The Bering-Aleutian Salmon International Survey (BASIS)

by

John Helle, Ed Farley, Jim Murphy, Angela Feldmann, Kris Cieciel, Jamal Moss, Lisa Eisner, John Pohl, and Mary Courtney

The fisheries oceanography survey of the Bering Sea, known as BASIS, is made possible by the international treaty that led to the organization of the North Pacific Anadromous Fish Commission (NPAFC). The NPAFC was established under the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean effective February 1993 and includes Canada, Japan, Republic of Korea, the Russian Federation, and the United States. The NPAFC Convention Area forms the world's largest marine conservation area for seven species of Pacific salmon, including chum (*Oncorhynchus keta*), coho (*O. kisutch*), pink (*O. gorbuscha*), sockeye (*O. nerka*), Chinook (*O. tshawytscha*), and cherry salmon (*O. masou*), and steelhead trout (*O. mykiss*).

The NPAFC promotes the advancement of scientific knowledge on the salmon-bearing ecosystems of the North Pacific and the international cooperation in achieving conservation and sustainable management of Pacific salmon. Directed fishing for Pacific salmon and retention of Pacific salmon onboard vessels fishing for nonanadromous fish is prohibited within the Convention Area. Member nations patrol and enforce salmon conservation within the Convention Area.

The large body of scientific evidence on growth and survival of salmon populations assembled by NPAFC member nations over the years has enabled development and testing of hypotheses about the effects of environmental change on living marine resources. For example, salmon abundance increased greatly following the 1976-77 ocean regime change in the North Pacific. However, as numbers of salmon increased in the two decades following the regime shift, salmon body size decreased, and age-at-maturity increased in most stocks in both North America and Asia. These observations supported the hypothesis that carrying capacity for salmon in the Convention Area may have been exceeded, which indicated the need for scientific investigation, as was subsequently reflected in the NPAFC Science Plan. Responding to the NPAFC call for carrying capacity research, the Alaska Fisheries Science Center (AFSC) directed the Auke Bay Laboratory (ABL) to form the Ocean Carrying Capacity Program (OCC). The OCC Program, established in 1994, is responsible for BASIS research in U.S. waters.

International BASIS

Drastic changes in physical and biological conditions in the Bering Sea during the 1990s in conjunction with extreme fluctuations in the abundance and growth of both North American and Asian salmon stocks prompted managers to call for more information on marine ecology of Pacific salmon. The coincidence of changes in the environment and salmon abundance and growth led to cooperative research on the mechanisms that link these changes. The response of NPAFC scientists was to develop an unprecedented and ambitious plan to sample the entire epipelagic ecosystem of the Bering Sea (Fig. 1). This plan, the Bering-Aleutian Salmon International Survey (BASIS), was designed to understand the biological response of salmon within an ecological context during a period of climate change. The OCC Program developed, tested, and implemented the sampling methods now employed in BASIS, and since 2000

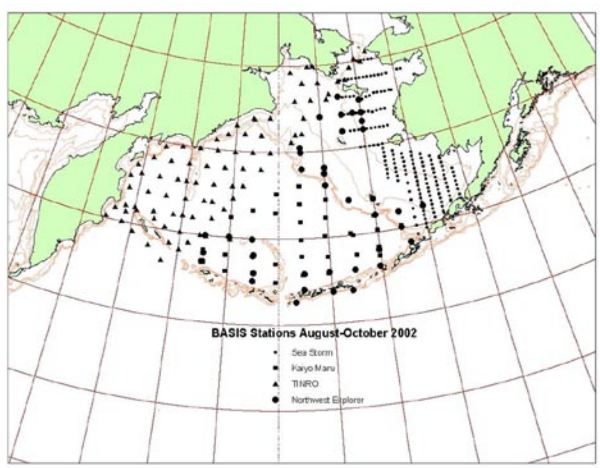

Figure 1. Map showing BASIS study area and research vessel stations in the Bering Sea. Dots indicate stations sampled by U.S. vessels, boxes indicate stations sampled by Japanese vessels, and triangles indicate stations sampled by Russian vessels.

has participated in a multiyear survey plan for collecting physical and biological oceanographic data in conjunction with epipelagic trawling operations in a geometrically systematic pattern.

