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Editorial

Variability in the Bering Sea ecosystem

There is widespread recognition that significant ecosystem changes have occurred in the Bering Sea over the last few decades. These changes are, in part, the result of shifts in decadal climate patterns such as the Pacific Decadal Oscillation (PDO) and Arctic Oscillation (AO) and, to a lesser extent, the influence of El Niño-La Niña. Reversals in the PDO and AO during 1976-1977 (Mantua et al., 1997) accompanied a large-scale regional shift from relatively cold to relatively warm temperatures in the Bering Sea (Stabeno et al., 2001). A weaker shift occurred in 1989 when just the AO changed sign and there was a concurrent La Niña (Overland et al., 1999; Hare and Mantua, 2000). During the late 1990s, the PDO changed sign again, and many (e.g. Schwing and Moore, 2000) have interpreted this change to imply a new regime shift. Often, climate shifts are difficult to recognize quickly because of the large interannual variability that the region exhibits.

Two important characteristics of the physical environment of the Bering Sea that are associated with climate change are the extent and duration of seasonal sea ice cover. These characteristics are intimately related to the timing of the spring phytoplankton bloom (Stabeno et al., 2001). Seasonal ice dynamics switched in the late 1980s from a warm phase that persisted since the regime shift of the late 1970s. The new pattern exhibits rapid buildup of ice in winter but earlier retreat in spring; this character has persisted through the potential regime shift of the late 1990s. Stabeno and Overland (2001) present evidence that the Bering Sea shifted towards an earlier spring transition in the 1990s, a pattern that has continued through 2002.

The biological environment has responded to climate shifts, too. At the bottom of the food chain, extensive coccolithophore (*Emiliania huxleyi*) blooms began appearing on the Bering Sea shelf in the summer of 1997 (Vance et al., 1998). Despite the variable and perhaps relatively poor conditions for coccolithophores that have prevailed since then, the blooms have recurred each summer. At higher trophic levels, changes in the distribution of some Pacific salmon (*Oncorhynchus* spp.) are related to the regime shifts of 1976-1977 and 1989 (Ishida et al., 2002). Walleye pollock (*Theragra chalcogramma*) distribution and abundance have varied with fluctuations in sea ice (Hunt et al., 2002). Shifts have also been observed in the populations of crab, seabirds, and marine mammals.

These and other changes were the subjects of a Climate Change and Carrying Capacity (CCCC) Topic Session at the 10th Annual Meeting of the North Pacific Marine Science Organization (PICES) in Victoria, B.C., Canada, in October 2001. The half-day session, “A Decade of Variability in the Physical and Biological Components of the Bering Sea Ecosystem: 1991-2001” attracted 48 abstracts considering the nature of climate changes in the Bering Sea over the past decade and the effects of these changes. The geographic scope included the western and eastern Bering Sea and adjacent marine areas such as the Sea of Okhotsk, the Chukchi Sea, and the central North Pacific Ocean. Many of the presentations from that session appear in this issue as fully developed manuscripts.

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Hunt and Stabeno (2002) describe support for the Oscillating Control Hypothesis (OCH) that relates climate forcing to trophic abundance and interactions in the southeastern Bering Sea. This hypothesis enables prediction of upper trophic species abundance, specifically walleye pollock, as a function of the relative temperature (warm or cold) and duration of climate fluctuations. The OCH is one of several concepts that seek to explain the changing productivity of the Bering Sea. As this issue goes to print, agreement is lacking within the scientific community about whether productivity actually has decreased or increased during the recent decades. Hopefully, the articles in this issue will lead to better understanding.

While decadal patterns influence the physical environment of the Bering Sea, year-to-year variability dominates this system. This behavior is evident in the results of Luchin et al. (2002), where “cold” and “warm” years were found in each of the climate regimes associated with the PDO and AO. The very warm years of 1997 and 1998 might be related to a major regime shift, comparable to the shift in 1976-1977 (Minobe, 2002). Longer records, however, are critical to differentiate between a sudden regime shift from warm to cold and extremes in a signal dominated by interannual variability.

Sea ice is a defining characteristic of the Bering Sea, not only affecting the baroclinic structure on the eastern shelf, but also influencing the timing of the spring bloom (Hunt and Stabeno, 2002). The timing of ice retreat from the eastern shelf in spring is related to the atmospheric circulation patterns (Minobe, 2002). Interactions between the Aleutian Low and Siberian High control the advance and retreat of ice, resulting in contrasting conditions in eastern and western Bering Sea - warmer conditions in the eastern part are often associated with colder conditions in the western (and vice versa).

