

ABSTRACT

Sinking Particles and Pelagic Food Webs in the SE Bering Sea: 1997-2002

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The southeastern Bering Sea shelf is an economically and ecologically important system that is subject to substantial natural and human-induced change (National Research Council, 1996). Despite this, long term observations are limited and fragmentary in time and space, which severely restricts our ability to identify the effects on the ecosystem due to climatic variability. During recent years, marked changes in the physical and biological environment of Bering Sea have occurred. The most comprehensive characterization of the changes in the physical environment has been based upon observations collected from biophysical moorings (Stabeno et al., 1998; 1999; 2001). Since 1995 Stabeno and collaborators have been monitoring site M2, over the Bering Sea middle shelf near 56°N, with funds provided by NOAA's Southeast Bering Sea Carrying Capacity (SEBSCC, Phases I, II, and III) and Fisheries Oceanography Coordinated Investigations (FOCI), measuring temperature, salinity, chlorophyll, current speed, and meteorological conditions. A time-series sediment trap has been deployed near that mooring since 1997. The composition of sinking organic material collected by the trap, along with a parallel time-series of zooplankton stable isotopic composition, has reflected changes in the pelagic food web during that period.

The biophysical mooring deployment will continue through 2002 if support is provided through the Pollock Conservation Cooperative (Whitledge and Stabeno proposal); unfortunately NOAA support for the mooring (except for some logistical support) will end in 2001, making their funding request to the PCCRI necessary to continue this very valuable series of observations. This proposal requests funds for two additional deployments of a time-series sediment trap, at the same time and location as the biophysical mooring, for analysis of the sediment traps samples, and for collection and analysis of zooplankton samples. The specific hypothesis to be addressed by the research proposed here is that the temporal variation of the quantity and composition of sinking particles depends on changes in the pelagic food web, which in turn are largely dependent on interactions among weather and climate. The research aims to improve understanding of biophysical controls on primary production and of the transfer of water column production to the benthos. The carbon and nitrogen stable isotope composition and selected biomarkers, including wax esters and sterols, will be measured in the trapped material, as has been done for Phases I and II of the SEBSCC program and for 2001 with support from the Pollock Conservation Cooperative Research Center. Together with the research being conducted by Stabeno, this proposed research will provide measurements to identify and characterize spatial and temporal variability of the physical environment and the biological response to changing conditions. Such monitoring is essential to address the influence of climate change on this ecosystem.

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Summary

The southeastern Bering Sea ecosystem has changed significantly since the 1960s, most obviously at high trophic levels. However, long term observations are limited and fragmentary in time and space, which severely restricts our ability to identify the causes. Only since 1995 have detailed, continuous data on the ocean environmental changes been collected, using moored instruments (Stabeno et al., 1998; 1999; 2001, 2002). A site over the middle shelf near 56° N has been monitored for water column temperature, salinity, chlorophyll, and currents, and meteorological conditions. A time-series sediment trap, which collects particles sinking out of surface waters, has been deployed at that site since 1997 (Smith et al., 2002), with funding from the NOAA Southeast Bering Sea Carrying Capacity program and the Pollock Conservation Cooperative Research Center. A parallel time series of zooplankton samples has been collected. The particles collected by the trap consist of intact phytoplankton, diatom frustules, coccoliths, zooplankton fecal pellets, and other detritus resulting from food web processes. By microscopic examination and chemical and stable isotopic analysis of the material, information on nutrient availability, phytoplankton and zooplankton communities, the timing of phytoplankton blooms, relative extent of phytoplankton grazing by zooplankton, and other important ecological information has been obtained. The composition of sinking organic material has reflected changes in the ecosystem in response to oceanographic conditions during the 1997-2002 period.