U.S. BASIS

Along the eastern Bering Sea shelf, the strength of coupling between primary and pelagic production in the southeastern region has a profound effect on productivity. The oscillating control hypothesis (OCH) is an important advance in our conceptual framework for understanding decadal-scale changes in this coupling and its importance to climate change and trophic structure on the eastern Bering Sea shelf. This hypothesis implies that overall pelagic fish production is predicted to oscillate between bottom-up and top-down mechanisms depending on the frequency of cold or warm years. During cold years, late ice retreat promotes an ice-associated bloom in cold water which results in much of the production sinking to the benthos, while in warm years, an early ice retreat results in a delayed spring bloom in open, relatively warm water, which enhances zooplankton production. During cold regimes, therefore, zooplankton prey for larval fish is limited, negatively impacting recruitment of fish populations on the shelf, whereas warm regimes are associated with strong zooplankton productivity and higher survival of larval and juvenile fish. At the start of a warm period, predator abundance is assumed to be low; therefore, pelagic fish production is mainly controlled by bottom-up forcing. As predator abundance increases, top-down forcing becomes more important. At the start of a cold regime, both top-down and bottom-up forcing may be important if predator abundance is high, with bottom-up forcing more important as predator abundance is reduced.

Researchers with the OCC Program have conducted shelf-wide surveys during fall 2000 through 2006 on the eastern Bering Sea shelf as part of the multiyear BASIS research program (Fig. 2). Salmon and other forage fish (e.g., age-0 walleye pollock, Pacific cod, and Pacific herring) were captured with a surface net trawl, zooplankton were collected with oblique bongo tows, and oceanographic data were obtained from conductivity-temperature-depth (CTD) vertical profiles. The focus of the BASIS research was on salmon; however, the broad spatial coverage of oceanographic and biological data collected during late summer and early fall provided

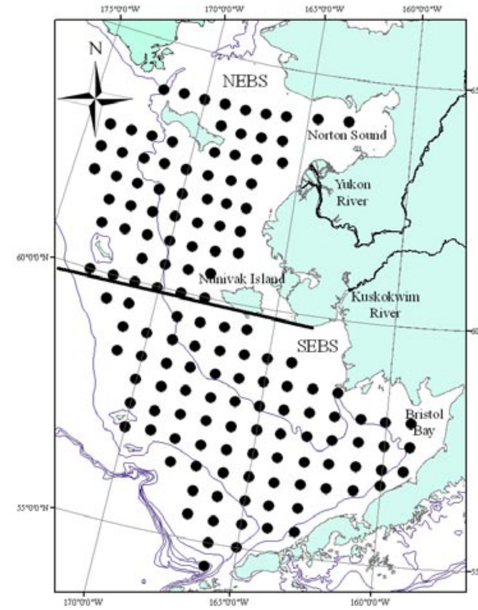

Figure 2. Proximate location for stations sampled during the U.S. Bering-Aleutian Salmon International Survey during 2002–06. Stations south of 60°N and east of 167°W were sampled during 2000 and 2001.

insight into how the pelagic ecosystem on the eastern Bering Sea shelf responded to changes in spring productivity. We highlight, therefore, the biological characteristics of key pelagic fish species captured on the eastern Bering Sea shelf during years with warm (2002-05) and cool (2000, 2001, and 2006) spring temperatures (Fig. 3).

Research on Forage Fish and Jellyfish

Walleye pollock (*Theragra chalcogramma*) is the most abundant pelagic fish species in the Bering Sea. Not only are pollock important commercially, but they also are an important food source for marine mammals, seabirds, and piscivorous fish, particularly during their first few years at sea. Understanding the physical and biological processes impacting the early life history of walleye pollock, therefore, is critical. BASIS research during 2000-05 suggests that age-0 pollock are distributed farther north during years with warm sea surface temperatures (SSTs) (Fig. 4); however, during 2006, a year with cool SSTs, the largest catch per unit effort of age-0 pollock occurred south of lat. 60°N. Average abundance (estimated by dividing the average number of age-0 pollock caught by the average volume of water swept for all trawls during the survey) increased annually from 2002 to 2004, declined slightly in 2005, and dropped significantly in 2006 (Fig. 5). Stomach content analysis indicated that age-0 pollock have

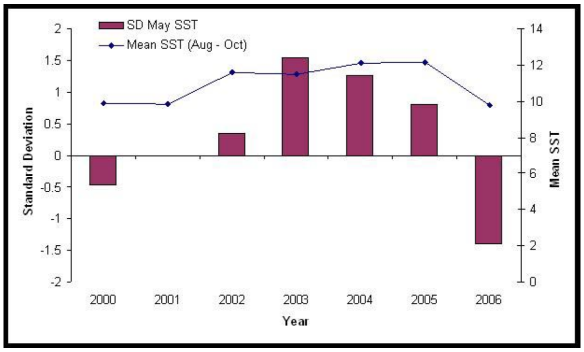

Figure 3. Mean sea surface temperature (SST) at 5-m depth (dotted line) from stations sampled during the 2000 to 2006 BASIS research cruise and standard deviations of May SSTs (bars) calculated as mean monthly SSTs averaged over the area 54.3°N to 60°N, 161.2°W to 172.5°W. The index values are the deviations from the mean value (2.33°C) for the 1970–2000 period normalized by the standard deviation (0.76°C). The index values are courtesy of http://www.beringclimate.noaa.gov.

