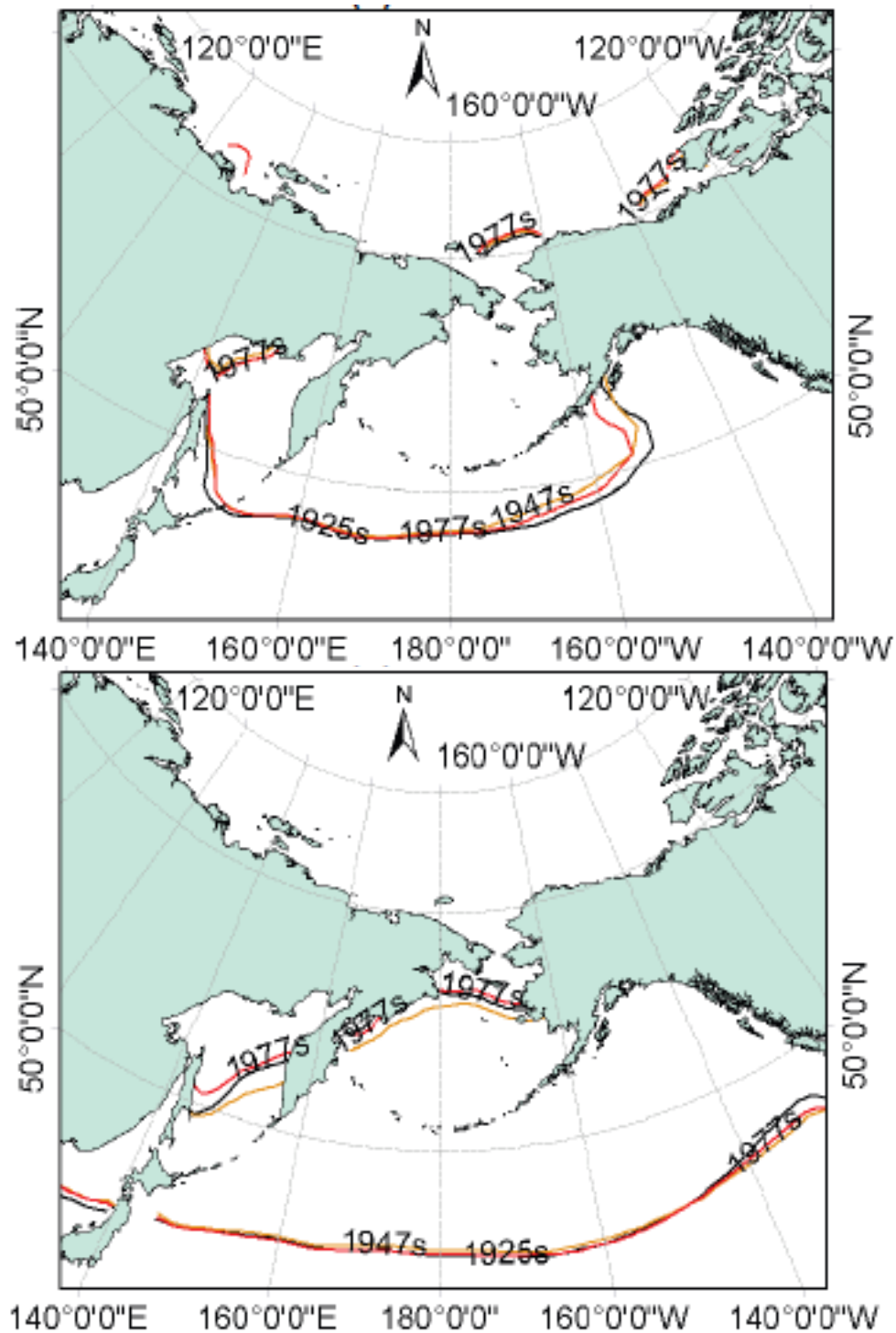


Figure 9- 2. Reference July (top panel) and December (bottom panel) thermal habitat ranges Chinook salmon during the Pacific Decadal Oscillation (PDO) periods of 1925s, 1947s, and 1977s. Source: O. Abdul-Aziz, N.J. Mantua, and K.W. Myers. Manuscript submitted. Potential climate change impacts on thermal habitats of Pacific salmon in the North Pacific Ocean and adjacent seas. SAFS/JISAO/UW.

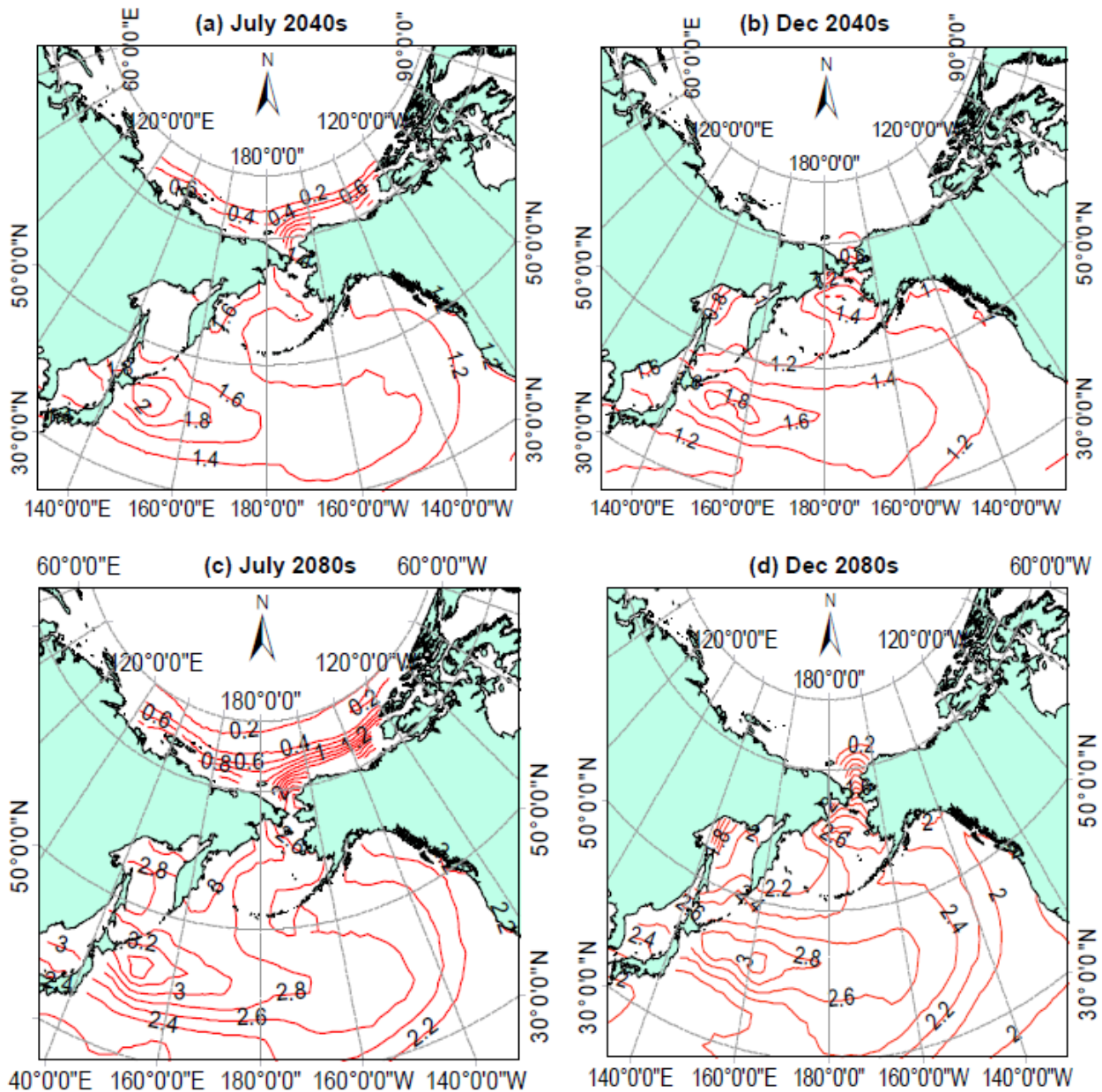


Figure 9- 3. Potential increases in mean sea surface temperature (SSTs, °C) of July and December in the North Pacific and Arctic Oceans by 2040s and 2080s under IPCC A1B scenario relative to their observed counterparts in the 1980s historical period. Source: O. Abdul-Aziz, N.J. Mantua, and K.W. Myers. Manuscript submitted. Potential climate change impacts on thermal habitats of Pacific salmon in the North Pacific Ocean and adjacent seas. SAFS/JISAO/UW.

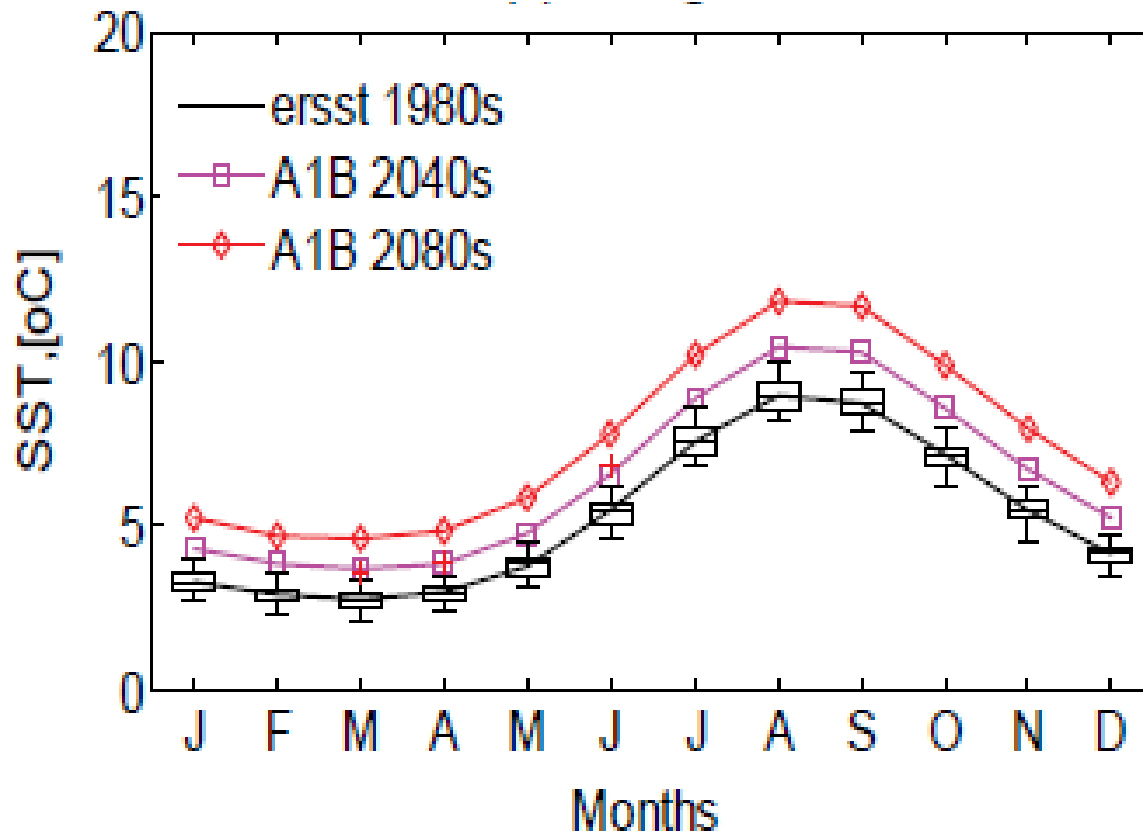


Figure 9- 4. Mean monthly sea surface temperatures (SSTs, °C) in the 1980s (historical, NOAA extended reconstructed SST, ersst version 3b), 2040s, and 2080s in the Bering Sea (54°N, 180°E/W). Data for the future time-frames represent A1B scenario. Data for future time-frames represent the IPCC A1B (medium) emissions scenario. Boxes represent statistics of historical SSTs with solid lines at the lower quartile, median, and upper quartile. Whiskers show the extent of SSTs within 1.5 times the inter-quartile ranges, while plus signs indicate outliers. Source: O. Abdul-Aziz, N.J. Mantua, and K.W. Myers. Manuscript submitted. Potential climate change impacts on thermal habitats of Pacific salmon in the North Pacific Ocean and adjacent seas. SAFS/JISAO/UW.

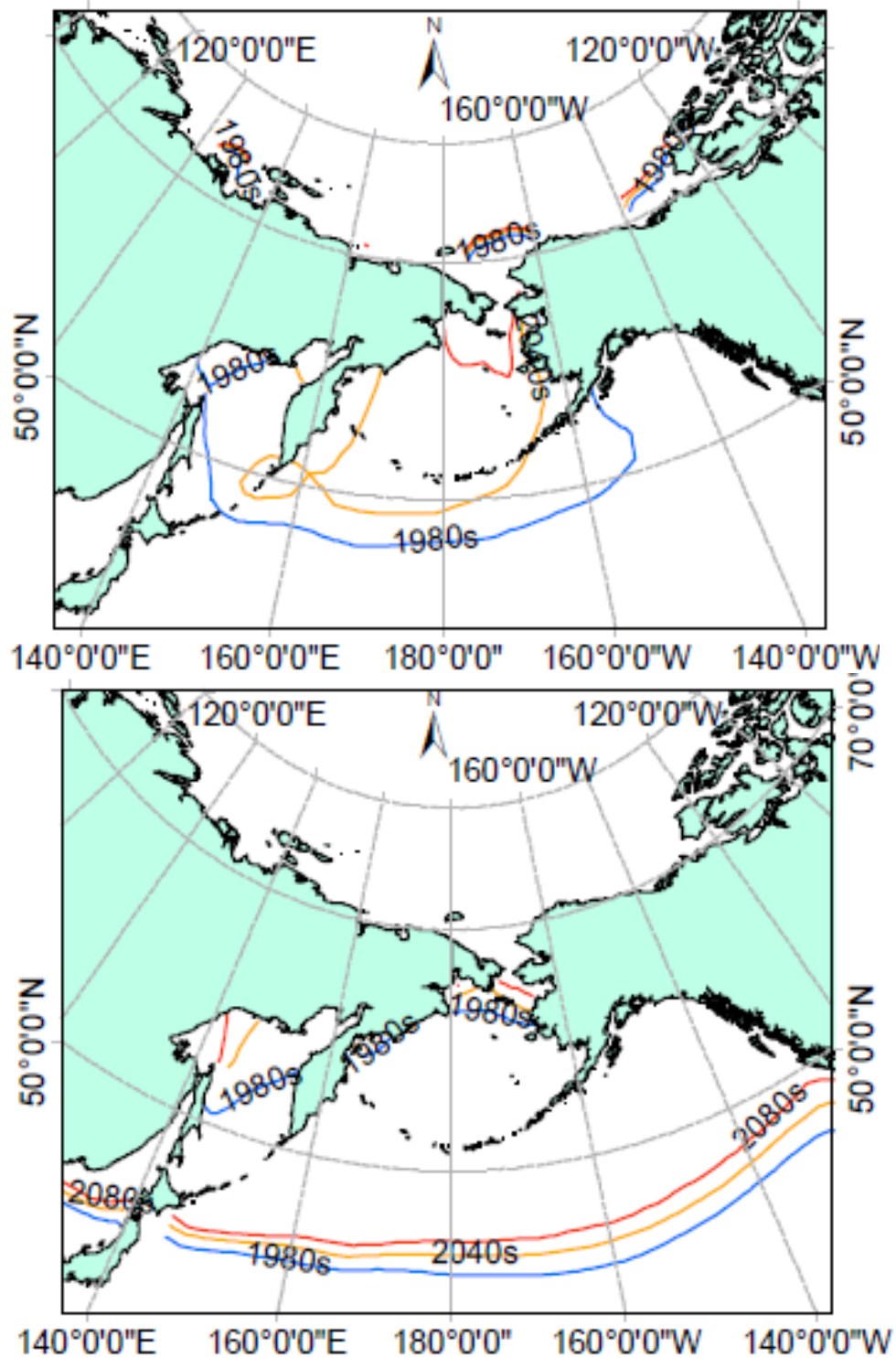


Figure 9- 5. Reference July (top panel) and December (bottom panel) thermal habitat ranges in 1980s (blue line), 2040s (yellow line), and 2080s (red line) for Chinook salmon under IPCC A1B (medium) emissions scenario. Source: O. Abdul-Aziz, N.J. Mantua, and K.W. Myers. Manuscript submitted. Potential climate change impacts on thermal habitats of Pacific salmon in the North Pacific Ocean and adjacent seas. SAFS/JISAO/UW.

VIII. DISCUSSION

Project goals and objectives of this 3-year project were achieved without major modifications. Below, we discuss our objectives and results with respect to what we know and what we need to know about Chinook salmon and the effects of climate-ocean conditions on their growth and survival in the Bering Sea to help achieve the goal of sustainable salmon fishery management and to enhance management decision making.

Discussion Objective 1: Develop a Comprehensive High Seas Chinook Salmon Database (1955-2009) for AYK SSI, Including LTK from the Bering Straits Region

Historical High Seas Research Data

Chinook salmon are the least abundant species of Pacific salmon in the ocean (Major et al. 1978; Healey 1991; Quinn 2005; Heard 2007). As such, there is relatively little information on their ocean life history compared to other more abundant species of salmon. What we do know about the ocean life history of Chinook salmon is based largely on historical data from commercial high seas salmon driftnet fisheries and salmon research vessel surveys (gillnet, purse seine, longline, and trawl fishing gear), tagging experiments, and stock identification studies conducted as part of the research programs of the International North Pacific Fisheries Commission (INPFC; 1953-1992) and the North Pacific Anadromous Fish Commission (NPAFC; 1993-present). Much of the historical high seas salmon data were archived by the High Seas Salmon Research Program, University of Washington, and were used to develop a database for the AYK SSI research program.

Much of the detailed background information on research methods used to collect high seas salmon data and the results of historical analyses of these data are reported in the annual reports, documents, bulletins, statistical yearbooks, and technical reports of INPFC and NPAFC (www.npafc.org). Prior to the end of authorized commercial high seas driftnet fisheries in 1992, INPFC research efforts focused largely on salmon distributed in North Pacific waters south of the Aleutian Islands, leading to significant gaps in information on AYK and other salmon stocks migrating in the Bering Sea. NPAFC-related research during the 1990s indicated that interannual variations in marine growth and survival of salmon are related primarily to climate and fishing (e.g., Myers et al. 2000). The results of NPAFC research also indicated rapid change in salmon ecosystems in the Bering Sea, and the need for new coordinated investigations to address this issue. NPAFC's Bering Aleutian Salmon International Survey (BASIS) project, which began in 2002, was designed to clarify the mechanisms of biological response by salmon to the conditions caused by climate changes.

NPAFC's ongoing BASIS research is providing new data on ocean conditions and the distribution, abundance, and trophic interactions of salmon across the entire Bering Sea in summer-fall (e.g., NPAFC 2001, 2005a,b). US BASIS research has focused primarily on trawl surveys of juvenile salmon (ocean age-.0) in surface waters (to a depth of 12-14 m) over the eastern Bering Sea shelf in summer and fall (August-October). Japanese research vessels have surveyed older age groups of immature and maturing salmon in the central Bering Sea with a surface trawl that fishes to 40-m depth (*Kaiyo maru*; Azumaya et al. 2005). Russia (TINRO-Centre, Vladivostok) has used a large pelagic trawl that fishes from the surface to about 40-m depth to survey all life history stages of salmon inside the Russian Exclusive Economic Zone (EEZ) in the western Bering Sea (2002-present). We incorporated some BASIS data pertaining to Chinook salmon into our database. However, AYK SSI users should contact the NPAFC's BASIS Working Group directly for updated datasets and approval to publish analyses of BASIS data.

Chinook salmon are a prohibited species in catches of groundfish fisheries operating in the eastern Bering Sea, Aleutian Islands, and northern Gulf of Alaska (Witherell and Pautzke 1997; Witherell et al. 2002; NPFMC 2008, 2009). Salmon bycatch data and associated biological samples (scales) and data collected by the North Pacific Groundfish Observer Program have provided a valuable source of information for our project, as well as other ongoing AYK SSI research on Chinook salmon. Observer Program samples and associated biological and catch data provide the only source of information on

Chinook salmon in the eastern Bering Sea in winter and early spring. Due to confidentiality agreements, however, there are some restrictions on reporting Observer Program data.

Local Traditional Knowledge (LTK)

The Local Traditional Knowledge (LTK) data collected for our project indicated significant declines in the number, health, and size of Chinook salmon in the Unalakleet region. Data obtained from local experts in Brevig Mission and Golovin were relatively limited, as these communities have access to and harvest far fewer Chinook than Unalakleet. Additional data were also collected on observed changes to the environment, climate and other species of fish. All three communities have noted significant changes to the environment of the region including the increasing unpredictability of local weather patterns. Our project was carried out in conjunction with another AYK SSI-sponsored project (#601), which collected similar data from six additional Bering Strait region communities.

The combination of decreases in abundance of AYK-region Chinook salmon and resultant harvest regulations imposed by the State of Alaska have initiated changes to local harvest and processing strategies. At least some Unalakleet fishers have changed their salmon fishing location from the Unalakleet River to adjacent marine waters because fishing regulations allow access to marine waters for longer periods of time than in rivers, and because people have had difficulty meeting their subsistence harvest needs in rivers. This is clearly not a solution for all Unalakleet area subsistence fishers, however. Many people do not have the necessary boats or other gear to fish in marine waters, and such a change would also likely have impacts on the availability of salmon. In terms of processing, king salmon strips are a highly valued and sought after product of subsistence fishing. Fishers have noted that with decreases in availability of Chinook, they have begun to, or are considering, trying to make strips from silver salmon. This is an accepted substitute, but less than ideal. Other species of salmon are also being targeted more intensively to make up for the decrease of Chinook available for subsistence harvest.

Time spent fishing is also impacted by the decreases in salmon abundance. Interviewees noted that it often takes much longer than previously to obtain the same amount of salmon. Additionally, the necessity of spending more time fishing potentially requires more fuel and/or time away from any wage-based employment, all of which have financial and other repercussions for families.

Salmon is a critically important food item for many individuals and families in communities across Western Alaska. For many families, salmon harvest is necessary for their yearly economic survival. It is a nutritional input that people expect and need to have. However, even for families that are able to survive financially without a large input of subsistence-harvested salmon, it can still be stressful to have less than you were formerly able to harvest and would ideally want. One wife and mother from Unalakleet stated, “It’s stressful to figure out how often you can have a taste of this, trying to make it last all winter until we can get some the next year.” Salmon is a culturally important food that people frequently talk about wanting to taste, and that reminds them of their heritage and important cultural values.

In addition to its importance for the economic survival of individuals and families, the importance of customary barter and trade, particularly of fish, has also been documented for the Bering Strait region (Magdanz et al. 2007). One very important impact resulting from a decreased availability of salmon is that individuals have less salmon available for barter and trade and sharing. A fisherwoman from Unalakleet talked about being distressed over having to tell friends from other communities that she did not have enough dry fish (salmon) to participate in their annual exchange; she typically barter with dry salmon for sea mammal products.

While definite causes of the observed changes in Chinook abundance and health in the Unalakleet region are uncertain, participants in this study (from all three communities) offered important observations that may lead to the development of new scientific hypotheses for testing. Potential areas of investigation for future research are discussed further in our synthesis of results (Objective 9).