The location of sea ice is a controlling factor in the regional CO_2 budget. Pipko et al. (2002) report that during fall, the carbonate system in the Chukchi Sea acts as a sink for atmospheric CO_2. This occurs as a result of interactions between various physical and biological processes such as mixing of different water masses, cooling, and photosynthesis-respiration. The general pattern is for CO_2 surface partial pressure to decrease toward the ice edge, in phase with the temperature decrease, whereas mesoscale variability of the carbonate parameters is controlled by the interaction between different water types. Further south, Takahashi et al. (2002) examined particle flux from sediment traps installed near the Aleutian Basin in the Bering Sea from 1990-1999 and in the central subarctic Pacific from 1990-2000. They found the mean flux in the Aleutian Basin to be about twice that of the central Pacific, and point out that under the present climate regime the Aleutian Basin of the Bering Sea is one of the most productive semi-pelagic/pelagic regimes in the world. Productivity over the basin is examined at the lowest trophic levels by Shiomoto et al. (2002). Their inference of phytoplankton biomass and distribution from surface chlorophyll samples during the 1990s indicated no statistically significant year-to-year or station-to-station variations. Saitoh et al. (2002) use satellite multi-sensor techniques to suggest that geographic variations in phytoplankton biomass within the Bering Sea during 1997 and 1998 can be linked to the location of the Aleutian Low in each year.

The prolific coccolithophore blooms are one of the recent striking examples of variable Bering Sea productivity. Shin et al. (2002) conducted field observations and experiments within the bloom over the middle and inner shelf during September 2000. They analyzed the variablity of C37 alkenones to determine possible mechanisms sustaining the *Emiliania huxleyi* blooms. Their research suggests that the bloom may be maintained by turbulent mixing similar to the transport of cold, slope water by eddies to the overlying surface water. During the summers of 2000 and 2001, Mizobata et al. (2002) studied the biological, chemical and physical structures of Bering Sea cyclonic and anticyclonic eddies, using satellite altimetry and shipboard sampling. Results of their shipboard transects revealed, in part, that inside a cyclonic (anticlockwise) eddy, upwelling at the center of the eddy was transporting nutrient-rich water towards the surface, resulting in a relatively high chlorophyll concentration under the pycnocline. On the other hand, nutrient-rich water was being transported into the euphotic zone along the up-bowed isopycnals at the edge of anticyclonic (clockwise) eddies, so that high chlorophyll concentrations occurred above the pycnocline within anticyclonic (clockwise) eddies. Iida et al. (2002) also suggest that the strength of a bloom is related to sea surface temperature (SST). Weaker blooms accompanied the cooler water temperatures of 1999 and 2001, whereas larger blooms occurred during the warmer years of 1998 and 2000.

Moving up the food chain, Coyle and Pinchuk (2002) examine zooplankton densities observed on the inner shelf of the southeastern Bering Sea during 1997, 1998, and 1999. They find that copepod production was greater during warm periods. In fact, the level of production could exceed the supply of phytoplanktonic food apparently available to support it. Under cooler conditions, calanoids could remove only a small percentage of the estimated daily primary production. The authors estimate that the annual carbon flux to benthic communities was about 50% lower during the warm years that during the cooler years.

At higher trophic levels, the responses to climate forcing occur directly from changes in the physical environment as well as from the bottom-up signal transferred through the food web. In the pelagic layer, climate and concomitant oceanographic variability determine the specific composition of fish communities and the characteristic changes in common species, like walleye pollock and Pacific salmon. Since the late 1980s, walleye pollock abundances have declined notably in the main areas of spawning and feeding migration. The fecundity and size-at-age of walleye pollock have increased because of weakening of density-dependent effects in recent years (Yanagimoto et al., 2002). Pacific salmon have undergone a northward shift in their distributions and changes in their growth parameters (Ishida et al., 2002). These changes could be related to a northward shift of the general pattern of upper ocean circulation as noted by recent SST trends. In the demersal fish communities, synchronous trends in abundances are identified for several species. These can be related to oceanographic conditions, particularly to the variable intensity of water exchanges between basin and shelf and to seasonal ocean processes, especially during spring (Wilderbuer et al., 2002). Some processes act through the dispersal of fish eggs and larvae and the transport of planktonic prey organisms. Others affect the biological productivity of lower trophic levels and the transfer of organic matter through the food web. Changes in physical parameters of the near-bottom layer can be important factors influencing the variability in annual recruitment patterns. The timing of shifts in the demersal fish communities is characterized by lags from the climate/oceanographic regime shifts (Conners et al., 2002) resulting from indirect effects of climate forcing, and complex internal relationships in the biological structure of ecosystems. Moore et al. provide the first comparative estimates of abundance for cetaceans in the eastern Bering Sea. The distribution of some species appears to have been associated with bathymetric features and prey locations.

The studies reported in this issue illustrate the dynamic nature of the Bering Sea. The passage of time will reveal how the recent variations in physics, chemistry, and biology will compare with past and future records. Will they fit neatly within a natural oscillation pattern dictated by climate fluctuations, or will they track a long-term trend caused, perhaps, by anthropogenic influences?

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