a more diverse diet dominated by calanoid copepods and larval fish in warm years (2004), whereas in cold years (2006), pollock have a less varied diet dominated by euphausiids. Cannibalistic feeding behavior of larger age-0 pollock (60-80 mm) was most pronounced in warm years, most likely due to the greater availability of smaller age-0 pollock (30 to 50 mm) as prey.

Overall, jellyfish relative biomass, defined as the total weight of a particular species in a 30-minute trawl, was lower in the cold year (2006) compared to the warmer years (2004 and 2005) during our study period. Jellyfish were present throughout the sample grid for each year, with the highest concentrations (relative biomass) for all species combined found in the Middle Shelf Domain. Of the six species sampled, *Chrysaora melanaster* had the highest density for all years, followed by *Aequorea* sp., *Cyanea capillata*, *Staurophora mertensi*, *Aurelia labiata*, and *Phacellocephora camtschatica* (Fig. 6). BASIS research indicated associations between gelatinous zooplankton and forage fish species during our survey; however, the timing and mechanisms driving these associations are not clearly understood.

Research on Sockeye Salmon: Indicators of Ecosystem Productivity and Dynamics

BASIS surveys, along with previous surveys, have established that the southeastern Bering Sea shelf is an important corridor for juvenile Bristol Bay sockeye salmon ocean migration. Two different migration pathways for juvenile Bristol Bay sockeye salmon have been observed. The first migration pathway is west in a narrow coastal band, nearshore along the coastal waters of the Alaska Peninsula. The second migration pathway is farther offshore along the northern and southern sides of Bristol Bay.

The size, relative marine survival, and relative abundance of juvenile Bristol Bay sockeye salmon were highest during 2002, a year with an offshore migration pathway, and lowest during 2000 and 2001, years when juvenile sockeye salmon were distributed nearshore. Differences in migration pathways for juvenile Bristol Bay sockeye salmon, therefore, appear to be a function of spring and summer SSTs, where cooler spring and summer SSTs are associated with the nearshore migration pathway (lower marine survival) and warmer spring and summer SSTs are associated with the offshore migration pathway (higher marine survival).

BASIS data suggest that years with warmer SSTs coincide with an increase in relative abundance (Fig. 7) and marine stage survival of juvenile Bristol Bay sockeye salmon. Data also suggest that size of the juvenile salmon after their first summer at sea coincides with higher marine survival, suggesting that mechanisms involved in early marine growth and abundance of juvenile salmon are keys to understanding juvenile salmon population dynamics and recruitment variability. Because size after the first year at sea is important to survival of Pacific salmon, smaller fish might compensate for their reduced size by eating more food: compensatory growth of smaller fish that are denied food occurs in Atlantic salmon (*Salmo salar*) and some teleost fishes once food items are restored. We found evidence for compensatory growth in our data: smaller age-1.0 sockeye salmon generally had higher relative feeding indices than age-2.0 sockeye salmon, indicating that these smaller fish had more food in their stomachs. In addition, the condition index of age-1.0 sockeye salmon was generally higher than age-2.0 sockeye salmon, suggesting that age 1.0-sockeye salmon were actively feeding at higher rates over a longer period of time. In some years (2000 and 2001), however, the smallest age-1.0 sockeye salmon had the lowest feeding indices, and there are indications that prey was a limiting factor during those years.

Diets of juvenile sockeye salmon reflected the impact of changing ocean conditions on their migration and the uniqueness of the eastern Bering Sea shelf ecosystem. For instance, juvenile sockeye salmon primarily fed on Pacific sand lance during years when they were distributed in nearshore