In summary, we believe that the historical high seas and LTK data on Chinook salmon assembled during our project will provide lasting benefit to AYK SSI as a base of historical information on the ocean life history, ecology, and local expert knowledge of Chinook salmon. The LTK interview database

enhances our ability to develop scientific hypotheses meaningful to regional issues. We anticipate these shared databases will continue to grow as additional ocean salmon research and LTK data are acquired from other AYK SSI-sponsored projects and cooperating programs. Regardless of any limitations, the historical data, as well as new data collected during our project, provide information for future research and restoration activities aimed at achieving the goal of sustainable salmon fishery management. The lack of a permanent archive for historical high seas salmon research samples and data is a problem that needs to be addressed by NOAA and other agencies contributing to this long-term research program.

Discussion Objective 2: Ocean Distribution and Migration Routes of Chinook Salmon

At the outset of this project, we noted that evaluating the AYK SSI's high priority hypothesis, "marine survival of salmon is more affected by variability in ocean temperature and environmental variables than by variability in marine fishing mortality," is complicated by a lack of information on ocean distribution, migration, and behavior of AYK salmon. As indicated by their low abundance and lengthy period of ocean residence (typically 3-5 years) relative to other salmon species, Chinook salmon have developed unique life history strategies of distribution and movements aimed at reducing ocean mortality. Among these, vertical migratory behavior in Chinook salmon is a key strategy for adapting to environmental variability, because it makes them less vulnerable than other species to physical forcing that affects only well-mixed surface layers. On the other hand, this same strategy makes them more vulnerable to marine fishing mortality in demersal and midwater groundfish trawl fisheries.

Ocean Distribution of AYK Chinook Salmon

We hypothesized that AYK Chinook salmon spend most or all of their marine life in the Bering Sea. Our hypothesis is based on very limited direct evidence from tagging experiments. The results of tagging studies are supported by indirect evidence from scale pattern analysis (SPA), which indicates that immature western Alaska, including Canadian Yukon, Chinook salmon are the dominant regional stock in the northwestern and central Bering Sea in summer and in the southeastern Bering Sea (west of 170°W) in winter (e.g., Major et al. 1978; Myers et al. 1987, 2003; Myers and Rogers 1988; Myers et al. 2003; Bugaev 2004, 2005; Bugaev and Myers 2009a). Results of SPA for the southeastern Bering Sea are supported by genetic stock identification at the regional (Western Alaska) stock level (NPFMC 2008, 2009). Using these multiple lines of evidence, we developed a simple conceptual model of ocean distribution and migration AYK Chinook salmon in the Bering Sea. Seasonal movements of Chinook salmon between deep basin (summer) and neritic (winter) habitats were supported by stable isotope analysis. We speculate that AYK Chinook salmon may respond to decadal-scale climate change by northwestward (warm decades) and southeastward (cool decades) shifts in ocean distribution, similar to those observed seasonally.

Much less is known about the stock origins of Chinook salmon migrating in the North Pacific Ocean. Despite extensive high seas tagging experiments, there have been no recoveries in the AYK region of Chinook salmon tagged in the North Pacific Ocean (Myers et al. 1996; Celewycz et al. 2009; this report). The results of SPA indicated significant interceptions of immature (primarily ages 1.2 and 1.3) AYK Chinook salmon by historical high seas driftnet fisheries operating in the central and western North Pacific Ocean, although these interceptions were much lower than in driftnet fisheries operating in the Bering Sea (Myers et al. 1993). Clearly, additional evidence is needed to corroborate SPA results. To assume that the ocean range of AYK Chinook salmon extends into the North Pacific Ocean, however, seems reasonable.

Currently, there are too few salmon research vessel surveys in the North Pacific Ocean or Gulf of Alaska to provide a sufficient number of samples for stock identification of Chinook salmon. One approach might be to use historical high seas scale collections for genetic stock identification of Chinook salmon. This would necessarily involve an international collaborative research project coordinated through the North Pacific Anadromous Fish Commission. Retrospective analyses, however, will not necessarily inform us about the effects of current and future changes in climate-ocean conditions on AYK

Chinook salmon distribution. Another potential approach would be to analyze the genetic stock composition of Chinook salmon in bycatch samples from pollock trawl fisheries operating in the Gulf of Alaska.

Overlap in Distribution of AYK Chinook Salmon with Other Species and Stocks

Relatively little is known about overlap in ocean distribution AYK Chinook salmon with other salmon species and stocks, and how climate change and fishing may influence overlaps in distribution of AYK Chinook salmon with their competitors, predators and prey. Tag, SPA, and genetic stock identification data indicate extensive overlap in distribution of hatchery and wild populations of immature and maturing Asian and North American salmon in the Bering Sea (e.g., Myers et al. 1996, 2007; Bugaev and Myers 2009a,b; Bugaev et al. 2009; Habicht et al. 2005, 2010). These include the most abundant populations of pink, chum, and sockeye salmon in the world, i.e., eastern Kamchatka pink salmon (wild), Japanese chum salmon (hatchery), and Bristol Bay sockeye salmon (wild) (Ruggerone et al. 2010a,b), all of which are distributed in AYK Chinook salmon foraging areas in the western and central Bering Sea basin in summer-fall. Tag data indicate overlap in distributions of AYK Chinook salmon and AYK chum salmon in the Bering Sea (this report). Results of SPA indicate young immature (predominantly age 1.1 and potentially age 1.0) Russian and AYK Chinook salmon intermix in summer-fall the northwestern Bering Sea inside the Russian Exclusive Economic Zone (REEZ; Bugaev and Myers 2009a). Relatively high abundance of Chinook salmon during BASIS surveys in the northwestern Bering Sea in 2003 may have resulted from changes in climate-ocean conditions that shifted summer-fall feeding aggregations of immature Russian and western Alaska Chinook salmon into the REEZ (Bugaev 2005; Bugaev and Myers 2009a). Data from Bering Sea shelf, slope, and basin habitats inside the US EEZ in winter show that AYK Chinook salmon intermix with other Chinook populations (hatchery and wild) from throughout their geographic range in Asia and North America. For example, SPA estimates of stock composition of Chinook salmon in the BSAI bycatch in the late 1970s and early 1980s averaged 60% western Alaska (including Canadian Yukon fish), 17% central Alaska, 14% Kamchatka, and 9% southeast Alaska and British Columbia. Similarly, SPA estimates of the regional stock composition of Chinook salmon in the BSAI bycatch in 1997-1999 averaged 56% western Alaska (including Canadian Yukon fish), 31% central Alaska, 5% Kamchatka, and 8% southeast Alaska and British Columbia, and the western Alaska stock group was dominated by AYK fish (66% AYK, 34% Bristol Bay; Myers et al. 2003). These estimates are supported in part by recoveries of coded-wire tagged Chinook salmon in the BSAI bycatch (e.g., Myers et al. 2005; Celewycz et al. 2009) and genetic analyses (NPFMC 2008, 2009).

We speculate that overlap in the Bering Sea distribution of AYK Chinook salmon and southern populations of North American salmon fluctuates on decadal, interannual, and seasonal scales with ocean warming or cooling in the Gulf of Alaska. Future climate-change scenarios predict that warming of the North Pacific Ocean may result in northward shifts the ocean ranges of southern populations of all salmon species into the Bering Sea. To maintain harvest levels in southern regions, increased supplementation of natural production with artificially produced salmon is also likely. Given that prey resources of Chinook salmon in the Bering Sea are limited, climate-induced increases in competitive interactions between AYK Chinook salmon and southern populations of hatchery salmon is an important issue for future research.

Distribution and Movements of Chinook salmon at Specific Life History Stages

We hypothesized that salmon minimize overlap in ocean distribution with other species and stocks by spatial and temporal partitioning of different size (age) and maturity groups. As first reported by Gilbert (1922), natural populations of AYK Chinook salmon have a ‘stream-type’ life history, that is, after hatching fry rear in streams for one year before migrating to the ocean at age 1.0. By entering marine habitats at a relatively large size, stream-type Chinook salmon likely reduce the risk of early ocean predation. At ocean entrance small juvenile salmon typically occupy littoral (intertidal) habitats, while larger juvenile salmon occupy neritic (low tide line to the edge of the continental shelf or 200-m depth contour) habitats (e.g., Brodeur et al. 2003). As they grow, juvenile Chinook salmon gradually move

farther from shore and the points of ocean entrance, where they are better able to avoid fish, bird, and marine mammal predators, and can feed on a greater diversity and size range of prey (e.g., Emmett et al. 2004; Orsi and Wertheimer 1995). In the eastern Bering Sea in summer-fall, juvenile Chinook salmon that migrate from rivers in western Alaska are distributed in well-mixed, low salinity, and shallow waters (< 50-m depth) over the inner continental shelf from Norton Sound to Bristol Bay (Farley et al. 2005a). In contrast, in the western Bering Sea juvenile Chinook salmon from rivers in eastern Kamchatka move from the inner shelf to waters off the continental shelf during an extended period through late October (Glebov 2000). By their second ocean summer (age 1.1), immature Chinook salmon are distributed primarily in epipelagic habitats off the continental shelf in the Bering Sea basin. Younger immature Chinook salmon migrate farther offshore than older age and maturity groups (Major et al. 1978). In summer-fall, foraging immature and maturing Chinook salmon are distributed over the entire western Bering Sea inside the REEZ (Starovoitov et al. 2004; Bugaev and Myers 2009a; this report). In winter, immature and maturing AYK Chinook salmon may be distributed primarily in neritic, continental shelf-break, and continental slope habitats in the eastern Bering Sea and Aleutian Islands. In their last winter and spring in the ocean, maturing Chinook salmon return to coastal (continental shelf) habitats before entering their home streams. This increases their susceptibility to marine fishing mortality. For example, in some years the southeastern Bering Sea groundfish bycatch of Chinook salmon includes a high percentage of older (probably maturing) fish in winter (87% ocean age ≥ 3 and older, Walker et al. 2007).

Our results revealed large gaps in life stage-specific information and a clear need to continue this research. There are at least five major gaps that need to be addressed: (1) distribution of juveniles at ocean entrance (estuary and near shore waters <20 m in depth); (2) distribution in winter relative to areas where Chinook salmon are caught by the BSAI groundfish trawl fishery; (3) distribution in the Aleutian Islands; (4) distribution and migration pathways of adult fish on the Bering Sea shelf; and (5) distribution in waters outside the Bering Sea.

Vertical Distribution of Chinook Salmon

Because Chinook salmon make extensive use of vertical habitats, studies restricted to evaluations of horizontal distribution are not sufficient to determine whether the ocean environment is a more important cause of variation in the abundance of salmon populations than marine fishing. We hypothesized that Chinook salmon have the ability to self-regulate their thermal environment, as well as other ambient conditions, by making extensive vertical migrations. During this study, we continued high seas tagging experiments with data storage tags (DSTs) to learn more about the vertical distribution of AYK Chinook salmon in the ocean. However, high seas tagging opportunities were very limited, and abundance of Chinook salmon in the Bering Sea was low in 2007-2009. Opportunities for tagging salmon with DSTs may be even more limited in the future, as 2010 was the last year of the *Wakatake maru* surveys.

Limited scientific evidence from a variety of different methods indicates diurnal, seasonal and ontogenetic shifts in vertical distribution of Chinook salmon. Erickson and Pikitch (1994) analyzed bycatch of Chinook salmon in US West Coast trawl fisheries, and found that bycatches were larger in winter and occurred at a greater range of depths (100-482 m), than in summer (<220 m). In the central Bering Sea, tracking of salmon carrying ultrasonic tags indicated that Chinook salmon were deeper (20-50 m) than other species (Ogura and Ishida 1995). On the northeastern Bering Sea shelf, Russian groundfish trawl fisheries caught Chinook salmon incidentally at depths to 360 m throughout year (Radchenko and Glebov 1997, 1998). Most (90%) Chinook salmon were taken at depths of 50-400 m below the surface, and fish were slightly deeper in August-September. Older fish were more abundant in winter catches and younger fish were more abundant in summer and fall catches. High diurnal variation in vertical habitat of all species of Pacific salmon (ambient temperature, as indicated by data storage tags) suggests that their offshore ocean distribution is more closely linked to distribution of prey and foraging than to sea surface temperatures (Walker et al. 2000). There was no apparent relation between sea surface temperatures and distribution of Chinook salmon in the bycatch of the eastern Bering Sea groundfish trawl fishery (J. Ianelli, NOAA Fisheries, pers. comm.). Depth data from a limited number of data storage tags (DSTs) confirm that Chinook have deeper vertical distributions than other salmon species

(Walker et al. 2007). Most salmon species displayed a diel pattern of vertical distribution, moving between shallower and deeper waters during the day and near the surface at night, except for Chinook salmon.

We inferred behavior of AYK Chinook salmon in the Bering Sea from DST recovery data (date, time, temperature, depth, salinity). A DST placed on a Chinook salmon in the Bering Sea in 2002 was recovered in the Yukon River in 2004. During eight seasons, the fish displayed a wide variety of behaviors. In summer, it was usually within the top 50 m. In the first winter it remained near 125 m, while in the second it remained within the top 50 m. Fall was a transition period between summer and winter, and in spring the fish underwent large (> 340 m) vertical movements. Temperatures experienced by the fish ranged from 1°C to 12°C. A comparison of sea surface temperatures and temperature profiles derived from tag data with oceanographic data indicated the fish spent most of its time in the central and southern Aleutian Basin, with part of its second summer and final homeward migration on the eastern Bering Sea shelf. Data from another tag on a maturing Yukon River Chinook salmon indicated it moved directly from the Basin to the Yukon in three weeks. Neither fish spent substantial amounts of time in the area of groundfish fishery operations. Temperature and depth data from electronic data storage tags are providing a valuable new source of information on AYK Chinook salmon habitat over extended periods. The most striking feature of the data is the great variability in the fish's behavior leading to large differences in the temperatures the fish experienced. The behavior varied between seasons and even between the same season in different years. The general pattern seemed to be one of high variance in depth but not temperature in winter and spring, when the water column is more homogeneous due to cooling and mixing, and large variance in temperature but not depth in summer and fall, due to much shallower dives through highly stratified surface waters.

Detailed information on behavior of Chinook salmon has come from other archival tags on fish off the coasts of southeastern Alaska and California. Chinook tagged by Murphy and Heard (2001, 2002) exhibited a wide range of behaviors, e.g., some fish remained near the surface at night and were deeper (40 m) during the day, some fish reversed this pattern, and some had mixed or no apparent patterns. Similarly, Hinke et al. (2005b) saw no consistent diel pattern but described four different patterns of vertical distribution in data from 15 Chinook salmon off northern California and southern Oregon: a shallow night pattern around 10 m; a shallow day pattern at 0–80 m; a deep (mostly night) pattern around 55 m; and a deeper pattern around 100 m (60–280 m). Data from two fish that overwintered at sea showed a seasonal shift in depth, with fish in the upper 150 m in fall and on average at 200 m in winter (rarely shallower than 100 m) (Hinke et al. 2005a,b). Data from fish at liberty in all months demonstrated a strong preference for waters between 8°C and 12°C throughout the year. They proposed that variation in depth use across individuals was probably due to thermoregulatory behaviors related to changes in local thermal conditions, while the seasonal cycle in depth use was regulated by bioenergetic needs (loss of surface productivity during winter drove the fish to seek prey resources at greater depths). Azumaya and Ishida (2005) also concluded that vertical movements played an important role in maintenance of an advantageous body temperature in chum salmon migrating from the Bering Sea to Japan.

The temperature preference of the California Chinook salmon was in marked contrast to the temperatures experienced by fish 1401 (1–11°C, excluding the final few days before entering the Yukon). Fish 1401 spent most of its time at temperatures below 8°C, except for summers. At another extreme, Wurster et al. (2005) used oxygen isotopes to estimate temperatures inhabited by Chinook salmon in Lake Ontario, and found that these fish inhabited waters of 19–20°C for up to two months during the summer. Otoliths cannot resolve features as fine as daily vertical movements, but clearly these fish tolerated much warmer temperatures than those off California and Oregon or in the Bering Sea. Winter temperatures could not be determined, due to lack of otolith growth in that season, but May and November temperatures were below 10°C. The overall seasonal cycle of temperatures looked much like an annual cycle of water temperatures.

The Chinook tagged by Hinke et al. (2005a,b) seem to have remained along the California and Oregon coast. Chinook caught incidentally by commercial trawl operations off the Washington, Oregon, and California coasts were found from the surface to 482 m (Erickson and Pikitch 1994). Few were

caught in summer, mostly above 220 m; catches were larger and deeper (100–482 m) in winter. Russian trawl fisheries captured Chinook salmon incidentally on the northwestern Bering Sea shelf at depths to 360 m throughout the year, with the majority (90%) at 50 to 400 m (Radchenko and Glebov 1998a, b). In 1997–2000 over 90% of the eastern Bering Sea groundfish trawl Chinook bycatch was caught at fishing depths between 25 m and 175 m; less than 3% were deeper than 300 m. In the winter depth distribution showed a bimodal tendency, with the bulk of fish at 25–75 m and a smaller peak at 200–300 m (Walker et al. 2007). Chinook were slightly deeper in autumn than winter in both the U.S. and Russian trawl fisheries.

Much of the bycatch of Chinook by the eastern Bering Sea trawl fishery has been concentrated along the shelf break, especially just north of the easternmost Aleutian Islands (“horseshoe area”). This pattern closely follows that of fishing effort by the fleet (NPFMC 2008). The locations we have inferred from the data on one Yukon Chinook salmon (tag 1401) do not overlap the fishing areas to a great degree except for the first winter, which may be near the horseshoe area. Neither do catch locations of Chinook by the Japanese mothership salmon fishery (1952–1992), which was restricted to basin waters in summer (Major et al. 1978; Major 1984), or catches by research vessels in the central Bering Sea in summer. As previously discussed, Bugaev and Myers (2009a) found that the western Bering Sea is an important summer–autumn foraging area for AYK and Russian stocks of Chinook salmon. Thus, it is not clear if trawl bycatch concentrations are actually concentrations of Chinook salmon or merely the result of fishing effort. In the winter of 2002–2003 fish 1401 was very likely near the Aleutian Islands in the southeastern Bering Sea (4°C temperatures at 125 m), and if other Chinook salmon choose this area, it could account for some of the bycatch in the horseshoe area. The water column through the passes is well mixed by strong tidal currents, and northward transport provides an important source of nutrients to the Bering Sea (Stabeno et al. 2005). Chinook may seek the horseshoe area as both an area of high productivity and a thermal refuge. We recommend winter DST and acoustic tagging and tracking studies of Chinook salmon in the horseshoe area to help clarify these issues.

Conceptual Models of AYK Chinook Salmon Distribution

Our simple conceptual model of distribution of AYK Chinook salmon does not account for interannual changes in ocean conditions and climate-related effects on ocean distribution and migration routes. In addition, our model does not show likely differences in ocean distribution and migration routes of salmon between “cold” and “warm” ocean years (e.g., Myers et al. 2007). New dynamic models, incorporating climate change effects on both horizontal and vertical ocean distribution and migration at critical life history stages, would be useful for evaluating potential changes in carrying capacity, growth and survival, interceptions by marine fisheries, and timing of adult returns to the AYK region.

Discussion Objective 3: Ocean Age, Growth, and Size-Selective Mortality of Chinook Salmon

Body size and growth, particularly at early marine life stages, are believed to be important factors influencing ocean survival of salmon (e.g., Parker 1962; Beamish et al. 2004a; Farley et al. 2007a). Scale pattern analysis has provided a powerful tool for evaluating factors affecting growth and survival of salmon at specific life-stages. For example, time-series analysis of scale pattern and abundance data indicated a substantial decrease in marine survival of Bristol Bay sockeye salmon during years of peak abundance of Russian (eastern Kamchatka) pink salmon, when immature (age 1.1) sockeye salmon were distributed off the continental shelf (Ruggerone et al. 2003).

We reconstructed growth histories of Bering Sea Chinook salmon using scales collected by the NOAA Fisheries Observer program (OBS Chinook), by scientists aboard the Japanese research vessel *Wakatake maru* (WAK Chinook), and from an existing time series (Ruggerone et al. 2007; 2009a,b) of adult Yukon and Kuskokwim Chinook (YUK and KUS Chinook), extended to include female YUK Chinook caught in 2005–2009. Growth histories of mixed-stock OBS and WAK Chinook salmon showed considerable high-frequency (interannual) variation, including alternating-year patterns of growth and potential density-dependent and size-selective ocean mortality. In 1999–2000, growth of YUK female

Chinook salmon shifted to a positive phase that continued through 2009, but did not result in increased adult returns to the river.

Estimation of ocean survival of Chinook salmon was beyond the scope of our study, although comparisons of scale size at age between OBS subadults and adult YUK and KUS Chinook provided potential evidence of size-selective ocean fishing mortality. However, interpretation of our comparisons between ocean and YUK/KUS samples was difficult because we did not know the stock composition of OBS and WAK samples. For example, statistically significant differences between age 1.4 OBS and YUK Chinook in mean total scale size through the last annual growth increment (SW4), might indicate size-selective mortality of large age 1.4 YUK Chinook salmon in the pollock trawl fishery. On the other hand, scale sizes of age 1.4 KUS Chinook were larger than age 1.4 OBS Chinook. Difficulties in interpretation might be resolved in future analyses, if stock of origin of individual fish in scale-growth time series can be identified by genetic analysis.

Body Lengths and Scale Size of Maturing Chinook salmon

Pacific salmon have a “periodic” life history strategy, whereby they attempt to achieve relatively high rates of somatic growth during periods of poor ocean conditions in order to maximize reproductive output during a final “burst” of good conditions (Winemiller and Rose 1992; McCann and Shuter 1997; Aydin 2000). Scale pattern studies have long indicated that growth rates of YUK Chinook salmon in the year prior to maturation are higher than at younger ocean ages (Gilbert 1922). Although winter data were limited, analyses of monthly length- and weight-at-age data from Japanese research vessel catches indicated that seasonal ocean growth of Chinook salmon was linear, i.e., Chinook salmon grow at similar rates in both summer and winter (Ishida et al. 1998). Composite growth curves of Chinook salmon developed by Major et al. (1978), however, indicated seasonality of growth, and seasonality of growth is usually evident in seasonal and annual growth patterns on Chinook salmon scales.

We found that mean body lengths of age 1.3 and 1.4 OBS Chinook salmon in January-March were always significantly less than mean lengths of age 1.3 and 1.4 YUK and KUS Chinook in June-July for both sexes. This suggests that AYK Chinook salmon experience a final, perhaps critical, growth spurt during their last six months (winter- spring) at sea. The annulus was always located at the outer edge OBS Chinook scales sampled in January-March, while at least some AYK and KUS Chinook scales had plus growth at the outer edge (SWPL). Measurements of SWPL growth of YUK and KUS Chinook may have been influenced by scale resorption (Ruggerone et al. 2007), however, YUK and KUS scales measured during our project were not resorbed along the measurement axis. We conclude that this last growth spurt of maturing AYK salmon must occur during an even shorter period (last 3 months at sea) than previously thought. Limiting factors during this last 3-mo period at sea may have a large effect on adult size at return, and identification of these factors needs to be an important focus of future research.

Sexually Dimorphic Growth

We found that sexually dimorphic growth rates of male and female YUK Chinook were discernable from an early age, which corroborates the results of Ruggerone et al. (2007, 2009a). Ages 1.3 and 1.4 females were significantly larger than males of their cohort, and this difference was manifested during earlier life stages in age 1.3s than 1.4s. In contrast, mixed-stock OBS females were significantly shorter than males for ages 1.2, 1.3 and 1.4, which may be due to age-specific differences in maturity schedules of male and female Chinook salmon. Our field and laboratory experience indicates that maturity of OBS Chinook in winter samples can be determined by visual examination of gonads. However, NOAA Fisheries observers did not routinely collect salmon maturity data. The lack of OBS Chinook maturity data complicated interpretation of our results.