Introduction

Significant climatic variations have occurred in the northern North Pacific Ocean and Bering Sea over the past 50 years, and these have been associated with major changes in the populations of marine mammals and fishes (National Research Council, 1996; Hunt et al., 2002). The seasonal advance and retreat of sea ice over the Bering and Chukchi Sea shelves clearly has a strong influence on biological processes in the Bering Sea. For example, the timing and grazing of spring blooms (Alexander et al., 1996), bottom water temperatures and the distribution of certain demersal fishes (Wyllie-Echeverria, 1995), a massive increase of jelly-fish over the southeastern shelf since 1990 (Brodeur, et al., 1999), recruitment of pollock (Ohtani and Azumaya, 1995; Quinn and Niebauer, 1995) and the geographic distribution of marine mammals have been linked to interannual variability seasonal sea ice in the Bering Sea. Hunt et al. (2002) proposed the Oscillating Control Hypothesis, which states that the southeastern Bering Sea pelagic ecosystem is governed from the top down during warm conditions, but from the bottom up during cold conditions. In warmer years, when sea ice is not present after mid-March, the phytoplankton bloom is closely coupled to zooplankton and thus there is abundant food for larval and juvenile fishes, which are limited by predation. In colder conditions, sea ice is present in spring, zooplankton do not graze the spring bloom effectively, and juvenile and larval fish survival is limited by lack of food.

The years 1997-2002 have shown a remarkable range of conditions. In 1997 a cold spring during which sea ice covered the middle shelf was followed by an unusually warm, calm summer (Stockwell et al., 2001). There were marked changes in phytoplankton populations, a die-off of seabirds, and a failure of the red salmon fishery. Coccolithophorid blooms have persisted over the southeastern shelf since 1997, although they had never been observed before (Stabeno and Hunt, 2002). It was much stormier during spring and early summer of 1998 than during 1997 and surface water temperatures were not unusually warm. Sea ice covered the mooring site only briefly in February and the depth-averaged water temperature remained well above normal. In contrast, 1999 was the coldest year since the 1970s, with extensive sea ice cover during spring. Sea ice retreated in March of 2000 and spring and summer temperatures were close to the long-term climatic mean. Sea ice coverage over the winter of 2000-01 was

less than average, no significant ice reached the mooring site, and middle shelf water temperatures were warmer than usual in spring. In 2002, sea ice again did not reach the mooring site, and conditions were even warmer than in 1997 (Stabeno et al., 2002; Stabeno and Hunt, 2002; Stabeno, personal communication).

Methods

Sediment traps were deployed at Site 2 over the middle shelf domain (56°53'N, 164°02'W, 35 m depth of deployment in a 70 m water column). This site was originally chosen because of its central location within the middle shelf domain of the southeastern Bering Sea (Coachman et al., 1986) and proximity to a transect sampled intensively during the late 1970s and early 1980s (during PROBES). Conditions there are expected to typify this area of the shelf. Other instruments on the moorings, deployed by the cooperating Phyllis Stabeno/Terry Whitledge project measured temperature, conductivity (salinity), currents, fluorescence (chlorophyll, related to phytoplankton abundance), nitrate, subsurface photosynthetically active radiation (light), and meteorological data.

On recovery, the sediment trap samples were split into several subsamples. One split was preserved in formalin for later microscopic examination. The remainder was screened (to remove the few large, intact zooplankton), filtered and rinsed free of preservative, and then the filters were stored frozen until analysis. Samples were analyzed for TOC, TN, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$ using the mass spectrometry facility located at UAF. Certain lipid indicators for phytoplankton and zooplankton sources (wax esters, triglycerides, sterols, fatty acids, fatty alcohols) are being measured to assess the relative extent of grazing of the phytoplankton (Wakeham, 1982). Microscopic examination enumerates intact diatom tests, fecal pellets, and other identifiable items such as zooplankton or their fragments. Zooplankton were collected on most of the mooring deployment /recovery cruises, occurring in February, April, and September. They were sorted to genus or species and analyzed for stable isotopic and lipid composition.

Results and Discussion

Sediment traps have been deployed continuously since late April, 1997, at Site 2 within the middle shelf domain (56°53'N, 164°02'W, 35 m depth of deployment in a 70 m water column). This research was originally supported by NOAA as part of the SEBSCC program. When the field phase of that program ended in early 2001, the Pollock Conservation Cooperative Research Center (PCCRC) provided funding to continue this important time series of observations at Site 2 for 2001-2002. Unfortunately, the summer 2002 samples were lost due to trap damage, apparently caused by fishing gear. In this report the May 2001-February 02 results are compared to the earlier SEBSCC data.