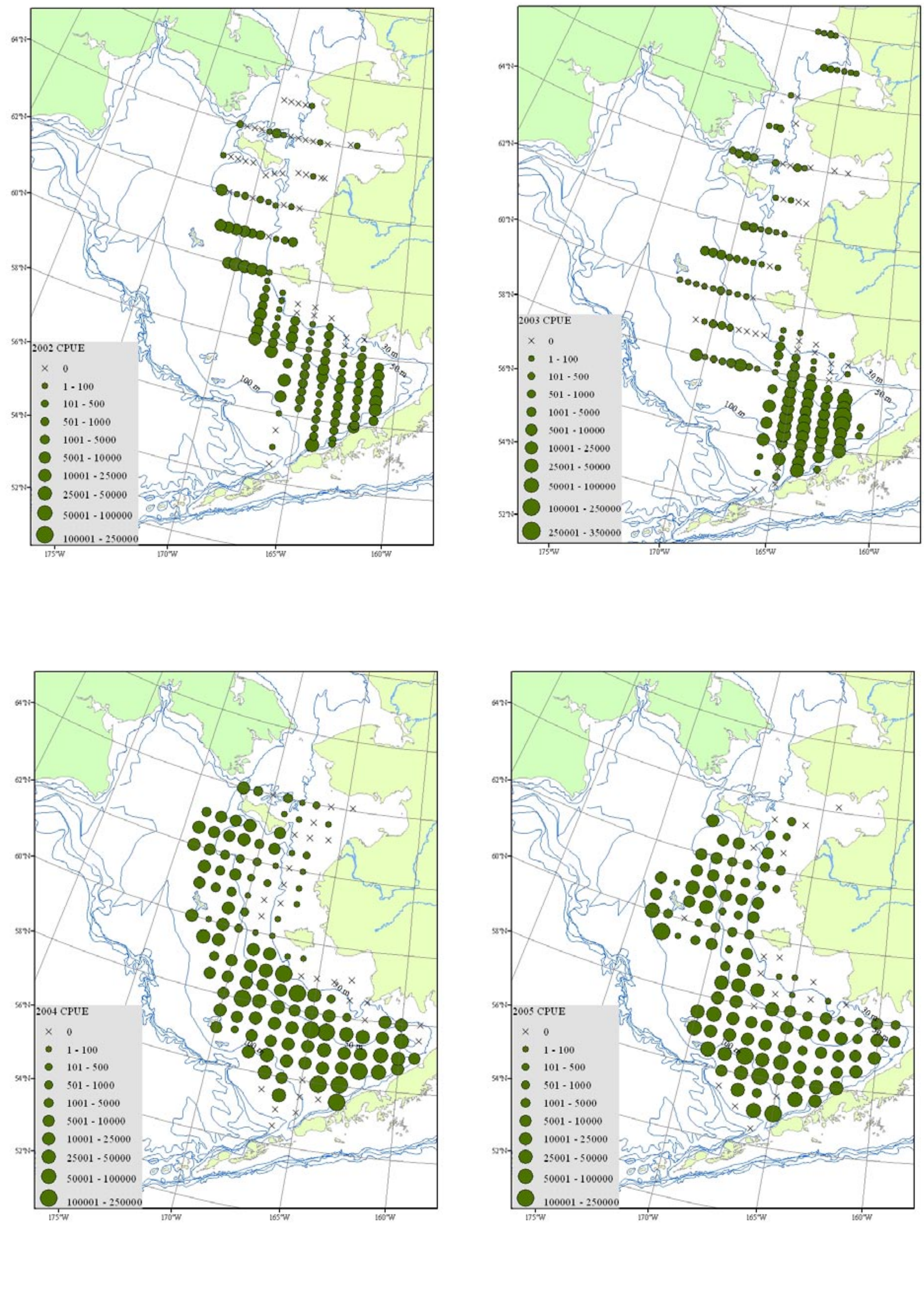

Figure 4. Young-of-the-year pollock distribution from August-October 2002-06 surveys in catch per unit effort (CPUE) based on 30-minute surface trawl hauls. (Continued on next page.)

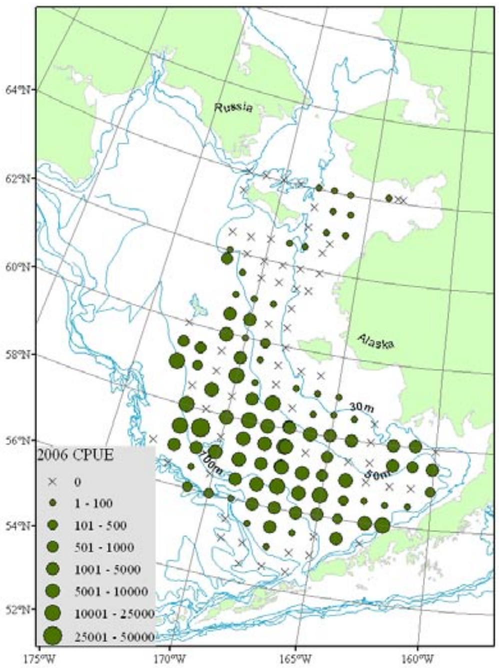

Figure 4. (Continued.)