Dependence of Annual Growth on Previous Years' Growth

Ruggerone et al. (2007; 2009a,b) found that interannual variation in adult length and scale growth at each life stage of AYK Chinook salmon was not related to variation in abundance (harvests) and ocean

conditions, annual scale growth of individual fish was dependent on previous years' growth, and adult length was positively correlated with both freshwater and ocean scale growth. Our analysis of YUK Chinook females supported the findings of Ruggerone et al. The scale patterns of ages 1.3 and 1.4 YUK female Chinook (1996-2008) showed a dramatic shift to higher than average growth that began with freshwater growth in 1999 or 2000 and progressed through subsequent ocean life stages with a one year lag per life stage. That this shift should be so pronounced and persistent is very curious and demonstrates the strength of Ruggerone et al.'s results. In contrast, the growth of OBS Chinook did not exhibit this pattern, and was more variable and independent of previous year's growth. Strong positive correlations between annual ocean growth increments SW2, SW3 and SW4 for age 1.3 and 1.4 OBS fish implies that marine growth was dependent on ocean conditions rather than initial fish size for OBS.

Alternating-Year Patterns in Abundance and Growth

Several scale-pattern studies have linked ocean growth and survival of other populations of Chinook salmon to the alternating-year pattern of pink salmon abundance (e.g., Grachev 1967, Ruggerone and Goetz 2004, Ruggerone and Nielsen 2004). Scale growth increments during the first two years of marine life of eastern Kamchatka (Kamchatka River) Chinook salmon were negatively correlated with the abundance of eastern Kamchatka pink salmon (Grachev 1967). In contrast, Ruggerone et al. (2007) found that scale growth increments during the second year of marine life (SW2) of adult YUK and KUS Chinook were consistently greater during odd-numbered years, when the abundance of adult eastern Kamchatka pink salmon is highest. We found that abundance and growth of even-numbered brood years of age 1.4 YUK Chinook salmon were negatively correlated with both low and high abundance years of adult eastern Kamchatka pink salmon when Chinook were ages 1.1 and 1.2 in the western and central Bering Sea. There also appeared to be a negative effect on abundance and growth of juvenile (age 1.0) YUK Chinook in years of high abundance of juvenile (age 0.0) eastern Kamchatka pink salmon.

The factors driving these alternating-year patterns of growth in Chinook salmon are unknown. Ruggerone et al. (2007) speculated that maturing Asian pink salmon might feed on prey one year younger than the same prey species consumed by YUK and KUS Chinook salmon during their second ocean year (cascading trophic interaction). During this life stage (SW2, age 1.1), AYK Chinook are distributed in northwestern and central Bering Sea basin habitats in summer-fall (Bugaev and Myers 2009a; Myers et al. 2009). Overlap in summer distributions of age 1.1 AYK Chinook salmon and adult pink salmon returning to eastern Kamchatka may be highly variable from year to year depending on climate-ocean conditions (Bugaev and Myers 2009a). For example, we observed that SW2 growth anomalies of age 1.2 WAK Chinook were in phase with pink salmon abundance during the early 1990s, shifted to a negative phase in 1997 that coincided with the strong ENSO cycle, and shifted to a positive phase starting in 2002 (similar to SW2 growth patterns of age 1.3 YUK Chinook).

We speculate that alternating-year growth patterns at the earliest ocean life stage (SW1) may reflect late summer-fall trophic interactions between Russian and AYK juveniles of both species in areas of intermingling in the northern Bering Sea. To our knowledge, there are no stock-specific data on overlap in ocean distribution of juvenile Russian pink salmon with juvenile AYK Chinook salmon in the northern Bering Sea. The 2002-2006 BASIS survey data showed that abundance of juvenile pink salmon in the northeastern Bering Sea was high in all years and distributions and diets of juvenile pink salmon overlap those of much less abundant juvenile AYK Chinook salmon (Davis et al. 2009b; Farley et al. 2009; Murphy et al. 2009). Genetic stock identification of juvenile pink salmon in U.S. and Russian BASIS samples and research on potential interactions between Russian pink salmon juveniles and AYK Chinook salmon juveniles in the northern Bering Sea in summer-fall are both important topics for future research.

Seasonal Growth Patterns and Size-Selective Mortality

Our results provide the first information on seasonal growth patterns of subadult eastern Bering Sea (OBS) and AYK-region (YUK) Chinook salmon, and indicated potential seasonal size-selective mortality and compensatory growth. Our results did not consistently support our hypothesis that smaller, slower

growing fish experience size-selective mortality during their first ocean winter. However, there may have been greater survival of larger fish during the first to second marine year. YUK females exhibited an increasing amount of winter growth (less summer growth) as they aged, while OBS Chinook showed the opposite trend. It is possible that these opposite trends reflect size-selective fishing mortality of Chinook salmon in the BSAI bycatch. However, we are reluctant to put complete faith in our seasonal scale growth increment data, because demarcations between end of fast summer growth and slower winter growth were more subjective than demarcation of annual growth increments. Because summer growth increments mirror annual growth increments closely, little may be gained from the additional time expenditure required to measure seasonal increments, particularly given the chance for measurement error.

In conclusion, we believe that reconstructions of growth histories of Chinook salmon from historical and ongoing collections of scales from marine research surveys and commercial fishery bycatch have the potential to inform fishery managers about ocean age, size, and growth-related issues. The development of age- and brood-year specific time series of freshwater and ocean growth for key index populations of adult Chinook salmon returning to the AYK region could provide a relatively inexpensive way to identify and monitor potential limiting factors related to climate-ocean conditions. To be most effective, use of ocean scale-growth time series should proceed in combination with the use of genetic tools to identify stock origins of individual fish in mixed-stock samples. In Objective 9, we further evaluated the relationships between climate-ocean conditions and reconstructed scale growth histories.

Discussion Objective 4: Map Climate and Ocean Conditions in Regions Where AYK Salmon Migrate

The results of mapping of climate-ocean conditions were discussed in other sections of the report (see Objectives 2, 6, 7, and 9). Sea and air surface temperature data provided the best measure of climate and ocean conditions in Bering Sea habitats used by Chinook salmon. The most important feature of AYK Chinook salmon ocean habitats, however, is the distribution and abundance of their preferred prey (squid, fish, euphausiids). Spatial and temporal mapping of squid, fish, and euphausiid prey distribution in the Bering Sea habitats of AYK Chinook salmon was not possible due to lack of data, and is an important topic for future research.

Discussion Objective 5: Seasonal Food Habits and Variation in Salmon Diets

We hypothesize that feeding aggregations of Chinook salmon in the ocean are segregated horizontally and vertically by body size, age, and maturity stage, and that their distribution is closely linked to the distribution of their preferred prey. In both the eastern and western Bering Sea in summer-autumn, juvenile Chinook salmon feed on larval and juvenile fish (capelin, Atka mackerel, pollock, herring, and sand lance; Farley et al. 2005b; Naydenko et al. 2005). In the central Bering Sea in summer, the major prey of immature Chinook salmon include squid (predominantly large *Berryteuthis anonychus*, 80-90 mm ML), euphausiids (*Thysanoessa longipes*), and fish (*Pleurogrammus monopterygius* and *Stenobrachius leucopsarus*) (Davis 2003). In the northwestern Bering Sea in autumn, immature Chinook salmon distributed over deep (basin) waters feed primarily on squid, and those over the shelf feed on fish (Efimkin et al. 2004; Volkov et al. 2005). Zooplankton account for a relatively small percentage of food consumed by Chinook salmon in summer-autumn (25-30% of food of juveniles; 3% of food of immatures; Naydenko et al. 2005). Our results provide the first data on the diets of immature and maturing Chinook salmon in the eastern Bering Sea in winter and early spring.

Many researchers have hypothesized that salmon are food limited during their offshore ocean feeding migrations (Rogers 1980, Rogers and Ruggerone 1993, Aydin et al. 2000, Kaeriyama et al. 2000, Ruggerone et al. 2003). At the same time, estimates of the biomass of prey resources in the ocean usually far exceed estimates of the amount of food that could be consumed by salmon (e.g., Shuntov and Temnykh 2005). A large increase in the abundance of Asian and North American pink, chum, and sockeye salmon since the mid-to late 1970s corresponded with a decrease in the body size of adult salmon

returning to both continents, leading some scientists to hypothesize that carrying capacity of salmon in the ocean was limited (e.g., Kaeriyama 1989, Ishida et al. 1993, Helle and Hoffman 1995, Bigler et al. 1996).

Competitive interactions likely play a significant role in food limitations in the open ocean. For example, Davis (2003) reported a significant increase in stomach fullness, mean prey weights, and the amount of fish and squid consumed by immature Chinook salmon in summer during even-numbered years when abundance of maturing East Kamchatka pink salmon in the central Bering Sea was low. Diets of large pink salmon (>1500g) included substantially more large squid and euphausiids than small pink salmon (<1000g). Davis (2003) concluded that the central Bering Sea basin in summer is a critical habitat for small (<1000g body weight; age 1.1) immature Chinook salmon, because of its role as a nursery area for juvenile and post-larval fish and squid that provide small immature Chinook salmon with a rich forage base. Our analyses showed that in 2007 all age groups of Chinook salmon (ages 1.1, 1.2, and 1.3) in the central Bering Sea fed on small gonatid squid (15-30 mm ML) in the central Bering Sea, although older fish also consumed large squid. This might indicate intraspecific competition for small gonatid squid or a high abundance of small gonatid squid. We speculate that interannual variation in the abundance or distribution of small gonatid squids (15-30 mm ML), which are an important prey of age 1.1 Chinook salmon, might provide a mechanism for observed odd-even year scale growth patterns of AYK Chinook salmon in their second ocean year (Ruggerone et al. 2007). There is a critical gap in information on the distribution, abundance, and life history of gonatid squid.

Davis et al. (2003) analyzed salmon food habits data from samples collected in the Bering Sea in autumn 2002. The stomach contents data from these collections were considered to be representative of the food habits of all salmon stocks (including AYK salmon) migrating in the study area. Fall 2002 data were compared with samples collected in summer 2002, and with data collected in summer during odd- and even-numbered years (1991-2001) from regions representative of the distribution of Yukon River salmon. Diet overlap between Chinook salmon and either sockeye or chum salmon was relatively low, as Chinook salmon were specialized consumers of fish and squid. Samples of stomach contents collected in autumn were less diverse in salmon prey composition than samples collected during summer, likely due to changes in prey availability.

Winter Food Habitats of Chinook Salmon in the Eastern Bering Sea in 2007

Discussion in this section was published in Davis et al. (2009a).

Chinook salmon food habits studies have been conducted in the western (Karpenko 1979, 1982; Karpenko and Maksimenkov 1988; Shuntov et al. 1993; Volkov et al. 1995; Glebov 1998; Karpenko et al. 1998; Koval and Karpenko 1998; Temnykh et al. 2003; Klovach and Gruzevich 2004; Smorodin et al. 2004; Volkov et al. 2007) eastern (Carlson et al. 1998; Murphy et al. 2003; Davis et al. 2004; Volkov et al. 2007), and central (Ito 1964; Murphy et al. 2003; Davis et al. 2004; Volkov et al. 2007) Bering Sea. Winter is the most critical period for ocean survival of salmon, but there are little or no food habits data for Chinook salmon during this season. This study is the first to analyze samples from the eastern Bering Sea in the January– March period. Previous November–December surveys offshore of southeast Kamchatka in the North Pacific (Sobelevskii and Senchenko 1996), Okhotsk Sea (Volkov 1996), and southwestern Bering Sea (Glebov 1998) reported ocean age-0 and older Chinook salmon consumed primarily nekton. Young Chinook salmon (21–40 cm FL) consumed up to 87% juvenile squids (including *B. magister*) and the remaining component of the diet was euphausiids (Sobelevskii and Senchenko 1996). In the winter, fish species consumed by Chinook salmon included capelin (*Mallotus villosus*), northern lampfish (*Stenobranchius leucopsarus*), Pacific sand lance (*Ammodytes hexapterus*), and walleye pollock. Some of the same species were identified from earlier winter Chinook salmon diet studies, including Myctophidae and capelin (Glebov 1998). Squid identified in winter 2007 diet samples included several species of gonatid squid, including *B. magister*, *Go. borealis*, *G. pyros*, and *G. berryi*. *G. kamtschaticus* has been identified in winter diets of Chinook salmon. (Glebov 1998), however, we observed this species only as juveniles in samples collected during the summer.

While Chinook salmon routinely inhabit waters considerably deeper than 50 m, this is the first study to examine the stomach contents of Chinook salmon caught at greater depths (51–569 m). Salmon trawl

surveys that include analysis of salmon food habits generally operate in the upper 50 m of the water column (NPAFC 2001; Volkov et al. 2007; Efimkin et al. 2008; Fukuwaka et al. 2008a). Chinook abundance estimates have been obtained to depths of 120 m (Walker et al. 2007) and Chinook salmon bycatch in commercial trawling operations has been reported to 360 m in the northeastern Bering Sea, 300 m in the eastern Bering Sea, and 482 m in U.S. west coast trawl fisheries (Erickson and Pikitch 1994; Radchenko and Glebov 1998a,b; Walker et al. 2007). While some Chinook salmon might have entered the trawl at shallower depths during descent or ascent of the fishing gear, depth-recording data storage tags placed on Chinook salmon show these fish routinely dive to 250 m in spring in southeast Alaska (Murphy and Heard 2001) and inhabit depths to at least 350 m during winter and early spring in the Bering Sea (Walker and Myers 2009). If Chinook salmon generally remain for several hours to feed within the broad 200-m depth intervals where they are caught, then we can assume the difference in the prey composition among the depth categories likely reflects true differences in the diet of fish caught in different depth habitats.

We observed that Chinook salmon stomach contents varied with fishing depth, with more euphausiids and fish offal in the stomach contents of Chinook salmon caught at < 200 m and more squid in the stomach contents of Chinook salmon caught at > 200 m. The preponderance of euphausiids in the stomach contents of Chinook salmon captured at < 200 m might result from higher abundance of these organisms at shallow depths. Preference for a particular depth range is characteristic of euphausiid species, and most of the species distributed in this area of the eastern Bering Sea generally have a maximum vertical range of 0 to 400 m (Mauchline 1980).

The preponderance of fish offal in the stomach contents of Chinook salmon captured at < 200 m might reflect the greater abundance of this material at shallower depths. Several other authors have described an inverse relationship between the amount of fish offal in stomach contents and water column depth (Hovde et al. 2002; Orlov and Moukhametov 2007). Perhaps the horizontal spread of fish offal away from the surface increases with depth, thus increasing the number of potential scavengers consuming it.

Piscine scavenging on offal generated from fish processing has been reported primarily from the diets of demersal fish, including Greenland halibut (*Reinhardtius hippoglossoides*; Hovde et al. 2002; Roman et al. 2007), Pacific halibut (*Hippoglossus stenolepis*; Orlov and Moukhametov 2007), Pacific black halibut (*R. hippoglossoides matsuurae*) and Kamchatka flounder (*Atheresthes evermanni*; Orlov and Moukhametov 2004), yellowfin sole (*Limanda aspera*; Brown et al. 2005), belligerent sculpin (*Megalocottus platycephalus*) and starry flounder (*Platichthys stellatus*; Tokranov and Maksimenkov 1995), great sculpin (*Myoxocephalus polyacanthocephalus*; Glubokov and Orlov 2005), southern cod (*Patagonotothen ramsayi*) and channel bull blenny (*Cottoperca gobio*; Laptikhovskiy and Arkhipkin 2003), Argentine hake (*Merluccius hubbsi*) and bigeye grenadier (*Macrourus holotrachys*; Laptikhovskiy and Fetisov 1999), and black dogfish (*Centroscyllium fabricii*; Punzon and Herrera 2000). However, consumption of fish offal has not been previously reported for any salmon species, including Chinook salmon. In winter, we found Chinook salmon feeding on fish offal identified as originating from walleye pollock (Buser et al. 2009). Food resources might be scarce in winter causing some Chinook salmon having a demersal distribution to scavenge offal discarded by the pollock fishery, thus supplementing their natural diet. Proximity and attraction to fish offal could affect distribution of Chinook salmon by motivating them to move to areas where fish are processed and chunks of fish are discarded.

Our study found immature Chinook salmon contained more euphausiids in their stomach contents than maturing fish. Analyses of Chinook salmon food habits by other investigators working in the Bering Sea have observed that small Chinook (< 40 cm) salmon consume more zooplankton, such as euphausiids, decapods, large crustaceans, and pteropods. Larger (> 40 cm) Chinook salmon consume more nekton, such as squid and fish (Glebov 1998; Farley et al. 2006; Volkov et al. 2007).

We did not observe a statistical difference in the proportion of various prey types in Chinook salmon of different ages. Because of the small number of stomach samples obtained from the youngest (ocean age-1) fish (n = 5; Table 1), data for ocean age-1 and -2 fish were combined. Combining the data from these age groups likely obscured potential differences in diet between small (young) and larger (older)

fish. If the number of ocean age-1 fish collected in winter could be increased in future studies, we suspect that significant differences in diet between young and older Chinook salmon will be found.

Consumption of age-0 walleye pollock by Chinook, sockeye, and chum salmon was reported in earlier studies of food habits in the Bering Sea (Davis et al. 2004; Farley et al. 2007b; Volkov et al. 2007). Our study showed the age of pollock consumed by Chinook salmon extends beyond consumption of juvenile (age-0) pollock to older age groups such as age-3 and possibly age-4 pollock (Table 3). This suggests pollock of the same age-class are susceptible to predation by Chinook salmon for several years, rather than escaping from salmon predation after the first year of life. Pollock might be vulnerable to predation by Chinook salmon until age-4, when pollock fully recruit into the eastern Bering Sea Pollock fishery (Wespestad 1993). The impact of salmon predation on pollock abundance has not been estimated, but future estimates will need to account for the successive years that a single cohort of pollock is vulnerable to salmon predation.

If prey availability or food habitat of Chinook salmon is reduced by climate-ocean effects, then increased intraspecific competition for food in the Bering Sea in winter could negatively affect growth, maturation, and survival of AYK Chinook salmon. Our results indicate that different age groups of Chinook salmon in the Bering Sea sometimes feed on the same species and sizes of prey. There is increasing evidence from recoveries of CWT fish and genetic analyses that substantial numbers of southern stocks of hatchery Chinook salmon (e.g., Cook Inlet, Southeast Alaska, British Columbia, Washington, Oregon, and California) migrate into the Bering Sea (e.g., Myers et al. 2005; J. Seeb, pers. comm.). Unfavorable ocean conditions in the Gulf of Alaska might result in a shift in distribution of these stocks into the Bering Sea, resulting in increased interactions between hatchery and wild populations of Chinook salmon. Furthermore, minor effects of density-dependent processes on juvenile salmon growth in the coastal zone may delay the seasonal timing of ontogenetic diet shifts in the open ocean, magnifying the effects on overall salmon growth rates. More information is needed on how ocean environmental conditions, particularly in winter and early spring, influence the growth, bioenergetics, maturation, and survival of AYK Chinook salmon.

Patterns of Marine Resource Utilization (Food and Habitat) by Chinook salmon in the Central Bering Sea (CBS) and Southeastern Bering Sea (SEBS), 2007-2009

Our analysis of the 2007 US observer samples was the first study of Chinook salmon winter diets in the southeast Bering Sea (Davis et al. 2009a). During Phase 3 of this project, we updated the Davis et al. (2009a) analysis with information on 2008 samples from the same area. This allowed us to evaluate interannual variation in Chinook salmon food habits with respect to seasonal differences in percentage of empty stomachs, seasonal changes in the proportion of fish prey in the diet, and comparisons of Chinook salmon size to prey body size. In 2007, we observed a higher percentage of empty Chinook salmon stomachs in winter than in summer samples and similar results were observed in 2008 samples. In 2008, additional samples were available in fall, when the percentage of empty stomachs remained relatively low. Results from analysis of both years support our previous conclusion, i.e., the high proportion of empty stomachs in winter samples may be due to a longer time interval between feedings in the winter than in summer and fall.

Diversity of the diet, including squid species and euphausiids in Chinook salmon diets in the SEBS in 2007 and 2008, was higher in winter than in summer samples in both areas (SEBS and CBS, Davis et al. 2009a). The pattern of species composition was consistent between areas. *B. magister* was frequently found in stomach samples in the SEBS, primarily in the winter samples. *G. kamtschaticus* was identified in samples collected in summer and fall in the SEBS. *G. borealis* was identified from stomachs in winter SEBS samples and during summer in CBS samples. In 2007, the percentage of fish in stomach contents collected in summer increased dramatically. In 2008 there was slightly more fish in summer samples, but the increase was not as large. Fish was a major component of young (ocean age-1) Chinook salmon in CBS. It is possible this is true for the SEBS, but this will await confirmation until more samples from this age group are collected in the SEBS. Davis et al. (2009a) observed more juvenile pollock were consumed

in summer than winter. However, few pollock were observed in stomachs of Chinook salmon in 2008 and pollock consumption is likely to be variable from year to year.

Fish offal was observed only in winter samples in 2007 and 2008 (Davis et al. 2009a). The proportion of offal in stomach contents collected in the SEBS was lower in ocean age -2 and older Chinook salmon in 2008 than in 2007. In these samples, consumption of fish offal was limited to the SEBS in winter. There was no evidence of fish offal consumption in the samples collected in other seasons in the same region, or from the CBS in summer. The observation supports the conclusion of Davis et al. (2009a) that by scavenging offal generated from fish processing Chinook salmon are supplementing their diet in winter, and there is year-to-year variation in the quantity of offal in the diets. Changes in the amount of offal in stomach contents likely reflects the degree of overlap between the winter distribution of Chinook salmon relative to the pollock fishing fleet, the water column depth over which offal is disposed, and the size distribution of the pieces of offal discarded during processing operations.

Analysis of 2007 and 2008 samples in the SEBS indicated a positive relation between predator size and maximum size of squid and fish in winter and no relation between prey and predator size in summer (Davis et al. 2009a). The range of squid sizes found in summer in both years was narrow, and may reflect a change in the availability of large *B. magister* in winter and small (younger) *G. kamtschaticus* in summer for consumption by Chinook salmon. Changes in prey size by season likely reflect changes in abundance of squid species of particular sizes that overlap with Chinook salmon (horizontal and vertical) distribution. In the summer in the CBS there was a positive relation between maximum squid prey size and salmon size and no relation between fish prey size and salmon body size. Based on our data, the largest squid consumed was 185 mm (ml; unidentified gonatidae) found in the stomach contents of a 77 cm (FL) Chinook salmon. The largest fish consumed was 280 mm (sl; pollock) eaten by a 79 cm FL Chinook salmon. These might be the maximum sizes of squid and fish prey that can be utilized by the Chinook salmon in these areas.