The $\delta^{15}\text{N}$ of zooplankton reflects both their trophic level and the $\delta^{15}\text{N}$ of the phytoplankton (the base of the food web), which in turn depends on the $\delta^{15}\text{N}$ of the nutrients that phytoplankton use for growth (Fry, 1988, Altabet and Francois, 1994). Zooplankton analyses found that the $\delta^{15}\text{N}$ was significantly greater for copepods, euphausiids (krill), and scyphozoan jellyfish in 1997 than in other years at M2 (Fig. 1). Stratification was unusually strong in 1997 due to unusually warm and calm weather conditions, and this resulted in an unusual degree of nutrient depletion at M2. The elevated $\delta^{15}\text{N}$ arose from ^{15}N enrichment of the residual nutrient pool as it was consumed by phytoplankton (e.g., Altabet and Francois, 1994). This interpretation assumes that the $\delta^{15}\text{N}$ of inorganic nitrogen initially available in spring was the same during all years. There is evidence that the fall-winter resupply of nitrate was the same for 1997-2001 (Stabeno et al., 2002), but ammonium concentrations or isotopic composition may have varied (see later discussion). As expected, because they are carnivorous zooplankton, the $\delta^{15}\text{N}$ of scyphozoans and chaetognaths (arrow worms) was usually greater than that of the herbivorous copepods and euphausiids. However, scyphozoan and chaetognath $\delta^{15}\text{N}$ decreased sharply in 2001, to nearly the same values as the herbivores. This decrease was evident at all three sampling times in 2001 (February, May, and

September. Since copepods and euphausiids had about the same $\delta^{15}\text{N}$ from 1998-2001 (Fig. 1), a change in the $\delta^{15}\text{N}$ of nutrients or phytoplankton is probably not the cause. This suggests a change in trophic level

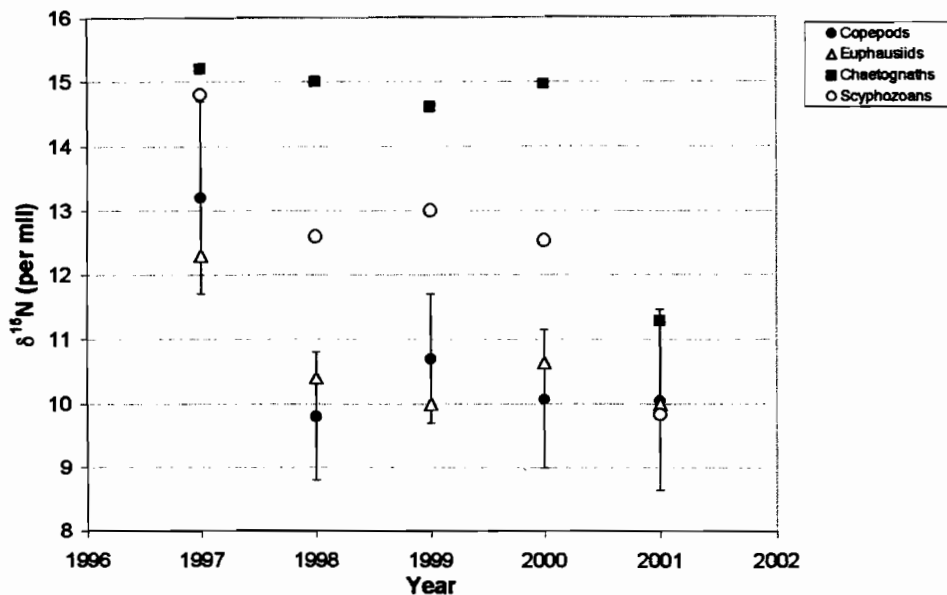


Figure 1. Bering Sea middle shelf zooplankton $\delta^{15}\text{N}$. For clarity, error bars (one standard deviation) are shown only for the copepod data. The variability of other taxa was similar.