locations (years with cold spring SSTs) and age-0 pollock when they were distributed farther offshore (years with warm spring SSTs). Feeding ecology of juvenile sockeye in the eastern Bering Sea, as indicated by BASIS diet analysis, is unique compared to other production regions of sockeye salmon; hyperiid amphipods (*Themisto pacifica*) provide the primary diet of juvenile sockeye in the western Bering Sea, and euphausiids are the primary prey of juvenile sockeye in the Gulf of Alaska. The large numbers of larval and juvenile fish on the eastern Bering Sea shelf provide a rich and productive feeding and rearing habitat for juvenile sockeye, possibly one of the key reasons for the success of the Bristol Bay sockeye salmon system.

Overall, BASIS research suggests that "warm regime" dynamics in the eastern Bering Sea may be linked with larger size and higher marine stage survival of juvenile sockeye salmon, and these conditions appear to be linked with increased abundance of forage fish along the eastern Bering Sea shelf.

The 2006 field season marked the final sampling year of the initial plan for BASIS. During the 5 years of field surveys in the Bering Sea, BASIS has not only provided new insight into the ecology of salmon in the Bering Sea, but also has contributed to our understanding of the eastern Bering Sea ecosystem through research on oceanographic conditions and pelagic fish species. BASIS has broad support in the NPAFC and AFSC, and plans for BASIS phase II (2007 to 2011) are being developed to continue this important pelagic ecosystem research of the Bering Sea.

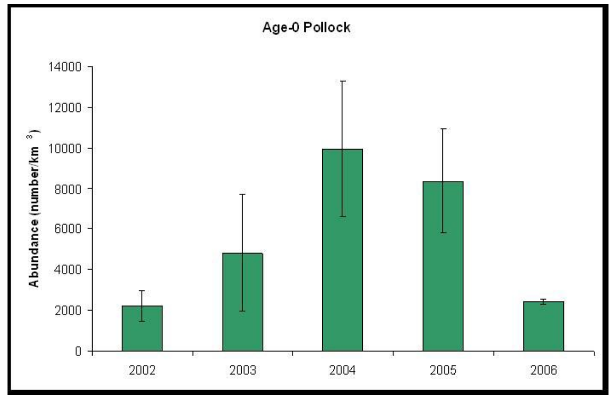

Figure 5. Mean annual age-0 pollock abundance (No./km^3) with 95% confidence intervals from August-October 2002-06 surveys.

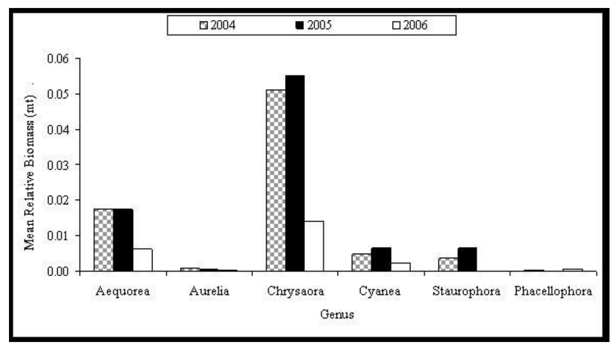

Figure 6. Total relative biomass in metric tons (t) distributed by genus and year for all trawl caught species in the eastern Bering Sea. Relative biomass is defined as the total weight of a particular species in a 30-minute trawl.

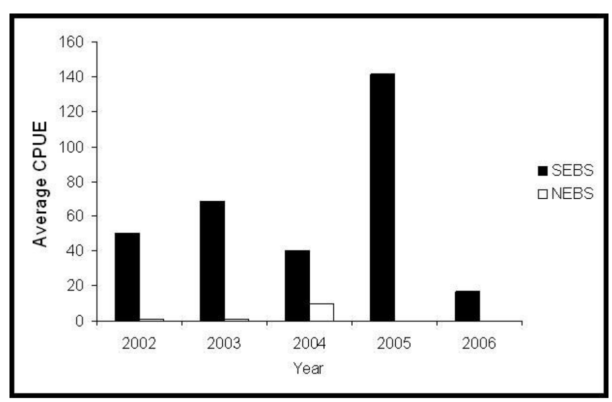

Figure 7. Relative abundance based on average catch per unit effort (number of juvenile sockeye salmon captured in a 30-minute trawl) in the southeastern Bering Sea (SEBS; stations south of 60°N) and in the northern Bering Sea (NEBS; stations north of 60°N).