Chinook salmon fishers of the AYK area have observed decreased variability and reduced overall body size of maturing Chinook salmon returning to Norton Sound in recent memory (since 15-50 years ago; Raymond-Yakoubian 2009). Local fishers suggest Chinook salmon prey consumption may have decreased in inshore areas before maturing fish re-enter freshwater because they have observed more fish with empty stomachs recently than in previous years. Reduction of maturing Chinook salmon body condition from less than optimal feeding and increased parasite load can increase in-river mortality and decrease lipid investment in eggs. Local residents have observed return timing of the first Chinook salmon to Unalakleet shifting from middle of May to later in June, which coincides with changing conditions such as with decreased food availability or cooler summer temperatures (Raymond-Yakoubian 2009). Our study of winter Chinook salmon food habits suggests there might be longer time interval between meals in winter compared to summer and fall samples. Therefore, for maturing fish moving to inshore areas it is critical to have a high feeding rate in the spring as a final opportunity for the maturing fish to improve or maintain its body condition before the start of the run upriver. Unfortunately, none of our sampling opportunities supplied marine samples during the spring when fish are maturing.

Squid is an important prey of Chinook salmon, but relatively little is known about the life history of squid in Chinook salmon diets. Chinook salmon stomach contents collected in winter in the SEBS contained the most diverse diet of squid species, primarily *B. magister* and *Go. borealis*, and less frequently *G. pyros* and *G. berryi*. *B. magister* is a large species having a maximum mantle length of 43 cm and it is the most well studied of the group (Nesis 1997). Larvae, juveniles, and immature *B. magister* live in midwater habitats, and make an ontogenetic descent to the bottom of the lower shelf and slope when squids begin maturing at approximately 15-20 cm (ML; e.g., Nesis 1997; Drobny et al. 2007). Maturation rates are protracted and early- and late- maturing females have been observed (Nesis 1997). In the western Bering Sea examination of statoliths indicated juveniles hatched from December to June with a peak in February and March (Arkhipkin et al. 1998). The lifespan of this squid is disputed, but Nesis (1997) concluded the evidence from statolith increments supported a 2-year life cycle for fall-hatched *B. magister* in the western Bering Sea. This life history includes six months of embryonic

development and 18 months after hatching (Arkhipkin et al. 1996). Males likely mature before females with most fall-hatched males reaching maturity in 10 months and most females reaching maturity and having mated by approximately 11-13 months (Arkhipkin et al. 1996; Nesis et al. 1997). Based on these observations, most spent fall-hatched individuals were 13-14 months old and the oldest individual was 16 months old. The Eastern Bering Slope Current (EBSC) has been found to be the main carrier of *B. magister* juveniles from spawning grounds in the eastern Bering Sea to the western side and seasonal variability of the EBSC affects juvenile migratory patterns (Arkhipkin et al. 1998).

Other gonatid squid prey of Chinook salmon are less well studied. *Go. borealis* is a squid of intermediate size that is found in Chinook salmon stomach contents in winter and summer in both the Bering Sea habitats we studied. This species is among the most common and most widely distributed of gonatid squids (Nesis 1997). Spawning may occur in pelagic habitats. Maturation begins at 6-7 cm ML and the life cycle is thought to be one year with spawning peaks in February to April and another from late June to September (Kubodera and Jefferts 1984). In the North Pacific south of the Aleutian Islands, *Go. borealis* distribution shifts through the summer to stay within the isotherms from 2° to 9°C in May to 8° to 14° C in August (Nesis 1997). Environmental temperatures are likely to play an important role in determining the distribution, spawn timing, and development rate in these organisms.

Although absent from winter samples, *G. kamtschaticus* was observed in stomach samples collected in the summer and fall in the SEBS. *G. kamtschaticus* grows to a large final size of 46 cm ML (Nesis 1997). This squid is distributed in pelagic habitats near the continental slope in the upper 50 m in the Bering Sea, and does not undergo diel vertical migrations (Nesis 1997). Larvae are likely to hatch primarily in May-June (Kubodera and Jefferts 1984) and postlarval and juvenile squids are most commonly found in the Bering Sea in July-August. The spawning habitat of *G. kamtschaticus* is likely pelagic, rather than on or near the sea bottom (Nesis 1997). The life span of this squid is undetermined and the taxonomy is disputed (Jorgensen 2009).

In the CBS in summer, *B. anonychus* was identified in Chinook salmon stomach contents. This squid is a small-bodied squid attaining a maximum size of approximately 15 cm ML. This squid performs diel vertical migrations in the epipelagic zone (Nesis 1997). *B. anonychus* is distributed in the southeast Bering Sea and is most abundant in the Gulf of Alaska (Nesis 1997). The spawning habitat is unknown but *B. anonychus* likely migrates northward in the Northeast Pacific during spring, with males maturing at a smaller size than females. Spawning may be located near the continental slope (Nesis 1997; Bower et al. 2002). Based on the distribution of larvae, likely spawning peaks occur from February to April and from June to September and the life span is thought to be one year (Kubodera and Jefferts 1984; Nesis 1997). Much of the basic biology and seasonal distribution of this important prey needs further investigation to evaluate the potential affect of future climate change on these organisms and their Chinook salmon predators.

In summary, the conclusions of Davis et al. (2009a) were supported by our analysis of another year of winter samples. The proportion of empty stomachs was higher in winter samples than in summer samples, and that may be due to a longer time interval between feedings in winter than in summer. Diversity of Chinook salmon diets was higher in winter than in summer, and was higher for ocean age-1 fish than the older ages. In summer fish prey comprised a large proportion of the diet of ocean age-1 Chinook salmon. Squid identified in samples showed a shift in species composition between seasons and areas. In the southeast Bering Sea *B. magister* was frequently found in stomach samples, primarily in the winter samples and *G. kamtschaticus* was identified in samples collected in summer and fall. *G. borealis* was identified from stomachs in both seasons and areas, and *B. anonychus* was only observed in summer samples in the central Bering Sea. Consumption of fish offal by Chinook salmon was confined to winter samples in the southeast Bering Sea, and suggests Chinook salmon scavenge from the discards of fish processing (Davis et al. 2009a). The amount of offal consumed by Chinook salmon likely varies from year to year based on degree of overlap between offal disposal and Chinook distribution, the size of the offal pieces, and the depth of the water column. Based on a comparison of fish and squid prey size to Chinook body size, there is a consistent positive relation between Chinook salmon body size and squid prey size by season and area. However, the relation between Chinook salmon body size and fish prey size

is more variable among areas and seasons. The high incidence of empty stomachs in the winter samples suggests small increases in winter temperatures could increase Chinook productivity by increasing their activity and prey consumption, if prey availability is not limited.

There are many areas of future research that would increase our knowledge of Chinook salmon food habits and their role in the Bering Sea ecosystem. Directed research on squid seasonal distribution in combination with environmental conditions would provide information on the factors affecting their distribution and the degree to which they are available for salmon predation. Information on squid juveniles obtained from plankton tows could be used to provide information on spawning habitats and timing. Information on larger juveniles and sub-adult squid could be gained from detailed identification of squid from stomach contents and from identification and measurement of squid caught in trawls. Important gaps remain spring sampling of Chinook, particularly in examination of food habits and body condition of Chinook salmon in the estuary where juvenile are exiting the river environment and the shallow (<30m) shelf areas where adult fish are returning before re-entry to the river.

Review of BASIS Food Habits Data

The discussion in this section was published in Davis et al. (2009b).

The review of 2002–2006 BASIS food habits studies of sockeye, chum, pink, and Chinook salmon identified important prey taxa of salmon in the Bering Sea. These taxa include euphausiids, crab megalopa and zoea, hyperiid amphipods, pteropods, chaetognaths, gonatid squids, Atka mackerel, lampfishes, Pacific sand lance, capelin, walleye pollock, herring, whitespotted greenling, prowfish, sablefish, and rockfish. Monitoring the abundance and distribution of these prey organisms using a standardized method will be useful for evaluating the feeding status of salmon in the Bering Sea. Investigations comparing salmon diets among areas of the Bering Sea showed the largest difference in salmon diets between the western and eastern regions. Diets of salmon collected in the western region contained more zooplankton, while salmon collected in the eastern region contained more ichthyoplankton and nekton.

Salmon stomach samples collected from deep waters contained more deep dwelling or vertically migrating prey species than salmon at shallower depths. Studies showed salmon feeding differed in relatively warm years, as compared to cooler years, suggesting some salmon species will do better under warming climate conditions than others. The BASIS food habits studies significantly increased the available information on salmon food habits during the fall in the western, central, and eastern regions. Limited studies suggest salmon food habits vary by season but more studies in the same sampling area in more than one season are required. Salmon prey composition shifts with increasing salmon body size, enabling large salmon to feed on relatively large-size fish such as young pollock, Atka mackerel, and lampfishes. As sea temperatures and environmental variability increase in the future, it is important that we continue to monitor salmon food habits, growth, and body condition if we are to understand how these changes will affect salmon populations in the Bering Sea.

Discussion Objective 6: Estimate Consumption and Growth Efficiencies Modeled Under Different Climate Scenarios

Conversion efficiency for young Chinook salmon during their first winter at sea on the SEBS shelf for the cold period (1972-76) was notably lower (9% compared to 23%) than for the warm period (1977-81). For the other age-maturity groups, habitats, and seasons, conversion efficiency between the earlier and later period were not substantially different. Low conversion efficiency for young Chinook salmon in winter is caused by the low net production of Chinook salmon under the cold regime for both the fast- and slow-growing fish. Net production was 20% of initial body weight for fast-growing fish and 24% of initial body weight for slow-growing fish in the cold period (1972-76). Under warmer conditions, net production was estimated to be substantially higher for fast (86% of initial body weight) and slow-growing fish (81% of initial body weight; Table 6-3). For Chinook salmon during their first winter at sea on the SEBC shelf break, low growth rates (and increased mortality) may result when fish are subjected to

low temperatures ($<2^{\circ}\text{C}$) during the winter for a substantial period of time (1-2 months). Comparing juvenile salmon growth rates during a recent cool and warm period (2002-2006) Farley et al. (2009) speculated warmer spring SSTs conditions on the eastern Bering Sea shelf were favorable for growth and survival rates of juvenile western Alaska salmon. Beamish and Mahnken (2001) suggested that growth-based mortality during the first winter at sea was the critical period that linked salmon production to climate. In our model the coldest month in the SEBS shelf break habitat is March. Under conditions of equal prey availability, we speculate Chinook salmon marine growth-based mortality during their first winter at sea is higher during a colder period (pre-1977) than during a warmer period (post 1977). Growth-based mortality in subsequent winters is not substantially different between cold and warm periods.

Fast and slow-growing Chinook salmon showed the same seasonal pattern between the two climate scenarios. Seasonal growth rates indicated cooler summer conditions and warmer winter conditions favored higher growth rates. Model input values were based on the best information available from this research project or from other relevant studies. The input values used for prey composition and prey and predator energy densities were either from results of this research project or from literature values from studies collected more recently than 1977. For this analysis, we assumed these factors were the same during the period before (1972-76) and after (1977-81) the 1977 regime shift. If Chinook salmon diet quality (prey composition and energy density) changed substantially between these periods, then this factor could change the results of our climate scenario comparison because diet quality and temperature affects Chinook salmon growth rate (Fig. 6-3 and 6-4).

The annual weight increment for each age-maturity group was back calculated from scales of female Yukon River Chinook salmon in the specific years used in this analysis (1972-76 and 1977-81). We assume the annual scale size increments collected from fish caught in gillnet fisheries (research and commercial) in the river are representative of the sizes of all female Yukon River Chinook salmon at those ages. The fish that return to the river and are caught in these fisheries represent the survivors of the brood, and may be larger than the actual mean annual size increment of the fish at sea and might not have survived to return to the river. In addition, if the gillnets are size-selective and catch larger fish than the average size of all returning fish, then our weight increments will be too large and the modeled growth rates and prey consumption will be over-estimated. We increased the y-intercept of the allometric mass function for consumption by 1.4 in order to account for the weight increment we estimated for immature ocean age-2, -3, and -4 fish and maturing ocean age -3 and 4 fish. This indicates either the model consumption parameters for larger Chinook salmon are too low, or the estimated annual weight increments are too large. For this analysis, we assumed it was most likely the consumption parameter that were too low because of the difficulty in performing physiological experiments on large Chinook salmon (>2.5 kg) and to address this problem decided to change in the height (not the slope) of consumption dependence on mass for larger-sized Chinook salmon.

Discussion Objective 7: Map Ocean Growth Potential.

Because of the lack of data on distribution and abundance of the major prey species of Chinook salmon, bioenergetics models were the best approach to mapping their ocean growth potential. Our modeling results provided a tool for mapping ocean growth potential of AYK Chinook salmon by life-history stage in any habitat where sea temperatures are known. Based on our analysis, if the minimum thermal environmental of the fish in winter is above 2.5°C and summer maximum temperature is approximately 13°C , this physical environment would be favorable for Chinook growth and survival.

Future research on ocean growth-potential mapping needs to focus on determining both horizontal and vertical distribution of AYK Chinook salmon with respect to distribution of their prey, and evaluation of life-stage specific variation in prey quality and feeding rates of Chinook salmon. Bioenergetic models demonstrated a high diet quality diet enables better growth of Chinook salmon at lower feeding rates and at a wider range of temperatures than a low quality diet. Under conditions of improved diet quality, the optimum temperature for growth of Chinook salmon shifts to warmer temperatures, by approximately 1°C . The thermal tolerance (range of temperatures permitting weight gain) of Chinook salmon decreases

and shifts to cooler temperatures with lowered diet quality and feeding rate, particularly in older immature and maturing fish. Juvenile sockeye salmon have also been shown to have a wider temperature tolerance and might be more frequently limited by feeding rate and prey quality than larger fish (Beauchamp 2009). If future climate conditions adversely affect Chinook salmon diet quality, then their thermal tolerance will be reduced.

In conclusion, water temperature is a key factor affecting the growth rate of Chinook salmon. The first winter at sea for young Chinook salmon is a critical time particularly when water temperatures are very low. Chinook salmon marine growth-based mortality is likely higher during a cold climate regime than during a warm regime for salmon during their first winter at sea. Improved diet quality favors increased temperature tolerance of fish as measured by fish growth rate. Future climate forecasts predict increasing variability. If Chinook salmon diet quality is adversely affected by future climate conditions then the fish's thermal tolerance may be reduced, which will not favor individual survival if more extremes of climate are expected. However, if diet quality is maintained under a warm climate scenario there is an opportunity for high growth rates and potential for Chinook salmon to mature at an earlier age and return to the river at a smaller body size.

Important gaps in the information required for development of Chinook salmon bioenergetics models remain. Field investigations are important and necessary for development of a complete life-history model of AYK Chinook salmon bioenergetics. In particular, information on nearshore movements, physical environment, and food habits for juvenile Chinook salmon immediately after entry into marine waters and for maturing fish immediately before returning to the river mouth would make a substantial contribution to development of life history models for AYK Chinook salmon. Basic physiological experiments such as weight and temperature dependent feeding rates for larger immature and maturing salmon will help resolve difficulties in estimating prey consumption for large fish. Temperature is a key factor affecting growth and potentially the survival of AYK Chinook salmon. Salmon-based temperature data collection using data-recording tags carried by salmon are needed to obtain daily and seasonal temperature profiles at water depths the fish inhabit and at time scales relevant to fish behavior.

Discussion Objective 8: Simulate Climate Effects on Age and Growth

Throughout the AYK region there is local knowledge of changes in age, size, and sex composition of adult Chinook salmon. For example, during our interviews residents of Unalakleet noted that Chinook salmon (kings) in recent years were much smaller than those in previous decades (1960s to early 1990s). Formerly they observed more variation in the size of kings, but now the size of kings seems almost uniformly small. Local experts noted that they see and catch many more "jack kings" (small, sexually mature males) than previously. Unalakleet residents estimated that the average size of kings is now 15-40 pounds (7-18 kg), whereas previously people regularly caught kings as large as 60-80 pounds (27-36 kg).

Scientific evidence of changes in age and size of AYK Chinook salmon is limited by inadequate stock assessment data throughout much of the region. However, recent declines in mean weights of commercial harvests and prevalence of the largest (oldest) Canadian-Yukon River Chinook salmon have been documented (e.g., Bigler et al. 1996; Hyer and Schleusner 2005; JTC 2006; Evenson et al. 2009). Stochastic simulations and simple additive genetic models have indicated that size-selective fishing on adults returning to freshwater might be causing rapid evolution of AYK Chinook salmon size (Bromaghin et al. 2008; Hard et al. 2009). Our analyses of scale growth patterns (proxy for growth in length) of AYK and Bering Sea Chinook salmon indicated significant interannual variation associated with regime shifts, climate, ocean environmental conditions, and biological interactions with other species.

Age and size at maturity, and incidence of jack males and minijacks, are all traits of Chinook salmon that are strongly influenced by both hereditary and environmental factors (e.g., Ricker, 1972, Gross 1987; Withler et al. 1987, Hankin et al. 1993, Heath et al. 1994, Hard 2004, Beckman and Larsen 2005). In our analyses, environmental gradients were reflected by different growth and mortality rates. Our results indicated that observed changes in age and size at maturity of AYK Chinook salmon can result from phenotypic plasticity, that is, different phenotypes (age and size at maturation) are produced under different environmental conditions without changes in genotype. Both plasticity and rapid evolution of

these traits involve tradeoffs between additional growth (associated with increased body size, fecundity, and egg size) and additional mortality (Healey and Heard 1984, Healey 1986), including size-selective fishing mortality. This can result in a mismatch between traits desirable to fishermen (e.g., big fish) and traits that increase reproductive success (fitness). Plasticity in response to climate change that increases survival at one life stage may reduce fitness at a later stage (e.g., high growth rates increase juvenile survival, resulting in density-dependent reduction in growth of immature and maturing salmon if food is limited). An important goal for future research is to understand the limits of plasticity in the response of AYK salmon to climate change and density-dependent factors.

Discussion Objective 9: Synthesize Information on the Ocean Life History and Climate-Ocean Effects on Chinook salmon

We synthesized LTK and scientific information on salmon life history and climate-ocean effects from our project, as well as in the scientific literature to further evaluate what we know and need to know to address the AYK SSI's research priority, "Marine survival of salmon is more affected by variability in ocean temperature and environmental variables than by variability in marine fishing mortality."

LTK-Identified Changes in Salmon and Environmental Conditions

Decrease in adult body size and food availability. The factor most frequently identified by Local Experts was a change in body size of adult Chinook salmon (usually a decrease in body weight and girth). Experts also reported an increase in adult salmon with empty stomachs might indicate a decrease in the amount of food available to salmon, at least at the end of the lifecycle prior to the fish entering freshwater to spawn.

Increase in disease. Local Experts reported an increase in the number of salmon with health issues. Problems included skin lesions, discolored skin and meat, bad smelling meat, meat containing pus, an increase in worms, as well as occasional, but more frequent than in the past, deformities.

Climatic/environment changes. Five major climatic/environmental changes needing further research were identified: (1) changes in the strength and direction of wind; (2) changes in the timing of freeze- and break-up; (3) potential warming of ocean and river water temperatures, possibly indicated by increases in algae, water grasses, jellyfish and erosion; (4) increased erosion events (frequency and size), particularly along river systems, that may impact salmon populations through addition of silts, gravels and organic materials into waterways; and (5) less snowfall than in the past to insulate the river ice, potentially leading to complete freeze up down to the riverbed, leading to an increase in egg to smolt salmon mortality.

Marine Fishing. Two major areas were identified as potential marine fishing problems needing further research and, perhaps, additional fishing regulations: (1) subsistence fishing in marine waters, which is currently allowed 7 days per week and, thus, may be putting too much pressure on Chinook populations; and (2) bycatch of Chinook salmon in the Bering Sea pollock fishery.

Salmon/trout interactions. A major problem identified by many local experts as needing further research was an increase over the past few decades in the abundance of trout, which are no longer harvested for dog food. Trout have been observed feeding intensively on eggs of spawning salmon and salmon fry.

We recommend that local experts, scientists, and fishery managers continue to collaborate under the auspices of AYK SSI to address these and other important issues (e.g., observed changes in run timing of adult Chinook salmon returns). Collection, analysis, and reporting of information from salmon and other species in subsistence harvests, as well as associated environmental data (physical, chemical, biological) may be an effective approach to obtaining stock-specific information on factors controlling reproductive potential and recruitment of AYK salmon populations.

Synthesis of Scientific Information on Ocean Life History and Climate-Ocean Effects

Over the past 50 years, a growing body of scientific evidence has linked climate change, ocean conditions, and fluctuations in the marine survival of salmon (e.g., Kaganovskii 1949, Birman 1966; Holtby et al. 1990; Percy 1992; Francis and Hare 1994; Mantua et al. 1997, Francis et al. 1998; Anderson and Piatt 1999; Beamish et al. 1999; Kareiva et al. 2000; Beamish and Mahnken 2001; Finney et al. 2002; Peterson and Schwing 2003; Beamish et al. 2004b; Kaeriyama et al. 2004; Mueter et al. 2005; Pyper et al. 2005). In the Bering Sea and North Pacific Ocean, both regional and hemispheric-scale atmospheric forcing influence ocean conditions (e.g., Mantua et al. 1997; Schumacher and Alexander 1999). Climate and ocean circulation systems in the Bering Sea and North Pacific Ocean are interconnected, and oceanographic conditions in these regions have been changing significantly over the past several decades, even prior to the well-established climate regime shift of 1976-1977 (e.g., Mantua et al. 1997; PICES 2004; Myers et al. 2007).

Several past syntheses of scientific information on the ocean life history of Chinook salmon identified key factors affecting growth and survival. Major et al. (1978) synthesized on high seas research vessel and Japanese mothership fishery data collected in offshore waters of the North Pacific Ocean from 1955 to 1970. Environmental conditions and fishing mortality were identified as key controlling factors during ocean life history stages (Fig. 9-6). However, the synthesis of Major et al. (1978) did not provide any specific data or results on environmental factors affecting ocean growth and survival of Chinook salmon. Healey (1991) updated the synthesis of Major et al. (1978) but also did not address the issue of climate-ocean effects on Chinook salmon growth and survival. Heard et al. (2007) synthesized information on long-term trends in biological characteristics of Chinook salmon, noting their extreme plasticity and diversified and complex life history compared to other Pacific salmon species. They also did not synthesize information on climate-ocean effects, but speculated that climate change might have already resulted in northward expansion of Chinook salmon ranges into Arctic regions, especially Beaufort Sea drainages of North America (Heard et al. 2007).

A number of variables, separately or in combination, were proposed as causes for the declines of salmon runs in western Alaska during the late 1990s (AYK SSI 2006). Time series analyses indicated strong co-variability in physical and biological variation in the Bering Sea and North Pacific Ocean (Hare and Mantua 2000). Changes in the abundance of zooplankton (jellyfish) in the Bering Sea in the 1990s were linked to climate change (Brodeur et al. 1999). Atmospheric forcing in the southeastern Bering Sea in summer 1997 led to mass mortality (starvation due to reduction in prey availability) of other species, e.g., short tailed shearwaters (*Puffinus tenuirostris*; Baduini et al. 2001). Warm water in the eastern Bering Sea in 1997 was indirectly related to the 1997 El Niño (Overland et al. 2001), and was directly associated with an anomalous high atmospheric pressure system that blocked storms and resulted in increased solar heating, warming of the water column, shallowing of the mixed layer, early depletion of nutrients in spring, a sustained bloom of coccolithophores (*Emiliania huxleyi*), and altered hydrographic regimes, including the strength and position of fronts of transition zones where prey organisms are concentrated (Napp and Hunt 2001; Stabenot et al. 2001). Cocolithophore blooms might have affected feeding conditions, leading to reduced growth and survival of both juvenile and adult salmon, through changes in benthic and pelagic food webs on the eastern Bering Sea shelf (e.g., Kruse 1998; Baduini et al. 2001; Stockwell et al. 2001). Late runs and smaller than average body sizes of adult salmon returning to western Alaska in 1997-1998 indicated that immature or maturing salmon were also affected by unusual ocean conditions during their extensive offshore feeding migrations. In addition, high ocean temperatures along coastal migration corridors in the eastern Bering Sea during the strong El Niño of 1997 or other factors (increased parasitism, predation, competition, and disease) might have caused high mortalities of returning adult salmon (D.E. Rogers, pers. comm.). Because of the lack of ocean monitoring and process studies of salmon in the eastern Bering Sea until the 2000s, however, there was little or no direct evidence linking anomalous ocean conditions in the late 1990s to changes in their marine survival of AYK Chinook salmon.