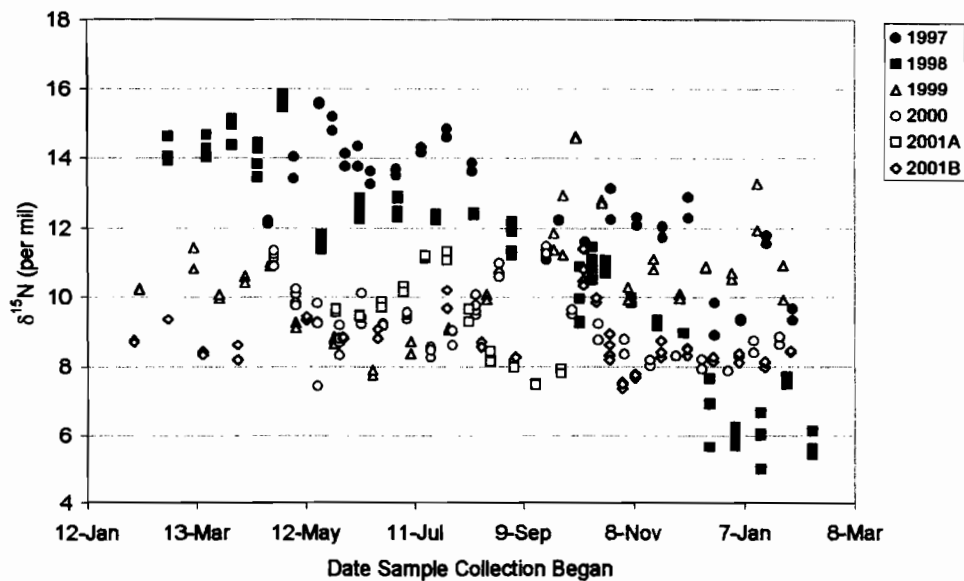


Figure 2. Sediment trap sample $\delta^{15}\text{N}$, Bering Sea middle shelf.

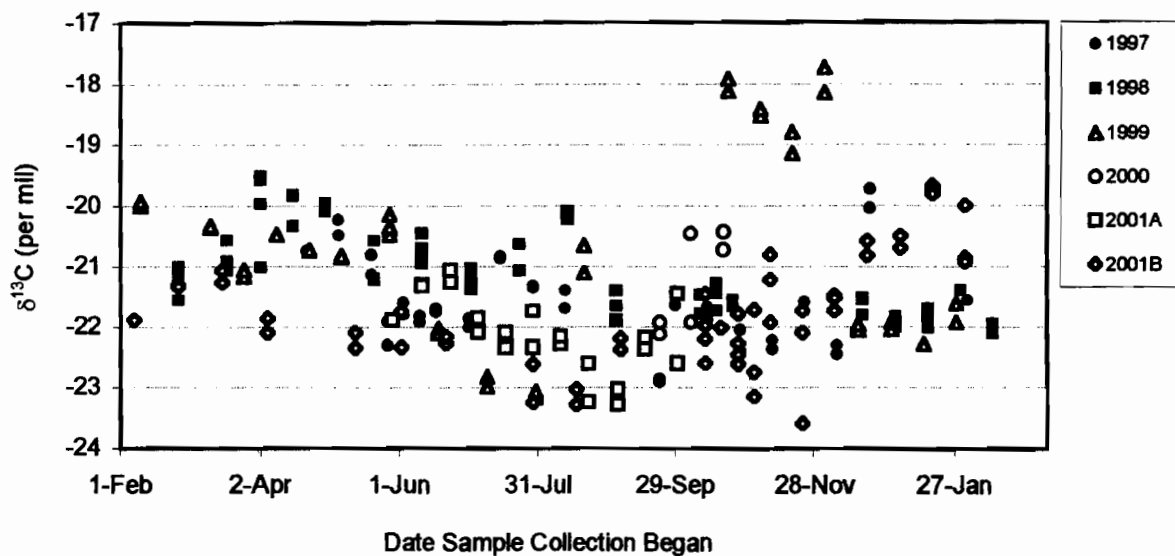


Figure 3. Sediment trap sample $\delta^{13}\text{C}$, Bering Sea middle shelf.