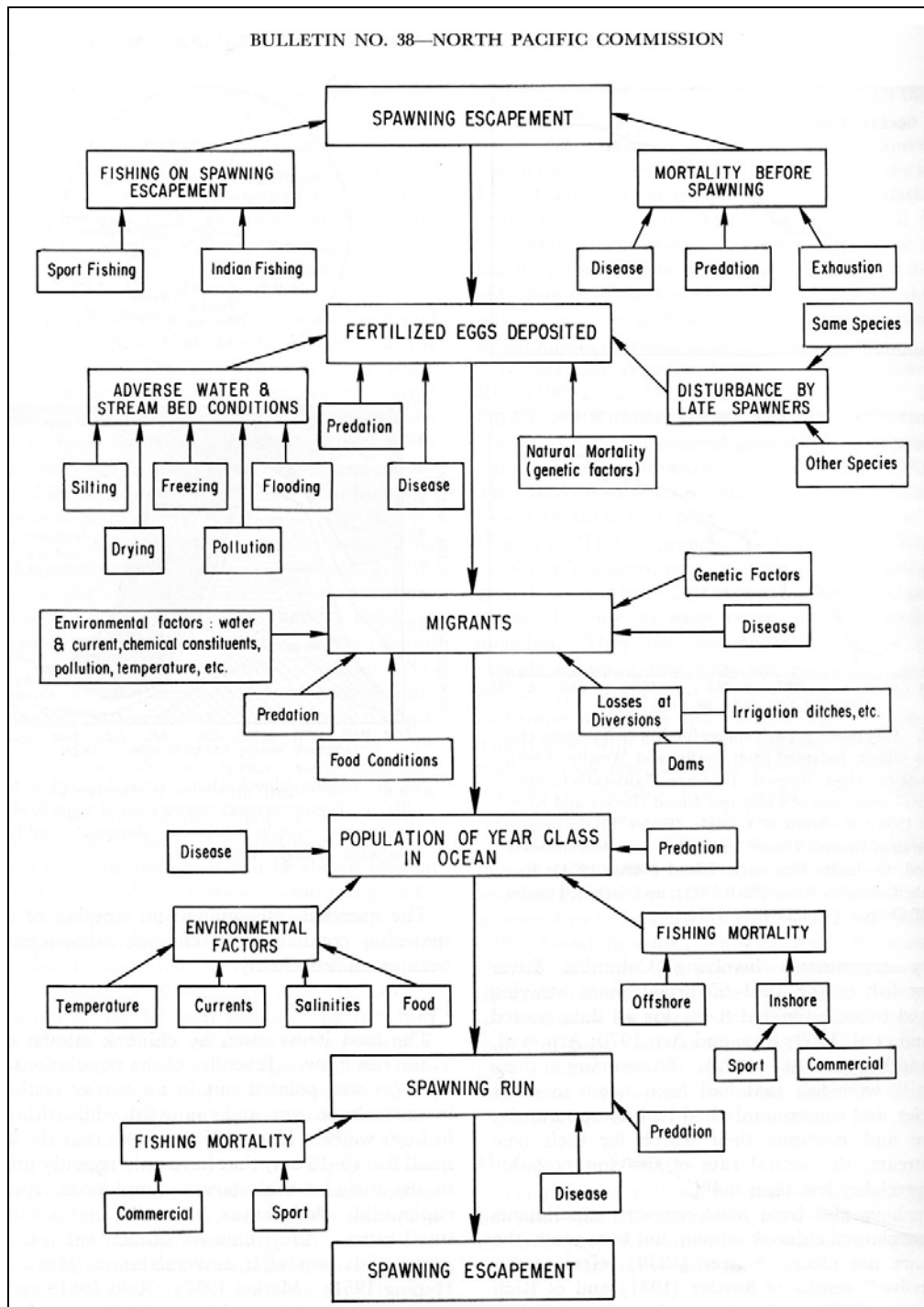


Figure 9- 6. Potential factors controlling reproductive potential and recruitment of a Chinook salmon population. Source: Major et al. (1978); original figure developed by K.H. Moser.

Recent examinations of physical–biological coupling using NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography; developed by the MODEL task team of PICES (North Pacific Marine Science Organization)) support the hypothesis that climate plays an important role in lower trophic ecosystem changes, however, the model does not accurately simulate observed decreases in zooplankton production in the eastern Bering Sea during the 1977-1996 climate regime (Aita et al. 2006). Aita et al. (2006) suggest that predation by fish (top-down control), which was not included in the NEMURO model, might have been the dominant control on zooplankton production in the eastern Bering Sea during the 1977-1996 climate regime. Future effects of climate changes are likely to be bigger than past changes because of human-caused global warming. Understanding regional and local patterns of climate change effects on AYK Chinook salmon is crucial, as these patterns can differ from global patterns.

Although adult returns of some AYK salmon populations have improved since the late 1990s, we assume that similar or even more dramatic fluctuations in AYK salmon runs will occur in the near future because of climate change. For example, ongoing transformations in salmon habitats in the Bering Sea ecosystem, including thinning of sea ice and northward movement of subarctic species into the arctic, are associated with global climate change (e.g., Hunt et al. 2002; Overland et al. 2004; Grebmeier et al. 2006). In the 2000s, winter seawater temperatures on the eastern Bering Sea shelf fluctuated between relatively warm years (2002-2005) and cool years (2006-present), providing BASIS scientists with a natural experiment to evaluate climate-ocean effects on the ocean distribution, growth, and survival of AYK Chinook salmon in the Bering Sea ecosystem. BASIS research indicated that ocean distribution and abundance of juvenile salmon over the eastern Bering Sea shelf differs in warm years vs. cool years (Farley et al. 2009). Warm sea temperatures on the eastern Bering Sea shelf were associated with larger size of juvenile salmon, and large size is positively related to ocean survival.

The fluctuations in physical ocean properties directly influence growth of salmon. Direct metabolic responses to different temperatures or salinities determine what fraction of an organism's energy budget supports basal and active metabolism rather than being allocated to somatic growth, reproduction, or high-energy lipid storage (Beauchamp *et al.*, 2007). Growth responses to temperature change are more pronounced for fish feeding at low rates or occupying sub-optimal temperatures, such as those encountered in the Bering Sea winter, whereas feeding rate or large shifts in prey quality affect growth more than the direct thermal effects on metabolism over a broad range of temperatures. Growth of salmon is an important factor influencing survival (Beamish and Mahnken 2001; Farley et al. 2007) and the first summer of feeding in the ocean is critical for achieving a size and sufficient energy stores to minimize predation and other size-selective sources of mortality during the first winter. Growth for older Chinook salmon is also important as fecundity is closely related to body size. Growth in the form of energy stores of mature returning adult salmon can determine success at reaching spawning grounds and the ability to locate, construct and defend redd sites.

Favorable early marine growth of salmon likely increases marine survival in subsequent life stages (Beauchamp 2009), and good marine growth during immature and maturing phases likely increases reproductive potential (Ruggerone and Nielsen 2009). As discussed above, LTK holds that conditions in the AYK region are warmer now (1990s to present) than in previous decades (1960s) and that adult Chinook salmon caught in the current warmer conditions are smaller in body size than the fish caught in previous decades. Our bioenergetics modeling results showed that when consuming a high quality diet, Chinook salmon achieve higher growth rates at warmer temperatures. Our simulations and models of age and growth indicated that recent growth and mortality rates of AYK Chinook salmon were relatively high. However, low growth rates were optimal for achieving maximum size and age at maturity. We suggest that under warmer climatic and favorable feeding conditions AYK Chinook salmon have higher growth rates, which result in earlier age of maturity and younger, smaller body size when they return to the river. Size-selective mortality by the winter BSAI pollock fishery and coastal marine and freshwater salmon fisheries likely also contribute to current low returns of older, larger Canadian Yukon Chinook.

In general, immature and maturing salmon in offshore waters are distributed in cool ($<17^{\circ}$), relatively fresh, nutrient rich sub-arctic and arctic waters. Research vessel catch and oceanographic data indicate that temperature and salinity preferences of Chinook salmon (upper thermal limit: 13.4°C ; upper salinity limit: 33.95) are similar to sockeye salmon (upper thermal limit: 13.3° ; upper salinity limit: 33.46), and both species prefer cooler and fresher seawater than pink, chum, and coho salmon (Azumaya et al. 2007). Azumaya et al. (2007) speculated that horizontal limits of food habitat of salmon might be defined by the upper salinity limit, while vertical distribution limits are dependent on the lower thermal limit. Lower thermal limits for Chinook salmon are not well defined, but DST data indicate that Chinook salmon can make dives to sub-zero water temperatures. Research vessel catch data indicate that the lower thermal limit for Chinook salmon ($<1.6^{\circ}\text{C}$) is lower than that other salmon species (Azumaya et al. 2007). Because Chinook salmon can tolerate very cold water temperatures, they can remain in the Bering Sea throughout the winter. We speculate that warm and more saline ocean conditions that prevailed in the eastern Bering Sea during the 1977-1996 climate regime (Aita et al. 2006), might have directly affected overwinter survival of Chinook salmon by reducing their food habitat and increasing the bioenergetic costs of feeding.

Our bioenergetics models demonstrated that Chinook salmon growth rates increase with increasing temperature to an optimal point at which growth rates decrease with increasing temperature. Modeled conversion efficiencies of young Chinook salmon during their first winter at sea on the SEBS shelf were notably lower during the pre-1977 cold phase of the PDO than during the post-1977 warm phase. For older age groups conversion efficiencies were similar in cool and warm PDO phases, but net production in terms of body weight was substantially higher during the warm PDO phase for both slow-growing (mature at age 1.4) and fast-growing (mature at age 1.3) Chinook salmon.

Our analysis of a continuous time series (1974-2008) of Japanese salmon research vessel data from the central Bering Sea indicated that average body size of immature age 1.2 Chinook salmon increased in response to warm climate-ocean conditions (positive phase of the PDO) and negatively to cool conditions. Ruggerone et al. (2007, 2009a) reported on correlations run between annual growth at each life stage for age 1.3 and 1.4 Yukon females and various climate indices (PDO, AL, AOI, and NPI and seasonal SST) over a 40 year time span. They did not find any significant relationships between these indices and growth of Yukon and Kuskokwim Chinook salmon although they did see an effect of the 1977 (abundance and SW1 growth increase) and 1989 (abundance and SW1 growth decrease) regime shifts. In contrast, we found that growth of mixed-stock OBS and WAK Chinook salmon was significantly associated with major ocean-climate events, i.e., the 1997 El Niño event, and large and smaller scale ocean/climate indices, i.e., Pacific Decadal Oscillation (PDO), May sea surface temperature (SST), Aleutian Low Pressure Index (ALPI), North Pacific Index (NPI) and other local climate measures of wind stress, temperature and pressure indices. Significant associations between growth and climate indices varied by life history stage.

Given equal prey availability, we speculate that growth-based mortality of Chinook salmon would differ between cold and warm climate periods only during the 1st winter at sea. How climate changes will affect Chinook salmon food habits through potential changes in prey availability and prey growth, however, is unknown. Pollock is a common prey of all species of juvenile salmon in the eastern Bering Sea of Chinook salmon at multiple life stages. Moss et al. (2009) found age-0 pollock were larger and more widely distributed in the eastern Bering Sea during warm years than in cooler years. Environmental temperatures were associated with changes in survival and growth of pollock (Moss et al. 2009). Increased production of sockeye salmon has also been associated with increased warmer sea water temperatures in the Bering Sea in spring (Farley et al. 2007b). Climate change effects on production and distribution of gonatid squid prey of Chinook salmon is unknown because much of the basic biological information about these species is unclear (Nesis 1997). Results of our study showed squids are an important component of Chinook salmon diets and that prey species composition shifts by season and habitat. Climatic changes likely affect these Chinook squid prey in different ways from one species to another.

In recent years (1992-2008) the scale growth of female Yukon Chinook salmon indicated a sudden positive shift around 2000. This shift was less apparent in samples from mixed stocks in trawl bycatch and central Bering Sea research catches. The shift corresponded to a large difference in winter sea level pressure over Alaska and the eastern Bering Sea between 1992-1998 and 1999-2004 (Fig. 9-1). The earlier period had pressures near long-term averages, while the later period had much lower pressures.

Winter Sea Level Pressure
1992-1998: normal

1999-2004: low pressure

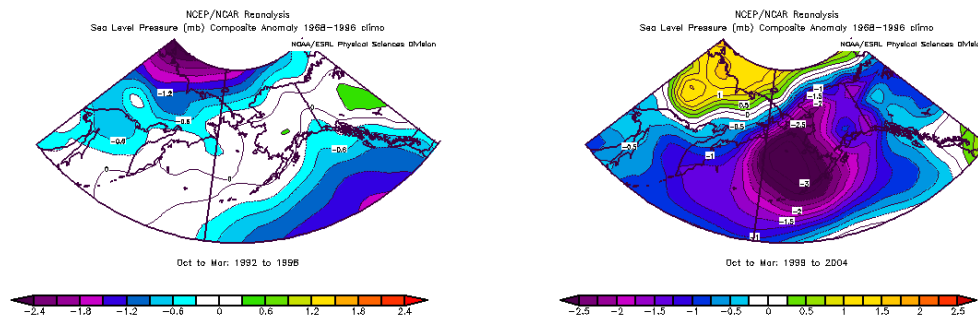


Figure 9-1. Winter sea level pressure differences between earlier (1992-1998) and later (1999-2004) periods. Data are anomalies from 1968-1996 averages and are from NOAA Earth System Research Laboratory at <http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl>.

This difference was also reflected in sea surface temperatures and meridional winds (Figs. 9-2 and 9-3). The later period had warmer SSTs in the eastern Bering Sea and stronger meridional winds (positive over Alaska, negative over the Anadyr Peninsula, Russia).

Summer SST
1993-1999: normal

2000-2005: warmer

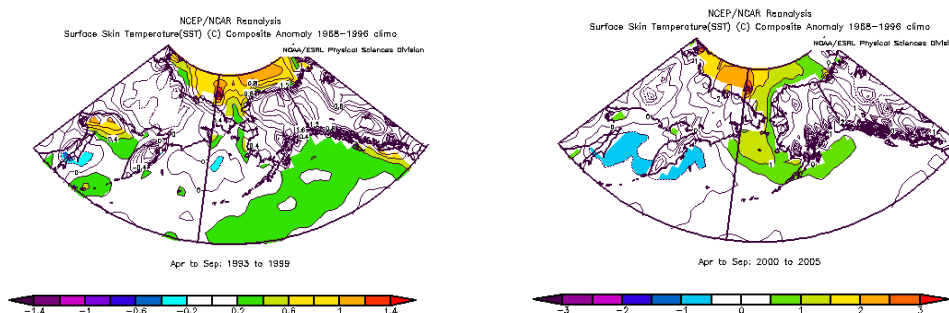


Figure 9-2. Summer sea surface temperature differences between earlier (1993-1999) and later (2000-2005) periods. Data are anomalies from 1968-1996 averages and are from NOAA Earth System Research Laboratory at <http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl>.

Winter Meridional (N-S) wind at 850 mb
1993-1999:

2000-2005:

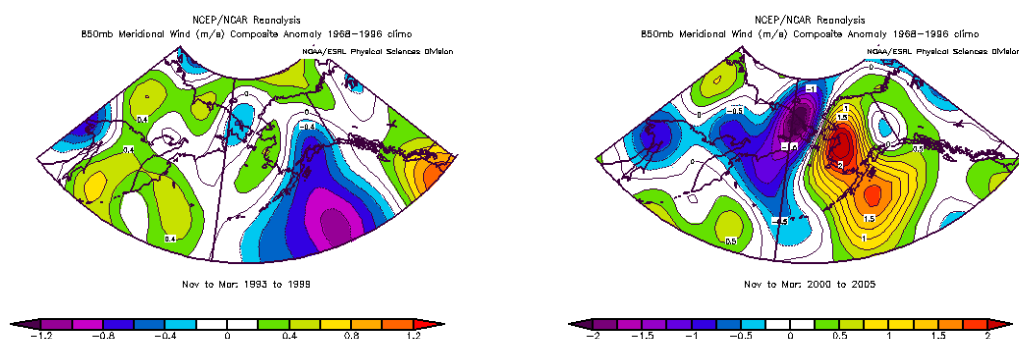


Figure 9-3. Winter sea level pressure differences between earlier (1992-1998) and later (1999-2004) periods. Data are anomalies from 1968-1996 averages and are from NOAA Earth System Research Laboratory at <http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl>.

The very strong negative pressure anomaly in the recent period would be associated with more storm systems, more clouds (less radiational cooling), and air circulation moving up (north) the eastern side of the low pressure area (over Alaska) bringing warmer air from the Gulf of Alaska. Colder air would have been brought down (south) over the western edge of the pressure anomaly area (i.e., over far eastern Russia). The stronger pressure anomaly would also create more winds, mixing the surface layer and bringing up nutrients on the shelf, with less ice cover and earlier melt out.

Our examination of correlations between various climate indices and annual scale growth of Yukon River Chinook salmon bears out this association. In brief, warmer temperatures over Alaska and at sea were associated with better growth. Indices associated with colder temperatures were correlated with poorer growth. Better growth was also associated with less ice cover and earlier melt out. There were a number of stronger correlations with Fairbanks surface air temperature, even in marine growth. For marine growth, this is probably a proxy measure, related to the weather patterns caused by the sea level pressure anomalies discussed above. Higher wind stress (easterly winds along the south shore of the Alaska Peninsula) in the spring (May-June) near Unimak Pass is also associated with poor growth. These winds are associated with coastal upwelling and transport of nutrients through Unimak Pass, which may sustain the spring bloom, but perhaps this also cools the surface temperatures and prevents the usual stratification and stable conditions that promote growth.

As Ruggerone et al. (2007; 2009a,b) found, growth of Yukon Chinook salmon was dependent on previous year's growth, which may obscure relationships between climate data and growth. However, female Yukon Chinook had higher than average growth in nearly every marine year for all six of the recent brood year's measured, especially age 1.4 fish. Even if growth in a given year is to some degree dependent on that in previous year(s), each of these year classes was getting a good start and growing well each year.

In contrast to Ruggerone et al. (2007; 2009a), we did find some significant relationships with climate variables. The variables we found most linked to growth of Yukon River Chinook salmon – lower sea ice cover and warmer temperatures – are both projected by climate models to change in the Bering Sea this century, with temperatures increasing at higher latitudes by 2°C and ice cover diminishing and retreating earlier (IPCC 2001, 2007; ACIA 2005). These conditions were associated with better growth for Bering Sea Chinook salmon. However, the relationship between warmer temperatures and other factors, such as freshwater conditions, fisheries effects, and food web productivity, is complex. It is also not clear why

Yukon River Chinook salmon run sizes have not increased even though recent growth has been good. Higher growth was recorded on scales even in recent colder years since 2006.

Assessment of the effects of climate and ocean conditions on Chinook salmon production in other regions has been attempted in several studies (e.g., Beamish et al. 1995; Ruggerone and Goetz 2004; Scheuerell and Williams 2005; Wells et al. 2006, 2007, 2008). Harvest patterns of AYK Chinook salmon appeared to be related to the 1977 ocean regime shift (Hare and Mantua 2000) and the 1997 El Niño (Kruse 1998) that influenced many marine species in the Bering Sea and North Pacific Ocean. Bradford (1995) reviewed estimates of salmon survival from the literature, but did not find any direct estimates of marine survival rates of naturally-spawning stocks of Chinook salmon. From fecundity and freshwater survival data, he estimated a species average for Chinook salmon of 1-2% marine survival, which was much lower than other species that rear in freshwater as juveniles (coho-10%, sockeye-6%).. This low marine survival rate was not accounted for by the relatively long ocean residence of Chinook salmon compared to coho and sockeye salmon. The extremely low marine survival of Chinook salmon hypothesized by Bradford (1995) is reflected in their low abundance relative to other salmon species throughout the Pacific Rim (Heard et al. 2007). Our analyses and models indicated that Yukon Chinook salmon currently have high growth and ocean mortality rates. Perhaps, the recent positive growth phase reflects a reduction in density-dependent growth effects due to low population abundance of Yukon River Chinook salmon.

In summary, our results indicate an uncertain future for AYK Chinook salmon. These northern populations are highly dependent on climate and ocean conditions in the Bering Sea, where they are distributed throughout their ocean life. Distribution of immature AYK Chinook salmon is farthest offshore during the 2nd summer-fall at sea, extending into the REEZ in the northwestern Bering Sea. Unlike other species of AYK salmon, AYK Chinook overwinter in the Bering Sea. Limited data from electronic tags showed Chinook salmon have a deeper vertical distribution than any other salmon species, with the known vertical range extending from the surface to a depth of 523 m (1,717 ft). These life-history traits make Chinook more susceptible than other AYK salmon species to bycatch in pollock trawl fisheries. In addition, consumption of fishery-generated pollock offal by Chinook salmon and other fish, bird, and mammal species is indicative of the disruption of natural food webs in the Bering Sea. Pollock offal is of low nutritional quality and perhaps a vector for diseases. The potential deleterious effects of offal consumption to reproductive potential and recruitment of AYK Chinook salmon populations are largely unknown. Offshore movement of salmon may be more closely related to water temperature than to age or body size (e.g., Nagata et al. 2007). The cumulative effects of climate change (e.g., increasing ocean heat content) might shift the Bering Sea summer feeding and overwintering grounds of AYK salmon farther to the north and west into the REEZ. This could increase competitive trophic interactions with Asian (Russian and Japanese) salmon and risks of interceptions by Russian fisheries.

Our projections of future changes in surface thermal habitats of Chinook salmon due to greenhouse gas emissions supported the results of previous studies (Welch et al. 1998a, 1998b; Kaeriyama 2008; Azumaya et al. 2007). By the 2040s, there is the potential for large decreases in Bering Sea surface thermal habitats of Chinook salmon. But Chinook salmon demonstrate a wide variety of behavior and thermal tolerances (Walker and Myers 2009), and their large geographical range (as far south as central California) and successful transplanted populations in the Great Lakes, New Zealand, and Chile indicate they can adapt to a wide range of conditions. This great flexibility gives some cause for optimism that they can adapt to changing oceanographic conditions. How future changes in climate and ocean conditions will affect life stage-specific ocean distribution and movements of AYK Chinook salmon with respect to ocean fisheries is still largely a mystery, and is an important topic for future research.

Crozier et al. (2008) reviewed genetic variation and heritability of salmon traits likely to be affected by climate change (heat tolerance, disease resistance, migration timing, etc.), and developed a conceptual model of how changes in environmental conditions shift optima and distributions of plastic response and potential selection pressure of phenological traits (timing of life-history events) in organisms with complex life histories. Traits of Chinook salmon during ocean residence such as growth rates and migration patterns were regarded as too poorly understood to suggest potential changes (Crozier et al.

2008). While data during ocean residence are certainly limited, we have assembled and provided to AYK SSI a database of information on Chinook salmon that may contribute to future research and understanding of these processes during ocean residence.

The complicated relationships within a long list of factors that may influence reproductive potential and recruitment of AYK Chinook salmon populations point out some critical needs for future research. In particular, the dependence of growth of AYK Chinook salmon on previous years' growth including that of young fish in freshwater (Ruggerone et al. 2007, 2009a,b) needs further investigation. The link, or lack of one, between growth and run sizes is also a major puzzle. Interactions between climate variables, growth, and survival should be explored in much greater depth, including both freshwater and ocean effects and effects on productivity and prey items.

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IX: DELIVERABLES

This section lists deliverables resulting from the project, including semi-annual progress reports, final reports, data/cruise reports, peer-reviewed manuscripts, and outreach (poster, oral, internet). All project deliverables were provided to AYK SSI in electronic format on a USB flash drive. Project investigators, cooperating investigators, and personnel are indicated in bold font.

Semi-Annual Progress Reports

- Myers, K., and R. Fosdick.** 2008. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 1 (712). Project Number 45559, Southeast Sustainable Salmon Fund Semiannual Performance Report (Submitted to AYK SSI/SSSF-ADFG, January 16, 2008).
- Myers, K., and R. Fosdick.** 2008. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 1 (712). Project Number 45559, Southeast Sustainable Salmon Fund Semiannual Performance Report (Submitted to AYK SSI/SSSF-ADFG, June 30, 2008).
- Myers, K., and R. Fosdick.** 2009. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 2. Project Number 45667, Alaska Sustainable Salmon Fund Semiannual Performance Report (Submitted to AYK SSI/AKSSF-ADFG, January 15, 2009).
- Myers, K., and R. Fosdick.** 2009. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 2 (712). Project Number 45667. Project Number 45667. Alaska Sustainable Salmon Fund Semiannual Performance Report (Submitted to AYK SSI/SSSF (ADFG), July 14, 2009).
- Myers, K.** 2010. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 3 (712). Project Number 45128 (700). Alaska Sustainable Salmon Fund Semiannual Performance Report (Submitted to AYK SSI/SSSF (ADFG), January 11, 2010).
- Myers, K.** 2010. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 3 (712). Project Number 45128 (700). Alaska Sustainable Salmon Fund Semiannual Performance Report (Submitted to AYK SSI/SSSF (ADFG), July 5, 2010).

Final Reports

- Myers, K. W., N. J. Mantua, N. D. Davis, R. V. Walker, J. A. Armstrong, B. Marden, J. Raymond-Yakoubian, R. Fosdick, H. Herter, A. C. Odden, M. Fukuwaka, and M. Kaeriyama.** 2008. AYK-Climate Ocean Effects on Chinook Salmon, Phase 1 (712). 2008 Arctic Yukon Kuskokwim Sustainable Salmon Initiative, Project Final Product. SAFS-UW-0802, School of Aquatic and Fishery Sciences, University of Washington, Seattle. 61 p. (This report, submitted to AYK SSI/SSSF(ADFG), August 30, 2008)
- Myers, K., and R. Fosdick.** 2008. AYK-Climate Ocean Effects on Chinook, Salmon Phase 1 (712). AYK SSI-Southeast Sustainable Salmon Fund Project Completion Form (Submitted to AYK SSI/SSSF (ADFG), August 30, 2008).
- Myers, K., and R. Fosdick.** 2008. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 1 (712). Project Number 45559. PSCRF Research, Monitoring, and Evaluation Projects (RM&E) Metrics Report. (Submitted to AYK SSI/SSSF-ADFG, June 18, 2008)
- Myers, K., and R. Fosdick.** 2009. AYK-Climate Ocean Effects on Chinook, Salmon Phase 2. Alaska Sustainable Salmon Fund Project Completion Report (Submitted to AYK SSI/AKSSF (ADFG), August 30, 2009).
- Myers, K.** 2010. AYK – Climate-Ocean Effects on Chinook Salmon, Phase 3 (712). Project Number 45128 (700). Alaska Sustainable Salmon Fund Project Completion Report. (Submitted to Alaska Sustainable Salmon Fund -ADFG, Juneau, September 17, 2010)
- Myers, K. W., N. D. Davis, R. V. Walker, J. A. Armstrong, W. J. Fournier, N. J. Mantua, and J. Raymond-Yakoubian.** 2010. Climate-ocean effects on Chinook salmon. Arctic Yukon Kuskokwim Sustainable Salmon Initiative, Project Final Product. SAFS-UW-1003, School of Aquatic and Fishery Sciences, University of Washington, Seattle.

Data/Cruise Reports

- Fukuwaka, M., N. Davis, M. Kuwaki, S. Imai, and K. Toge.** 2007a. International salmon research aboard the R/V *Wakatake maru* in the central North Pacific Ocean and Bering Sea during the summer of 2007. North Pacific Anadromous Fish Commission Bulletin Document 1046. 19 pp. Hokkaido National Fisheries Research Institute, Fisheries Research Agency. (This document is available to the public online at <http://www.npafc.org>)
- Fukuwaka, M., S. Sato, S. Imai, N. D. Davis, K. W. Myers, R.V. Walker, J. M. Murphy, K. Cieciel, J. Moss, V. I. Karpenko, A. V. Bugaev, and S. F. Zolotukhin.** 2007b. Recoveries of high-seas tags in 2006-2007, and tag releases and recoveries of fin-clipped salmon in 2007 from Japanese research vessel surveys in the North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin 1042. 15 pp. Hokkaido National Fisheries Research Institute, Fisheries Research Agency (This document is available to the public online at <http://www.npafc.org>)
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- Kaeriyama, M., H. Kudo, K. Myers, H. Herter, and I. Mio.** 2007. Cruise report, Salmon Research Group, *Oshoro maru* cruise number 180, Leg 2—Southeastern Bering Sea, St. Lawrence Island polynya (SLIP), and mouth of Yukon River). Salmon Research Group (SRG-HU), Graduate School of Fisheries Sciences, Hokkaido University, Hakodate, Japan (see Appendix to this report.)
- Kaeriyama, M., H. Kudo, K. Myers, C. Odden, and I. Mio** 2007. Cruise report, Salmon Research Group, *Oshoro maru* cruise number 180, Leg 3 (Bering Straits, Chukchi Sea). Salmon Research Group (SRG-HU), Graduate School of Fisheries Sciences, Hokkaido University, Hakodate, Japan (see Appendix to this report)

Kaga, T., and **N.D. Davis**. 2009. International salmon research aboard the R/V *Wakatake maru* in the Central North Pacific Ocean and Bering Sea during the summer of 2009. NPAFC Doc. 1194. 18 pp. National Salmon Resources Center, Fisheries Research Agency. (Available at <http://www.npafc.org>)

Peer-Reviewed Publications

Bugaev, A.V., and **K.W. Myers**. 2009. Stock-specific distribution and abundance of immature Chinook salmon in the western Bering Sea in summer and fall 2002–2004. N. Pac. Anadr. Fish Comm. Bull. 5: 87-97. (Available at www.npafc.org).

Buser, T., **N.D. Davis**, I. Jiménez-Hidalgo, and L. Hauser. 2009. Genetic techniques provide evidence of Chinook salmon feeding on walleye pollock offal. N. Pac. Anadr. Fish Comm. Bull. 5: 225-229. (Available at www.npafc.org).

Davis, N.D., K.W. Myers, and W.J. Fournier. 2009. Winter food habits of Chinook salmon in the eastern Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 5: 243-253. (Available at www.npafc.org).

Davis, N.D., A.V. Volkov, A.Ya. Efimkin, N.A. Kuznetsova, J.L. Armstrong, and O. Sakai. 2009. Review of BASIS salmon food habits studies. N. Pac. Anadr. Fish Comm. Bull. 5: 197-208. (Available at www.npafc.org).

Myers, K.W., R.V. Walker, N.D. Davis, J. L. Armstrong, and M. Kaeriyama. 2009. High seas distribution, biology, and ecology of Arctic-Yukon-Kuskokwim salmon: direct information from high seas tagging experiments, 1954-2006. Am. Fish. Soc. Symp. 70: 201-239. (Available at www.npafc.org).

Walker, R.V., and K.W. Myers. 2009. Behavior of Yukon River Chinook salmon in the Bering Sea as inferred from archival tag data. N. Pac. Anadr. Fish Comm. Bull. 5: 121-130. (Available at www.npafc.org).

Outreach (Oral, Poster, and Internet)

AYK SSI. 2007. Information about the *Oshoro maru* cruise and mini-symposium on the “Spotlight” page of their internet website (available online at http://www.aykssi.org/temporary/High_Seas_Salmon.htm)

Buser, T., **N.D. Davis**, I. Jiménez-Hidalgo, and L. Hauser. 2009. Genetic techniques provide evidence of Chinook salmon (*Oncorhynchus tshawytscha*) feeding on walleye pollock offal. Poster presented at NPAFC International Symposium on the Bering-Aleutian Salmon International Surveys (BASIS): Climate Change, Production Trends, and Carrying Capacity of Pacific Salmon in the Bering Sea and Adjacent Waters, November 23-25, 2008, Sheraton Seattle Hotel, Seattle, Washington, USA.

Davis, N.D., K.W. Myers, and W.J. Fournier. 2008. Winter food habits of Chinook salmon in the eastern Bering Sea. . Poster presented at NPAFC International Symposium on the Bering-Aleutian Salmon International Surveys (BASIS): Climate Change, Production Trends, and Carrying Capacity of Pacific Salmon in the Bering Sea and Adjacent Waters, November 23-25, 2008, Sheraton Seattle Hotel, Seattle, Washington, USA.

Davis, N.D., K.W. Myers, and W.J. Fournier. 2009. Winter food habits of Chinook salmon in the eastern Bering Sea. Presented at the January 2009 Alaska Marine Science Symposium in Anchorage (Poster presentation; pdf file of poster available from kwmyers@u.washington.edu)

Davis, N.D., A.V. Volkov, A.Ya. Efimkin, N.A. Kuznetsova, J.L. Armstrong, and O. Sakai. 2008. Keynote-3: Review of BASIS food habits studies and considerations on continuing and new research directions. Invited keynote oral presentation at NPAFC International Symposium on the Bering-Aleutian Salmon International Surveys (BASIS): Climate Change, Production Trends, and Carrying Capacity of Pacific Salmon in the Bering Sea and Adjacent Waters, November 23-25, 2008, Sheraton Seattle Hotel, Seattle, Washington, USA.

Fosdick, R. 2007. "Bering Strait Region Local and Traditional Knowledge Pilot Project, A Comprehensive Subsistence Use Study of the Bering Strait Region". Marine Ecosystem

- Responses to Global Climate Change in the Bering and Chukchi Seas, a mini-symposium to mark the 2007 cruise of the T/S *Oshoro maru*), August 4, 2007, Old St. Joseph's Hall, Nome, Alaska (Oral presentation of results from a study funded by the North Pacific Research Board)
- Fournier, W.J.**. 2010. Seasonal diet, energetic condition, and consumption of Chinook salmon in the Bering Sea. Poster presented at the January 2010 Alaska Marine Science Symposium in Anchorage (Poster presentation; pdf file of poster available from kwmyers@u.washington.edu)
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X. PROJECT DATA

This section of the report summarizes data collected during the project in order to preserve the opportunity for other researchers and the public to access these data in the future.

Historical High Seas Salmon Data (1954-2009)

(1) Description of the data (see Table 1-1). These data are an historical and recent (from this project) collection of high seas salmon research vessel catch, effort, biological (age, sex, length, maturity, scale growth measurement data and images, food habits data and images), tagging data, and some associated oceanographic data. The collection also includes some historical high seas commercial salmon and squid driftnet fishery catch and biological data, data on other salmon species and other ecologically-related species, and associated oceanographic data. Most of the data were collected during U.S., Canadian, and Japanese INPFC-related high seas research cruises and observer programs (1955-1992), cooperative U.S.-U.S.S.R. high seas salmon research (1983-1991, cooperative NPAFC-related research (1992-present), and sampling of prohibited species bycatch by the US NMFS North Pacific Groundfish Observer Program (1977-1982, 1997-1999, 2007-2009).

(2) Format of data. MS Excel workbooks. Each distinct time series of data were formatted in separate MS Excel Workbooks that include one metadata worksheet and one or more data worksheets. The metadata worksheet in each workbook includes biological, geographic, and database location information, data formats, and descriptions of variables. MS Excel file names are descriptive of the file contents, including the country and agency, organization, or program that collected the original data, the data type, and the years covered by the time series. The files were grouped into folders according to five major categories of data (catch, specimen, tag, food habits, and scale measurement data).

(3) Custodian/archive of the data. The data are currently archived by the High Seas Salmon Research Program, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. This is not a permanent archive, and copies of the data files (on USB flash drive) were provided to AKSSF and AYK SSI. Requests for the data should be made directly to AKSSF and /or AYK SSI. In some cases, original data sources can be contacted to obtain permissions and updated versions of files.

(4) Access limitations on the data. In general, there are few access limitations on the data. However, each MS Excel Workbook contains a metadata worksheet with information on access limitations placed on the data.

Local Traditional Knowledge Interview Data

The LTK data collected for this project consist of a series of digitally recorded interviews conducted in the participating communities (Brevig Mission, Golovin and Unalakleet). These interviews were stored on archival quality CDs in the Eskimo Heritage Program archives housed at the offices of Kawerak, Inc. in Nome, Alaska. The archives are accessible to the public and researchers for educational purposes. Copies of interviews can be obtained by contacting the Eskimo Heritage Program: Colleen Reynolds, Program Director, Eskimo Heritage Program, Kawerak, Inc., PO Box 948, Nome, AK 99762, phone: (907) 443-4386; fax: (907) 443-4458, email: creynolds@kawerak.org.

XI. ACKNOWLEDGEMENTS

This project was a collaboration among scientists of the University of Washington, Kawerak Inc. (Nome), the Alaska Fisheries Science Center (Seattle) and the Auke Bay Laboratories (ABL, Juneau), National Marine Fisheries Service (NMFS), the Hokkaido National Fisheries Research Institute (Kushiro, Japan), Hokkaido University (Hakodate, Japan), the US Geological Survey, Alaska Science Center, Biological Research Division (USGS-BRD, Anchorage), Natural Resources Consultants, Inc. (Seattle), and the Alaska Department of Fish and Game. K. Dunmall developed the initial proposal for local traditional knowledge (LTK) portions of this project for Kawerak, Inc. R. Fosdick, Kawerak, Inc., administered LTK research and local organizing and implementation of outreach activities during Nome port calls of the *Oshoro maru*. We thank the three local assistants who worked on this project: M. Nayokpuk (Brevig Mission), C. Oliver (Golovin) and M. Eakon (Unalakleet). We also thank the Brevig Mission Traditional Council, the Chinik Eskimo Community and the Native Village of Unalakleet for their cooperation and assistance. We especially thank the local experts interviewed who shared their knowledge and experiences: in Brevig Mission– R. Rock, Sr., R. Olanna, H. Seetot, E. Seetot Jr. and D. Seetot; in Golovin – I. Aukongak, M. Olson, R. Amarok, T. Punguk, T. Anungazuk, and D. Anungazuk; in Unalakleet – S. Johnson, B. Eakon, J. Ivanoff, L. Paniptchuk, L. Eakon, M. Katongan, D. Katongan, O. Koutchak, and M. Koutchak. We thank S. Saitoh, Chief Scientist, M. Kaeriyama, Captain T. Meguro, and all crew members and scientists of the T/S *Oshoro maru* for collecting IPY survey data and salmon samples and data. A. Coleen Odden, Kawerak, Inc., and H. Herter, Marine Advisory Program, Alaska Sea Grant, participated as local observers in the *Oshoro maru* cruise. We also thank Jim Ianelli of the Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, for information on Chinook bycatch in the eastern Bering Sea trawl fisheries. One temperature-depth tag was purchased by the Auke Bay Laboratory of the National Marine Fisheries Service, NOAA, which also supported scientists who tagged both fish recovered in the Yukon River. A grant from the North Pacific Research Board to NPAFC was used to purchase the other data tag. We thank the scientists and crew of the *Wakatake maru* and *Kaiyo maru* for their assistance in tagging the fish, and give our deep appreciation to the fishermen who returned the tags. A. Bugaev, KamchatNIRO provided Russian BASIS scale samples and associated data. M. Fukuwaka, Hokkaido National Fisheries Research Institute provided a time series of Japanese high seas salmon research vessel data on Chinook salmon. We thank Captain Y. Murata and crew (30-40 cadets) in 2007, and scientists of the *Wakatake maru* for collecting survey data and salmon samples and data in 2008-2009. Washington Sea Grant (WSG project # R/F-160; Grant # NA07OAR4170007) provided support for N. Davis to participate in the 2007-2009 *Wakatake maru* survey. E. Farley (ABL) provided U.S. Bering-Aleutian Salmon International Survey (BASIS) data. G. Ruggerone, natural Resources Consultants, Inc., provided a time series of scale measurement data for Yukon River Chinook salmon. O. Temnykh and V. Sviridov, TINRO-Centre, provided Russian BASIS data. T. Azumaya, Hokkaido National Fisheries Research Institute, Fisheries Research Agency, provided Japan BASIS data. K. Aydin and J. Berger, NOAA, NMFS, Alaska Fisheries Sciences Center, and the North Pacific Groundfish Observer Program administered special project collections by observers from Chinook salmon the Bering Sea groundfish fisheries in 2007-2009, and we give special recognition to all of the observers who collected samples and data for in this project. P. Wilkins (NMFS Observer Program) coordinated sampling of Chinook salmon at processing plants in Dutch Harbor. We are very grateful to the plant managers in Dutch Harbor and their companies for permission to work in their plants: D. Boisseau, Westward Seafoods, D. Goodfellow, Alyeska Seafoods, and don Graves, Unisea Seafoods. M. Haught, UW, School of Oceanography, analyzed isotope samples. A.V. Volkov, A.Ya. Efimkin, and N.A. Kuznetsova, Pacific Scientific Research Fisheries Center (TINRO-Center), Vladivostok, Russia, and O. Sakai, National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Shimizu, Japan, collaborated in a review of BASIS salmon food habits studies. D. Beauchamp provided software and advice on bioenergetics analyses. P. Stabeno, D. Kachel, and S. Salo of the Pacific Marine Environmental Laboratory/NOAA (PMEL) provided oceanographic data and assistance in formatting it. We thank M. Atchison for coordinating acquisition of 3-D NEMURO model data, and gratefully

acknowledge N.M. Aita for provision of these data. We especially thank O. Abdul-Aziz for simulations and modeling of climate change effects on high seas thermal habitats of Chinook salmon. We thank K. Gillis, Program Director, AYK-SSI, and the ADFG SSSF staff for their assistance with project administration, management and reporting, and Joseph Spaeder, Research Coordinator, AYK-SSI, for helping us with research coordination and public outreach.

This project was funded by award #NA04NMF4380162 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, administered by the Alaska Department of Fish and Game for the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (<http://www.aykssi.org/>). The statements, findings, conclusions, and recommendations are those of the author and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration, the U.S. Department of Commerce, or the Alaska Department of Fish and Game. This report is a final product for AKSSF project nos. 45559 (Phase 1), 45667 (Phase 2), and 45128 (Phase 3), "AYK: Climate-Ocean Effects on Chinook Salmon (712)" and the Arctic Yukon Kuskokwim Sustainable Salmon Initiative.

XII. PRESS RELEASE

Are Kings of the far North Threatened by Climate Change and Fishing?

Wild king salmon in the Arctic-Yukon-Kuskokwim (AYK) region of Alaska are becoming the iconic “poster child” for what might happen if global greenhouse gas emissions and industrial-scale fishing continue to force rapid changes in their ocean habitats. King salmon are the least abundant, longest-lived, and largest-bodied of all species of Pacific salmon. For thousands of years since the end of the last ice age, northern populations have developed unique biological traits that enable them to survive natural changes in freshwater and ocean habitats.

A 3-year study, sponsored by the AYK Sustainable Salmon Initiative, identified and evaluated characteristic biological traits of kings migrating in the Bering Sea, and explored their response to changes in climate-ocean conditions. The study was conducted by scientists at the University of Washington and Kawerak, Inc., a regional non-profit corporation of Native Villages in the Bering Straits Region.

Subsistence harvesters in three Bering Strait communities - Brevig Mission, Golovin and Unalakleet – contributed local traditional knowledge to this study. They observed many important changes including decreases in adult salmon abundance and body size; increases in fish with empty stomachs, diseases, parasites, and deformities, environmental changes in wind, ice, and temperatures, accompanied by increases in algae, water grasses, jellyfish, and erosion events; increases in marine subsistence harvests; and salmon bycatch in the Bering Sea pollock fishery.

Multiple lines of evidence indicated that kings respond to variation in climate-ocean conditions and fishing by changes in size and age at maturation, growth, and survival. A strong El Niño Southern Oscillation (ENSO) climate event in 1997-1999 affected their ocean growth and survival, and some populations have yet to recover. AYK kings are distributed for most of their lives in the Bering Sea. Immature kings migrate far offshore, where their distribution extends into the Russian Exclusive Economic Zone. Data from electronic tags showed that kings have a deeper vertical distribution than any other salmon species, with a vertical extending from the surface to a depth of 523 m (1,717 ft). Unlike other species of salmon, AYK kings overwinter in the Bering Sea pollock fishery area. These traits make them more susceptible than other salmon species to bycatch by economically important winter trawl fisheries, which might have contributed to the slow recovery of some populations.

This was the first study of winter diets of kings in the trawl bycatch. Their primary winter food was squid, although many fish had empty stomachs. All age groups of kings consumed fish offal, identified as walleye pollock by DNA analysis. Consumption of pollock offal, likely generated by the pollock fishery operations, had not been previously reported for any salmon species. Pollock offal is of low nutritional quality and perhaps a vector for transmission of diseases.

Warm temperatures over Alaska and at sea and high quality diets are associated with increased growth of kings. Climate-ocean variables most closely linked to increased salmon growth – lower sea ice cover and warmer temperatures – are projected by climate models to change in the Bering Sea during this

century, with temperatures increasing at higher latitudes and ice cover diminishing and retreating earlier. Increases in sea surface temperatures under medium greenhouse gas emissions scenarios may result in large reductions in king salmon habitat in the Bering Sea by the end of this Century.

Growth of Yukon kings shifted to a positive phase in 1999-2000, but adult returns did not increase. At low abundance levels, kings are more vulnerable to adverse effects of ocean conditions and fishing. Researchers concluded that relationships among climate, fishery, and other factors affecting growth and survival of AYK kings in both marine and freshwater habitats are complex and point to critical needs for management and restoration actions to ensure sustainability of northern populations of kings.

XIII. APPENDICES

Appendix 1: Oshoro maru- Cruise Report, Leg 2

Cruise Number/Leg Number: OS180/Leg.2

Area of Operations:

Bering Sea (Southeastern Bering Sea, SLIP, and Mouth of Yukon River)

Itinerary

Date depart/port: July 24, 2007/Dutch Harbor, AK

Date arrive/port: August 3, 2007/ Nome, AK

Participating organizations:

Salmon Research Group (SRG-HU)

Graduate School of Fisheries Sciences, Hokkaido University

Group Leader (Chief Scientist):

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Personnel:

Hideaki Kudo M / SRG-HU

Kate Myers F / UW

Heidi Herter F / UAF

Ikue Mio F / SRG-HU

Nagashima M / SRG-HU

Cruise Objectives:

The objectives of this cruise were to survey growth, feeding ecology, and trophic dynamics of Pacific salmon in the Bering Sea.

Summary of Operations:

Operation Tows

60cm bongo (60Bon) 19 operations

Long-line (10 hachi, 33 hooks/hachi, about 1000 m long) 4 operations

Bottom trawl net 6 operations

Angling 35 operations

Samples Collected (Individuals /bottles)

Chum salmon: 80

Pink salmon: 2

Sockeye salmon: 8

Coho salmon: 15

Chinook salmon: 2

Total salmon: 101

Zooplankton: 38

Summary of Cruise:

We collected 101 salmon for analyzing stomach contents and stable isotopes, and 38 zooplankton-samples for analyzing trophic level in the ecosystem using stable isotope analysis.

Narrative:

We were able to complete all of our station objectives during this cruise.

Recommendations:

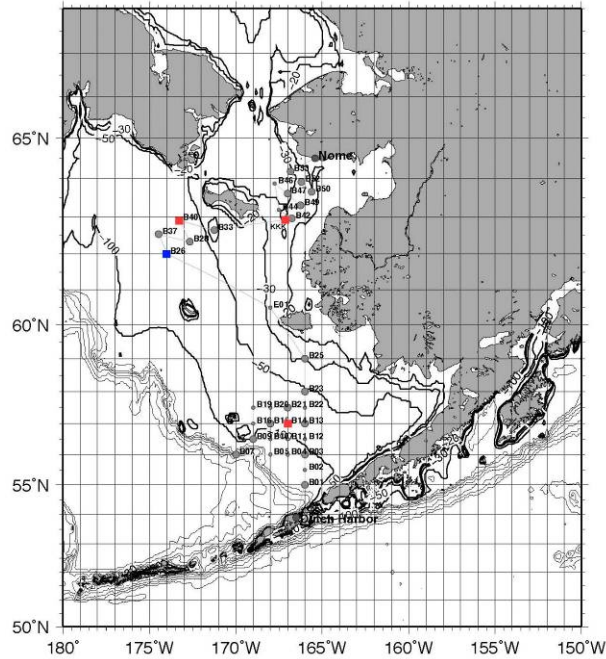
For catching salmon, the long-line should be operated in early morning.

Acknowledgments

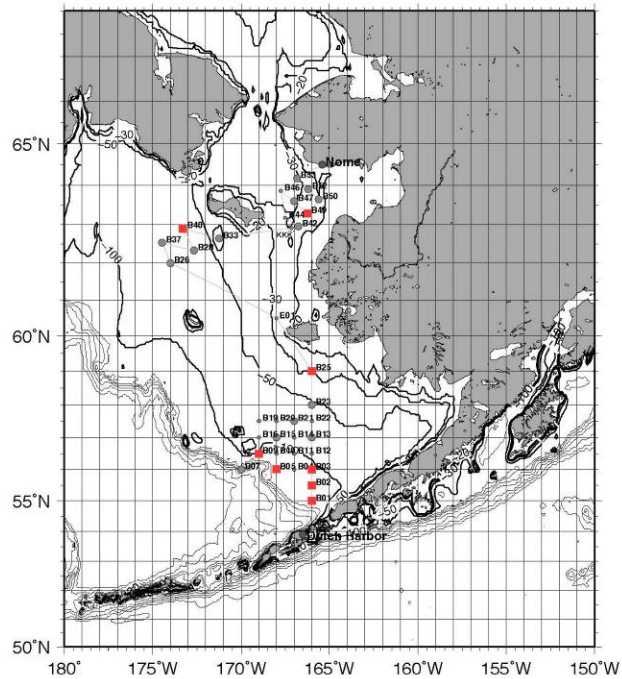
We thank Captain Toshimi Meguro and all crewmembers of the T/V *Osboro-maru* for collecting samples.

Appendix Table 1-1. Summary of station locations, dates, gear operations (LL=longline, TWL=bottom trawl, Angle= angling with fishing rods and reels, Bong=Bongo net) and salmon catch by species (unit = number of fish) during Leg 2, July 24 - August 3, 2007.

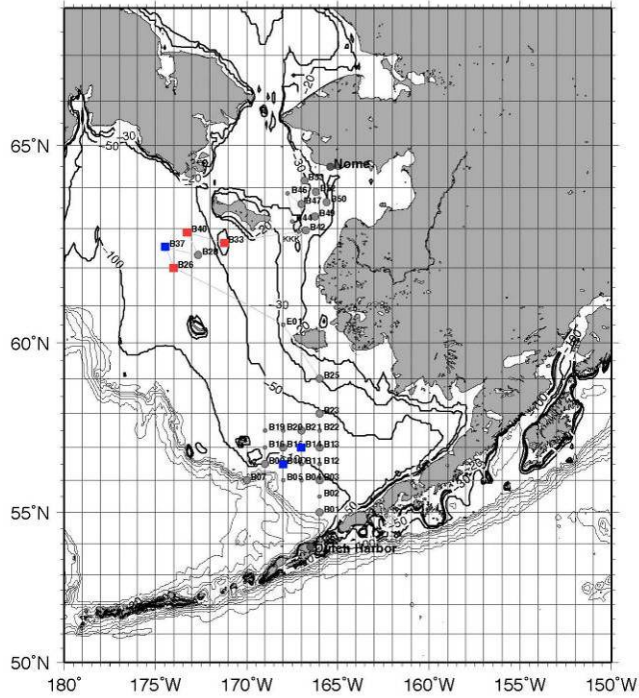
St.	OS	Lat	Long	Dat	LI	TW	Angl	Bon	Chu	Pin	Soc	Coh	Chi	To
B01	OS070	55-	166-	7/2			1	1	5	1				6
B02	OS070	55-	165-	7/2			1					1		1
B03	OS070	55-	166-	7/2			1	1	4		7	5		16
B04	OS070	56-	166-	7/2			1							
B05	OS070	55-	168-	7/2			1				1			1
B07	OS070	56-	170-	7/2			1							
B09	OS070	56-	168-	7/2			1	1	2	1		3		
B10	OS070	56-	167-	7/2		1	1							
B11	OS070	56-	167-	7/2			1							
B12	OS070	56-	166-	7/2			1							
B13	OS070	56-	166-	7/2			1	1						
B14	OS070	57-	167-	7/2	1	1	1		1			3		4
B15	OS070	57-	167-	7/2			1	1						
B16	OS070	56-	168-	7/2			1							
B19	OS070	57-	168-	7/2			1							
B20	OS070	57-	167-	7/2	1		1							
B21	OS070	57-	167-	7/2			1	1						
B22	OS070	57-	165-	7/2			1							
B23	OS070	57-	165-	7/2			1	1						
B25	OS070	58-	166-	7/2			1	1				2		2
E01	OS070	60-	168-	7/2			1							
B26	OS070	62-	174-	7/3		1	1	1	40					40
B37	OS071	62-	174-	7/3		1	1	1						
B28	OS071	62-	172-	7/3			1							
B40	OS071	62-	173-	7/3	1	1	1	1	17				2	19
B33	OS071	62-	171-	7/3		1	1	1	10					10
KK	OS071	62-	167-	8/1	1		1	1	1					1
B42	OS071	62-	166-	8/1			1	1						
B44	OS071	63-	167-	8/1			1							
B46	OS071	63-	167-	8/1			1							
B47	OS071	63-	167-	8/1			1	1						
B49	OS071	63-	166-	8/2			1	1				1		1
B50	OS071	63-	165-	8/2			1	1						
B52	OS071	63-	166-	8/2			1	1						
B53	OS071	64-	166-	8/2			1	1						
Tota					4	6	35	19	80	2	8	15	2	10



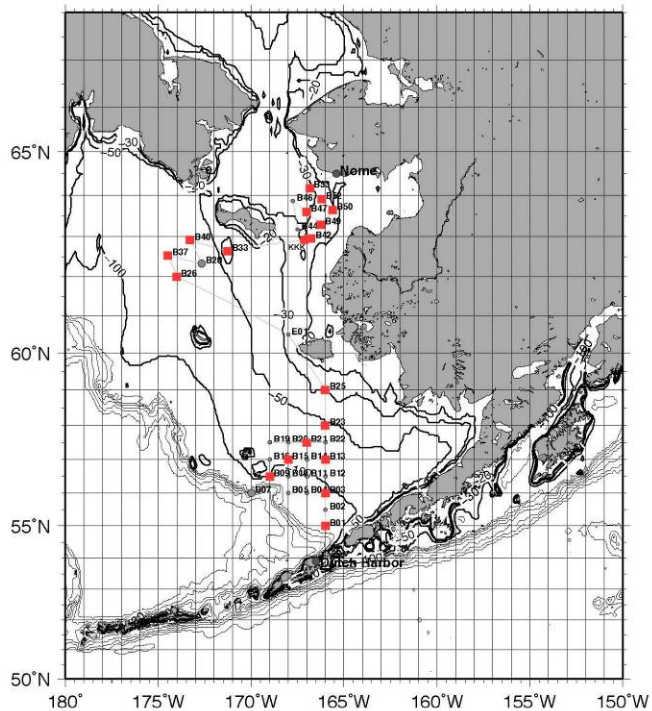
Appendix Figure 1-1. Survey stations for longline operations in the Bering Sea. Salmon were collected at red stations, and not caught at the blue station.



Appendix Figure 1-2. Survey stations for angling operations in the Bering Sea. Angling was done at all stations during OS180/Leg 2. Salmon were collected at red stations.



Appendix Figure 1-3. Survey stations for bottom trawl operations in the Bering Sea. Salmon were caught at red stations, and not collected at blue stations.



Appendix Figure 1-4. Survey stations for Bongo net operations in the Bering Sea (red squares).

Appendix 2: Oshoro maru- Cruise Report, Leg 3

Cruise Number/Leg Number: OS180/Leg.3

Area of Operations:

Chukchi Sea

Itinerary

Date depart/port: August 5, 2007/Nome, AK

Date arrive/port: August 12, 2007/ Nome, AK

Participating organizations:

Salmon Research Group (SRG-HU)

Graduate School of Fisheries Sciences, Hokkaido University

Group Leader (Chief Scientist):

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Personnel:

Hideaki Kudo M / SRG-HU

Kate Myers F / UW

Agnes Colleen Odden F / Kawerak Inc.

Ikue Mio F / SRG-HU

Nagashima M / SRG-HU

Cruise Objectives:

The objectives of this cruise were to survey ecosystem dynamics, and growth, feeding ecology, and trophic dynamics of Pacific salmon in the Chukchi Sea.

Summary of Operations:

60cm bongo (60Bon), 13 operations

Long-line (10 hachi / 2 operations, 5 hachi /1 operation , 34 hooks/hachi, about 1000 m long), 3 operations

Bottom trawl net, 5 operations

Angling, 8 operations

Samples Collected (Individuals/bottles)

Pacific salmon: 0 individuals

Zooplankton: 13 bottles

Micronekton & Nekton: <50 individuals

Summary of Cruise:

We collected many organisms such as zooplankton, micronekton, and nekton for evaluating the function of Chukchi Sea ecosystem using the stable isotope analysis. We, unfortunately, could not collect Pacific salmon. Adult salmon were likely migrating to coasts and rivers for spawning, or to other ocean areas for feeding.

Narrative:

We were able to complete all of our station objectives during the cruise of this cruise.

Recommendations:

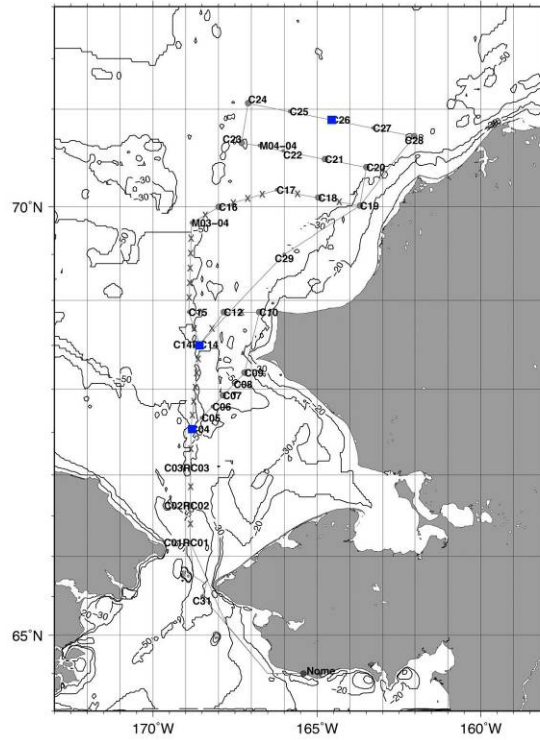
In this year, the survey period was too late for evaluating ocean conditions and collection of adult Pacific salmon in the Chukchi Sea. It should be better to survey in the Chukchi Sea during early summer (July).

Acknowledgments

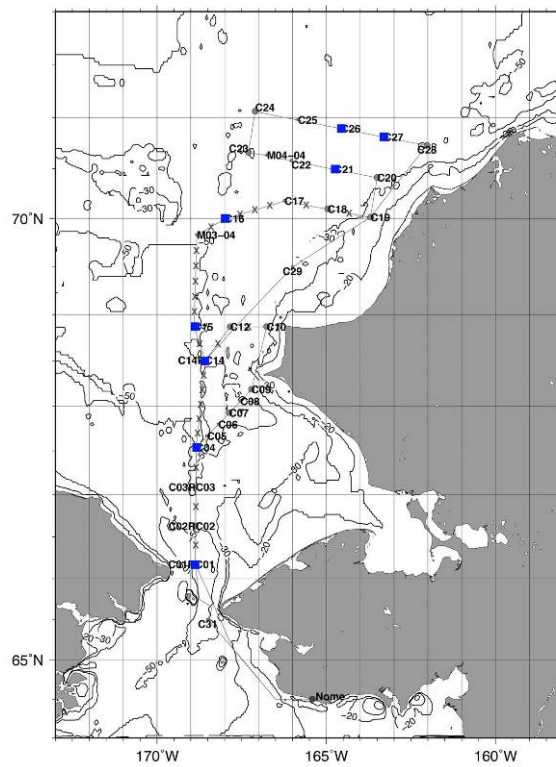
We deeply thank Captain Toshimi Meguro and all crewmembers of the T/V Oshoro-maru for collecting samples.

Appendix Table 2-1. Summary of station locations, dates, gear operations (LL=longline, TWL=bottom trawl, Angle= angling with fishing rods and reels, Bong=Bongo net) and salmon catch by species (unit = number of fish) during Leg 2, August 5, 2007 to August 12, 2007.

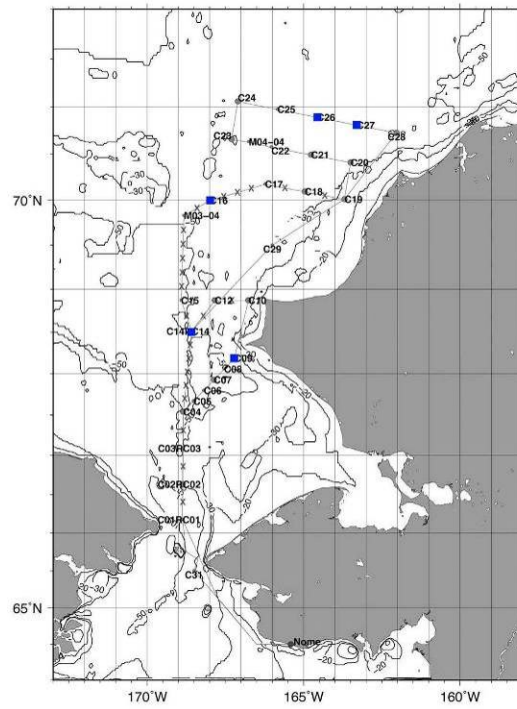
St.	OS	Latitude	Longitude	Date	LL	TWL	Angle	Bong	Salmon Catch
C01	OS07113	66-10.69N	168-52.65W	8/5			1		0
C02	OS07114	66-37.87N	168-51.88W	8/6				1	
C03	OS07115	67-04.97N	168-50.31W	8/6					
C04	OS07116	67-32.40N	168-50.71W	8/6	1		1	1	0
C05	OS07117	67-40.16N	168-31.02W	8/6					
C06	OS07118	67-58.02N	168-11.49W	8/6					
C07	OS07119	67-55.78N	167-52.00W	8/6				1	
C08	OS07120	68-03.57N	167-32.34W	8/6					
C09	OS07121	68-11.17N	167-13.58W	8/6		1		1	0
C10	OS07122	68-52.19N	166-48.41W	8/7				1	
C12	OS07123	68-52.32N	167-50.18W	8/7					
C14	OS07124	68-30.57N	168-34.47W	8/7	1	1	1	1	0
C15	OS07125	68-52.29N	168-54.63W	8/8					0
M03-04		69-50.29N	168-49.62W	8/9					
C16	OS07126	70-00.03N	167-59.66W	8/9		1	1	1	0
C17	OS07127	70-10.62N	166-13.58W	8/9					
C18	OS07128	70-05.73N	164-57.94W	8/9				1	
C19	OS07129	70-00.78N	163-41.49W	8/9				1	
C20	OS07130	70-24.77N	163-29.68W	8/9					
C21	OS07131	70-29.79N	164-45.65W	8/10			1		0
C22	OS07132	70-34.58N	166-01.97W	8/10					
M04-04		70-38.25N	166-44.15W	8/10					
C23	OS07133	70-39.73N	167-17.84W	8/10					
C24	OS07134	71-03.992N	05.329W	8/10				1	
C25	OS07135	70-58.88N	165-48.74W	8/11					
C26	OS07136	70-53.97N	164-33.96W	8/11	1	1	1	1	0
C27	OS07137	70-48.81N	163-17.66W	8/11		1		1	0
C28	OS07138	70-43.763N	01.891W	8/11				1	
C29	OS07139	69-30.19W	165-59.96W	8/12			1		0
Total					3	5	7	13	0



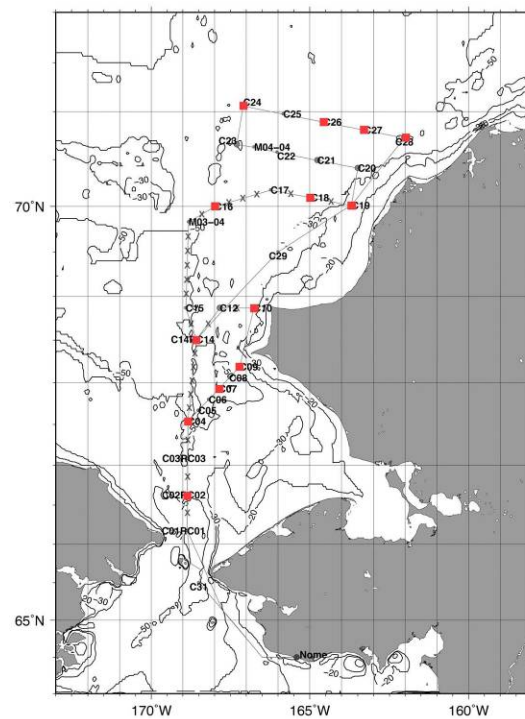
Appendix Figure 2-1. Survey stations for longline operations in the Chukchi Sea (blue squares).



Appendix Figure 2-2. Survey stations for angling operations in the Chukchi Sea (blue squares).



Appendix Figure 2-3. Survey stations for the bottom trawl operations in the Chukchi Sea (blue squares).



Appendix Figure 2-4. Survey stations for bongo net operations in the Chukchi Sea (red squares)

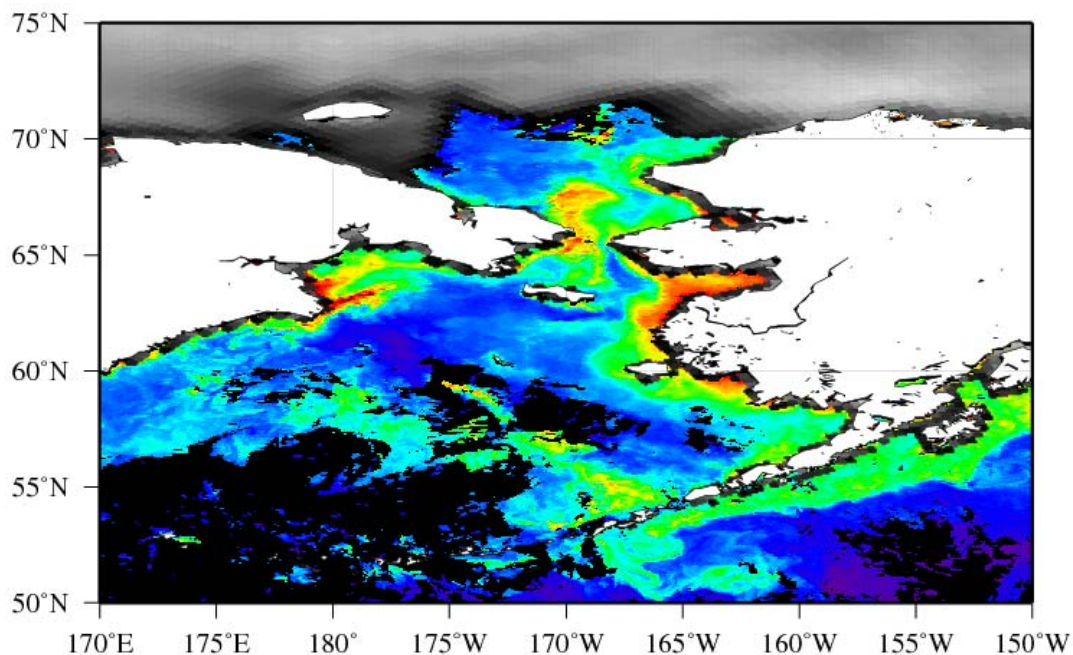
***Appendix 3: Marine Ecosystem Responses to Global Climate Change in the Bering and Chukchi Seas
(A Mini-Symposium to mark the 2007 IPY cruise of the T/S Oshoro maru)***

sponsored by:
Hokkaido University, Graduate School of Fisheries Sciences
Japan Aerospace Exploration Agency (JAXA)
University of Washington, College of Ocean and Fishery Sciences

August 4, 2007
Old St. Joseph's Hall
407 Bering Street, Nome, Alaska

Organizing Committee:

- 1) Chairs
Sei-Ichi Saitoh (Hokkaido U.)
Kate Myers (U. Washington)
Masahide Kaeriyama (Hokkaido U.)
- 2) Local Members
Rose Fosdick, Kawerak, Inc.
Heidi Herter, Alaska Sea Grant
Colleen Odden, Kawerak, Inc.



**Marine Ecosystem Responses to Global Climate Change
in the Bering and Chukchi Seas**
(A Mini-Symposium to mark the 2007 IPY cruise of the T/S *Oshoro maru*)

4 August 2007

Old St. Joseph's Hall
407 Bering Street, Nome, Alaska

Time

09:00 Opening Remarks and Introduction: Chairpersons Sei-ichi Saitoh (Hokkaido University) and Kate Myers (University of Washington); R. Fosdick (Kawerak, Inc.)

Session I Chemical and Biological structure of the North Pacific, Bering and Chukchi Seas (Chair: Sei-ichi Saitoh, Hokkaido University)

09:10 Prae Supcharoen, **Applications of Radium and Thorium Isotopes to Quantify Horizontal and Vertical Exchanges in the Bering Sea**

09:30 Kenshi Kuma, Saori Kitayama and Yukiko Matsumura, **Vertical distribution and source of iron in the North Pacific Ocean and the southeastern Bering Sea**

09:50 Brenda L. Norcross, Brenda A. Holladay, Morgan S. Busby, Kathryn L. Mier, **Oceanography, Ichthyoplankton, and Juvenile Fish Assemblages of the Bering Strait and Chukchi Sea, Summer 2004**

10:10 – 10:40 Break

Session II **Introduction of graduate students** (One minute speech for each graduate student)

10:40 Presentation of one page paper

Hiroshi Yahaba: Japan Coast research – current velocity & density in mouth of Mutsu Bay

Ayako Enoki: Relation between optical property and primary productivity in the seasonal ice zone

Amane Fujiwara: Discrimination of dominant size in natural phytoplankton communities in sub-Arctic waters from satellite data

Yukiko Matsumura: Influence of iron and nutrients on the phytoplankton bloom in the southeastern Bering Sea

Ikue Mio: Is foraging behavior of Pacific salmon reflected in food habits in the North Pacific?

Takashi Uyama: Relation between marine mammal distribution and marine environment

Yoshiyuki Isghitani: Phylogenetic relationship among radiolarians in the North Pacific

Osamu Tsuruoka: Taxonomy of *Icelus mororane* and its related genera

Session III Climate Change and Ecosystem response in the Bering and Chukchi Seas (Chair: Masahide Kaeriyama, HU)

- 11:00 Atsushi Yamaguchi, Nao Yamada, Naonobu Shiga, **Inter-annual changes in planktonic copepod community in the SE Bering Sea shelf during summers of 1994-2005**
- 11:20 Kohei Mizobata, Jia Wang, Sei-Ichi Saitoh, Tohru Hirawake and Meibing Jin, **Chlorophyll and primary production in the Pan-Arctic Oceans and Submarginal Seas**
- 11:40 Sang Heon Lee, **Current Carbon Uptakes in the Western Arctic Ocean**
- 12:00 – 13:00 Lunch
- 13:00 Chu Wan-Loy, Wong Chiew-Yen, Harvey Marchant & Phang Siew-Moi, **Comparing the Response and Adaptive Strategies of Antarctic, Tropical and Temperate Microalgae to Ultraviolet Radiation (UVR) Stress**
- 13:20 Ian G. Gleadall, **Hot and Cold Running Octopuses?**
- 13:40 Katherine W. Myers, Nancy D. Davis, Robert V. Walker, Janet L. Armstrong, and Nathan J. Mantua, **Climate-Ocean Effects on Pacific Salmon Survival**
- 14:00 Masahide Kaeriyama and Hideaki Kudo, **Growing Importance of Sustainable Fisheries management for Pacific salmon (*Oncorhynchus* spp.) to deal with the human risks on the ocean ecosystem**
- 14:20 – 14:40 Break

Session IV Community Talk (Chair: Kate Myers, UW)

- 14:40 Heidi Herter, **Adapting to climate change in Alaska's coastal communities**
- 15:00 Colleen Odden, **As a result of Global Warming, the Arctic ice is thawing very rapidly**
- 15:20 – 16:00 **General Discussion**

Appendix 4: Traditional Knowledge and Norton Sound Salmon Variability Project Interview Guide

1. Who taught you to fish for salmon?
2. What is your earliest memory of salmon fishing?
3. How long have you been fishing for salmon?

What was this change; where did it happen; when did it happen; why did it happen?

4. Have you seen any significant changes in salmon populations in your lifetime?
 - What do you think causes year-to-year changes in the salmon returns?
5. Have you seen any significant changes in salmon behavior in your lifetime?
6. Have you seen any significant changes in salmon migrations/movement patterns in your lifetime?
7. Have you seen any significant changes in salmon health in your lifetime?
 - Have you noticed a change in the quality of salmon flesh (soft/skinny/smelly/harder to preserve, etc.)?
 - Have you seen lamprey scars, sea lice, worms, cysts or sores?
8. Have you ever seen dead salmon (not spawners) washed up on beaches? What species, where, when?
9. Have you noticed changes in the size, shape of salmon?
 - Do you think these changes are related to changes in the climate or ocean environment (e.g. temperature, wind, cloud cover, sea ice, salinity, currents, availability of food)?
 - Do you think changes in body size of salmon are related to ocean fishing? Why?
10. What salmon species have you used in the past?
11. What species do you use now?
12. If different, why has this changed?
13. Has the gear you use to catch salmon changed?
 - What kind of boat (type and size) and what kind of motor (type and size) do you use to fish for salmon?
14. Do changes in the climate or the ocean environment impact salmon returns? How?
15. Does ocean fishing affect salmon returns?
 - Which has a bigger impact on salmon returns? Why?
16. Do you ever fish in the ocean? What kind of fish are you trying to catch?
 - Have you ever caught a salmon in the ocean? What species? Where?
 - If salmon, how did you catch the salmon (type of boat, fishing gear)? When you catch a salmon in the ocean do you know what river it is from? How?
17. Do you know other people who fish for salmon in the ocean? Who?
 - What species, where, when? How did they catch the salmon (type of boat, fishing gear)?
18. Have you ever caught salmon in the ocean or in a river with net marks from ocean fishing?
19. Other than fishing, have you ever seen salmon in the ocean? For example, have you ever seen salmon jumping out of the water in the ocean?
20. Have you ever seen eagles, seabirds, marine fish, or marine mammals eating salmon in the ocean?
21. Have you ever seen salmon in the ocean near sea ice?
22. Have you ever seen salmon feeding in the ocean? Do you know what species? Where? When?

23. Have you ever seen salmon interacting with other animals in the ocean (i.e. other fish, birds, whales, etc.)?
24. Can declines of one species tell you about the future of another?
25. Have you encountered any salmon species that haven't been here before?
26. Have you encountered any other fish species that you haven't seen before?
27. Do you catch any of the new species of fish that have arrived in this area?
28. Are particular species that were here, no longer present?
29. Have salmon species moved into new streams that they haven't used before or that only other salmon species used in the past?
30. Do you know where each species spawns?
31. Do salmon spawn in different areas than they used to?
32. Where do you catch each species of salmon? Map
33. Are these the same areas that you fished in the past?
34. If not, why not?
35. Are there more or less of each species of salmon?
36. When did you begin to see these changes in population numbers?
37. Where have you seen these changes (what creeks or rivers)?
38. Approximately how many fish per set of your net do you get? Is this different than in the past?
39. Can you tell me about the runs for each salmon species – when and where they take place?
 - Reds (sockeye); Pink (humpys); Coho (silvers); Chum (dogs); Chinook (kings)
40. Are these runs different than in the past?
41. Are they larger or smaller in size?
42. Do they begin earlier or later?
43. Do they last as long or are they shorter?
44. Are the runs more or less predictable than in the past?
 - Is this related to climate?
 - Is this related to ocean fishing? How do you know?
45. Is there any way to tell, at the beginning of a run/season, if a run will be strong or not?
46. What does each salmon species eat (in freshwater or the ocean)?
 - Have you seen a change in the amount or type of food in the stomachs of salmon caught in freshwater or the ocean?
47. Can you remember any particularly good or bad years for salmon?
48. Can you describe what made it bad or good and where it happened?
49. Did you ever hear stories from your parents or anyone else about how salmon fishing was in the past?
50. Can you talk about climate changes or environmental changes that you have seen in your lifetime?
51. When did you start to notice these changes?
52. Where did you start to notice these changes?
53. What do you attribute that change to?
54. Do you think it has affected salmon in any way?

55. Have you noticed any changes associated with freeze-up?
56. Have you noticed any changes associated with break-up?
57. Have you noticed any other changes related to sea ice?
58. Do you think any of these changes have affected salmon in any way? How?

59. Is the climate/weather more or less predictable, or just as predictable, as it was in the past?
60. In what ways?
61. Have you noticed changes in water temperatures?
 - Ocean currents?
 - Plankton blooms?

62. Have you noticed changes in wind patterns or wind strength?
63. Have you noticed changes in vegetation (land or aquatic)?
64. Have you seen new insects, or changes in insects?
65. Have you seen new species of birds, or have some disappeared?
66. Do you see more bears than in the past?

67. What do you think is responsible for any or all of these environmental changes?
68. Do you think the changes have affected salmon?

69. How have people here adapted to the changes you have described (environmental or salmon related)?
70. Have you noticed any changes in other animal populations?
71. Do you think they are being affected by the same causes as salmon?

72. Have people begun to replace one species of salmon with another, in terms of what they are catching?
73. Do you spend more or less time salmon fishing than in the past?
74. What about others people in the community?
75. Are there more or less people salmon fishing now than in the past?
76. Did you depend more on salmon in the past than you do now?
77. Why has that changed?

78. Have you, or people in general, changed their attitudes about salmon?
79. Are there certain ways that they used to be treated or handled, but aren't any more? (Prohibitions)
80. What do you think about the relationship between people and salmon?
 - How has this changed in your lifetime?
 - How did your parents or grandparents think about the relationship between people and salmon?

81. Why are salmon important to people? Has this changed over time?
82. What is the relationship of fish to the community? Has this changed over time?

83. What do you think causes year-to-year changes in the salmon returns?

Inupiaq/Yupik names for salmon species

84. Is there anything else that you would like to say about salmon?
85. Is there anything else that you would like to say about the environment?
86. Is there anything that you would like to say about how salmon are managed?
87. Do you have any recommendations about how salmon should be managed?

Appendix 5: Photographs of LTK Project Participants

Project Participants: Brevig Mission



Delbert Seetot



Elmer Seetot, Jr.



Helena Seetot



Robert Rock, Sr.



Rita Olanna

Project Participants: Golovin

(no picture available for Robert Amarok)



Irene Aukongak



Toby and Debbie Anugazuk



Florence Doyle



Maggie Olson



Thomas Punguk

Project Participants: Unalakleet



Ben Eakon



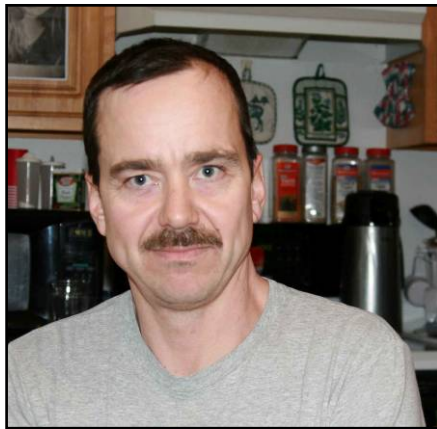
David and Mildred Katongan



Jerry Ivanoff



Mae and Oscar Koutchak



Shane Johnson



Laura Paniptchuk



Theresa Nanouk

Appendix 6. Description of Climate, Ocean and Biological Indices Used in Statistical Analyses and Models.

Table 6-1. Climate, Ocean and Biological Indices used in correlation analyses and regression models.

Climate Indices	Acronym	Description	Data Source	Source URL
Alaska Index	AlaskaIndx	A measure of atmospheric circulation responsible for ice cover variations in the Bering Sea from year to year. The AI represents the mean winter (December through March) normalized 700-hPa anomalies in Alaska/Yukon (60°N-70°N, 130°W-160°W), 1949-2008. The base period for index normalization is 1961-2000.	PMEL/NOAA	http://www.beringclimate.noaa.gov
Aleutian Low Pressure Index	ALPI	A measure of the relative intensity of the Aleutian Low pressure system of the north Pacific (December through March), calculated as the mean area (km ²) with sea level pressure ≤ 100.5 kPa and expressed as an anomaly from the 1950-1997 mean. A positive index value reflects a relatively strong, or intense Aleutian Low.	DFO (Canada)	http://www.pac.dfo-mpo.gc.ca/science/species-especies/climatology-ie/corirco/indices/alpi.txt
Arctic Oscillation	AO	The leading mode of Empirical Orthogonal Function (EOF) analysis of winter monthly (DJF) mean 1000 mb height during 1979-2000 period. The index presented here is normalized using 1961-2000 base period.	PMEL/NOAA	http://www.beringclimate.noaa.gov
Bering Sea Pressure Index - spring	BSPIsp	Mean spring (April through June), sea level pressure averaged over the Bering Sea (55°-65°N, 170°E-160°W), 1948-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Bering Sea Pressure Index- winter	BSPIw	Mean winter (December through March), sea level pressure averaged over the Bering Sea (55°-65°N, 170°E-160°W), 1948-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Sea Ice Retreat after March 15th at Mooring 2	Ice Retreat (post 3/15 M2)	The number of days after March 15 when the average ice concentration within the box is >10% of the total area around Mooring 2 (56-58°N, and 163-165°W) on the eastern Bering Sea shelf, 1978-2008.	PMEL/NOAA	http://www.beringclimate.noaa.gov

Appendix Table 6-1 (continued)

Climate Indices (continued)	Acronym	Description	Data Source	Source URL
May Sea Surface Temperature - SE Bering Sea	MaySSTS EBS	Sea surface temperature during May in the southeastern Bering Sea calculated as mean monthly SST averaged over the area 54.3-60.0°N, 161.2-172.5°W, 1948-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Multivariate ENSO Index	MEI	El Niño-Southern Oscillation (ENSO) is characterized by the Multivariate ENSO Index (MEI). The annual MEI is based on bi-monthly sliding averages of six observed variables over the tropical Pacific: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky, 1950-2008 relative to 1950-1993 reference period.	NOAA/ESRL	http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/table.html
Multivariate ENSO Index - winter	MEIw	El Niño-Southern Oscillation (ENSO) is characterized by the Multivariate ENSO Index (MEI). The ENSO effect on the Northern Hemisphere reaches its maximum during winter (December-January). The MEI is based on six observed variables over the tropical Pacific: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky, 1950-2008 relative to 1950-1993 reference period.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
El Nino	NINO3.4 AnnAvg	Niño 3.4 is a measure of monthly sea surface temperature anomalies averaged over the equatorial Pacific (5°North-5°South)(170-120°West) then averaged by year. (NOTICE: ON AUGUST 1, 2001 THE BASE PERIOD USED TO CALCULATE THE MONTHLY NIÑO REGION ANOMALIES WERE CHANGED FROM (1961-1990) TO (1971-2000).	JISAO	http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices

Appendix Table 6-1 (continued)

Climate Indices (continued)	Acronym	Description	Data Source	Source URL
North Pacific Index	NPI	The area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W, available since 1899. The winter index is the average NPI from November through March (year of January), and the anomalies are normalized using the base period 1961-2000.	PMEL/NOAA	http://www.beringclimate.noaa.gov
Pacific Decadal Oscillation	PDO	The leading principal component of mean annual (January through December) sea surface temperature anomalies for the North Pacific Ocean to the north of 20N latitude, 1900 - 2007.	JISAO	http://www.jisao.washington.edu/data/pdo/
Sea Ice Cover	Sea Ice Cover	The ice cover index is the average ice concentration for Jan 1-May 31, in a 2-deg x 2-deg box (56-58°N, 163-165°W). The final index is given as normalized anomalies for each year, for the period 1979-2008, relative to the 1981-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Siberian Alaska Index	SibAlaskan ndx or SAI	The Siberian/Alaskan Index (SAI) measures atmospheric circulation responsible for ice cover variations in the Bering Sea from year to year. The SAI represents a difference between the mean winter (DJFM) normalized 700-hPa anomalies in two regions, Siberia (55°N-70°N, 90°E-150°E) and Alaska/Yukon (60°N-70°N, 130°W-160°W), 1949-2008. The base period for index normalization is 1961-2000.	PMEL/NOAA	http://www.beringclimate.noaa.gov
Siberian Index	SibIndx	The Siberian Index (SI) measures atmospheric circulation responsible for ice cover variations in the Bering Sea from year to year. The SI represents the mean winter (DJFM) normalized 700-hPa anomalies in Siberia (55°N-70°N, 90°E-150°E), 1949-2008. The base period for index normalization is 1961-2000.	PMEL/NOAA	http://www.beringclimate.noaa.gov/

Appendix Table 6-1 (continued)

Climate Indices (continued)	Acronym	Description	Data Source	Source URL
Sea Surface Temperature SE Bering Sea	SST JFMA M2	The average sea surface temperature at Mooring 2 (57°N, 164°W) for the period January 15 through April 15 which indicates the severity of the winter as a whole over the shelf of the southeast Bering Sea, 1950-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Winter Sea Surface Temperature SE Bering Sea	SST JFM Prib	Sea surface temperature anomalies during winter (January - March) 100 miles south of the Pribilof Islands, calculated as mean monthly SST averages, 1959-2008 relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
St Paul Island Surface Air Temperature - annual	StPaulSATa	Monthly mean values of surface air temperature at St. Paul (57.1°N, 170.2°W) were obtained from the National Climatic Data Center (NCDC). The monthly values were averaged for full year, 1916-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
St Paul Island Surface Air Temperature - winter	StPaulSATw	Monthly mean values of surface air temperature at St. Paul (57.1°N, 170.2°W) obtained from the National Climatic Data Center (NCDC). The monthly values were averaged for four winter months, December through March, 1916-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
West Pacific Index	WestPacifclndx or WPw	West Pacific index in winter (December, January, February), 1951-2008, and spring (March, April, May), 1950-2007, relative to 1950-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Fairbanks Average Air Temperatures				
Average Air Temp. January - March	FairSATwinter or JFM	Average winter (January through March) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwwcgi.dll?wwDI~StnSrch~StnID~20022291

Appendix Table 6-1 (continued)

Fairbanks Average Air Temperatures (continued)	Acronym	Description	Data Source	Source URL
Average Air Temp. April - June	FairSATspring or AMJ	Average spring (April through June) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20022291
Average Air Temp. July - September	FairSATsummer or JAS	Average summer (July through September) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20022291
Average Air Temp. October - December	FairSATfall or OND	Average fall (October through December) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20022291
Average Air Temp. November - March	FairSAT(winter) or NDJFM	Average winter (November through March) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20022291
Average Air Temp. May - September	FairSAT(summer) or MJJAS	Average spring (May through September) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20022291
Annual Fairbanks Average Air Temp.	FairSATannual or ANNUAL	Average annual (January through December) air temperatures at Fairbanks, Alaska.	NCDC	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20022291

Appendix Table 6-1 (continued)

Wind Stress Measures	Acronym	Description	Data Source	Source URL
High Winds at Mooring 2 - spring	HiWind M2 spring or Strong Winds	The number of days each year during the period 1 May through 15 July in which the daily average surface (10 m) wind speed exceeds 9.5 ms ⁻¹ at Mooring 2 (57°N, 164°W), 1950-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
June/July Mixing at Mooring 2	JJ Mix M2	Wind mixing is characterized by the average value of cubed friction velocity u^3 for 1 June - 31 July. Friction velocity was derived from the wind stress, assuming constant density at 1.25 kg m ⁻³ . The June-July index was calculated for the grid point in the vicinity of Mooring 2 (57°N, 164°W), 1950-2008, relative to the 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
May Mixing at Pribilof Islands	MayMix Prib	Wind mixing is characterized by the average value of cubed friction velocity u^3 for 1-31 May. Friction velocity was derived from the wind stress, assuming constant density at 1.25 kg m ⁻³ . The May index was calculated for the grid point 57.2°N, 169.7°W, which is the closest to St. Paul (57.1°N, 170.2°W), 1950-2008, anomalies relative to the 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
N - S winds at Pribilof Islands	NS Wind Prib	The monthly values of the meridional surface (10 m) wind component at the point 57.5°N, 170°W, 1949-2008, relative to 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Optimal Windy Days at Mooring 2	OptWindDays M2	The number of days each year during the period 1 May through 15 July in which the daily average wind speed was 4.8 to 9.5 ms ⁻¹ at the location of Mooring 2 (57°N, 164°W), 1950-2008. The data presented are deviations from the mean for 1961-2000.	PMEL/NOAA	http://www.beringclimate.noaa.gov/

Appendix Table 6-1 (continued)

Wind Stress Measures (continued)	Acronym	Description	Data Source	Source URL
Wind Stress across the Alaskan Peninsula - November to April	WindStresw AKPen or NDJFMA or WSNA	The along-peninsula component of the wind stress (N m-2) at Unimak Pass (54°N, 165°W) is assumed to be oriented along the 55-235° radial. WindStresw AK Pen or NDJFMA is calculated for November through April. WSNA is the annual index calculated for all months. Negative values signify anomalously strong winds from the "east" (55° toward 235°), associated with northward transports through Unimak Pass, 1951-2008, anomalies relative to the 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Wind Stress across the Alaskan Peninsula - May and June	WindStress AKPen MJ	The along-peninsula component of the wind stress (N m-2) at Unimak Pass (54°N, 165°W) is assumed to be oriented along the 55-235° radial. This index is calculated for May through June. Negative values signify anomalously strong winds from the "east" (55° toward 235°), associated with northward transports through Unimak Pass, 1950-2008, anomalies relative to the 1961-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Biological Indices				
Bristol Bay Sockeye Abundance	BB Sockeye	Bristol Bay sockeye salmon (<i>Oncorhynchus nerka</i>) runs, 1956-1997, are available from the Post-1977 Regime Shift Homepage. The data since 1997 are available from the Bristol Bay Salmon Historical Information web site of the Alaska Department of Fish and Game.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Groundfish Diversity	Groundfish Diversity or SWI	Groundfish diversity (Shannon-Wiener index), 1982-2006, anomalies relative to 1991-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/

Appendix Table 6-1 (continued)

Biological Indices (continued)	Acronym	Description	Data Source	Source URL
Eastern Kamchatka Pink Salmon Abundance	Kam. Pink Salmon or pinks	Annual abundance estimates (total run = catch plus escapement) of eastern Kamchatka pink salmon, 1952-2007.	NPAFC & TINRO	Estimates from Ruggerone et al. 2010; NPAFC documents: http://www.npafc.org ; and O. Temnykh (pers. comm.), TINRO Centre, Vladivostok
Pollock Abundance	Pollock (age group specified)	Recruitment of walleye pollock (<i>Theragra chalcogramma</i>) to the eastern Bering Sea pollock recruitment (1963-2006) and its biomass in metric tons (1964-2007), anomalies relative to 1981-2000 mean.	PMEL/NOAA	http://www.beringclimate.noaa.gov/
Yukon River Chinook Abundance	Yukon R. Chinook (age group specified)	Annual abundance estimates of Yukon River Canadian Chinook Salmon, by age group. Total run and escapement by brood year 1983 - 2003 based on 3 area index, Eagle Sonar (2005 - 2008), and local radio telemetry (2002-2004). Page 119, Appendix Table A10, Age 1.4 (6) only, Eagle Sonar 3-Area Index	ADFG, K. Howard; JTC (2010) DOC RIR report:3A-10-01	www.sf.adfg.state.ak.us/FedAidpdfs/RIR.3A.2010.01.pdf

Appendix Table 6-1 (continued)

Acronyms		Description	Source URL
ADFG		Alaska Department of Fish and Game	http://www.adfg.state.ak.us/
DFO		Department of Fisheries and Oceans, Canada	http://www.dfo-mpo.gc.ca/
ESRL		Earth System Research Laboratory of NOAA	http://www.esrl.noaa.gov/
JISAO		Joint Institute for the Study of the Atmosphere and Ocean	http://jisao.washington.edu/index.html
NCDC		National Climatic Data Center	http://www.ncdc.noaa.gov/oa/ncdc.html
NOAA		National Oceanic and Atmospheric Administration	http://www.noaa.gov/climate.html
NPAFC		North Pacific Anadromous Fisheries Commission	http://www.npafc.org/
PMEL		Pacific Marine Environmental Laboratory	http://www.pmel.noaa.gov/
TINRO		TINRO Center	http://www.tinro.ru/