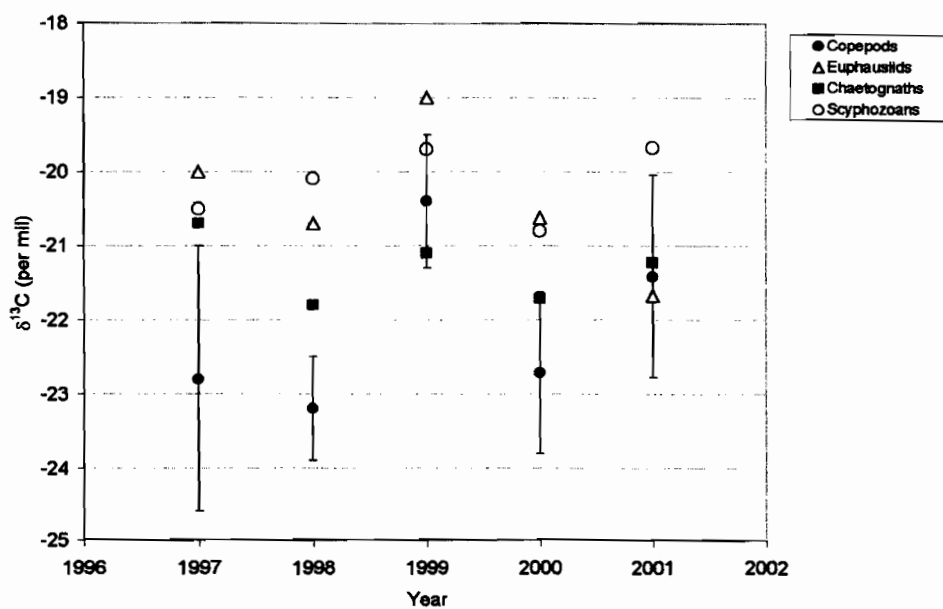


Figure 4. Bering Sea middle shelf zooplankton $\delta^{13}\text{C}$. For clarity, error bars (one standard deviation) are shown only for the copepod data. The variability of other taxa was similar.

of the scyphozoans and chaetognaths in 2001. The cause is unknown, but 2001 was unusual in that winter 2000-01 water temperatures were the warmest of the entire 1995-2002 record, there was no sea ice, and the spring bloom occurred quite late, in mid-May (Stabeno and Hunt, 2002).

The pattern of $\delta^{15}\text{N}$ in the sediment trap samples was clearly different in 1997 and 1998 compared with all later years (Fig. 2). During 1997 and 1998, the $\delta^{15}\text{N}$ of Site 2 sediment trap samples decreased from early spring through summer, fall, and winter (Fig. 2). The value appeared to "reset" abruptly to the annual maximum in February or March; the timing of this event corresponded to the reappearance of intact diatoms and flagellated protozoans in the samples and lipids characteristic of phytoplankton. These appeared before stratification of the water column or the spring phytoplankton bloom, consistent with the early appearance of some water column fluorescence due to chlorophyll (Stabeno et al., 1999; Stabeno and Hunt, 2002). During 1999, 2000, and 2001 there was a $\delta^{15}\text{N}$ decrease from spring to summer, but the values increased again in fall. Most years there was an increase in the sediment trap collection of material and in the numbers of diatoms in the samples during April or May, coincident with water column stratification and a spring bloom. This was associated with decreased $\delta^{15}\text{N}$. The increase of $\delta^{15}\text{N}$ in the fall was associated with the onset of fall mixing and increased collection of phytoplankton remains, including coccoliths and diatoms and their characteristic lipids, by the sediment trap.

During 1997-98, the sediment trap $\delta^{15}\text{N}$ ranged from about 12 to 16 ‰ at Site 2 (Fig. 1). The lower part of this range is consistent with an origin in a combination of sinking diatom aggregates and crustacean fecal material. The higher $\delta^{15}\text{N}$ values may also reflect microbial decomposition of the particles before they entered the traps, or origins from higher trophic level organisms. The $\delta^{15}\text{N}$ of spring and summer, 1999-2001 Site 2 sediment trap samples was about 2 ‰ less than in 1997 and 1998, ranging between 7 and 11 ‰ (Fig. 1). We are as yet not certain what was responsible for this change, but it appears to be linked to changes in nutrient availability (Smith et al., 2002). During 1997, stratification was strong and nutrients were depleted throughout the photic zone, which extended into the pycnocline (Stockwell et al., 2001). Such depletion would result in enrichment of the residual nutrients in ^{15}N (e.g., Altabet and Francois, 1994), leading to the heavy $\delta^{15}\text{N}$ values seen in zooplankton and sediment trap samples in 1997. The spring and summer of 1998 were much stormier, resulting in repeated deep mixing, and high surface water nutrient concentrations through June. Nutrient data are presently available only through 1999, but they suggest that one reason for the interannual differences in $\delta^{15}\text{N}$ was the markedly lower ammonium concentrations in spring of 1999. The source of the elevated ammonium in 1997-98 could be organic matter, with high $\delta^{15}\text{N}$, that sank to the sediment-water interface the previous year and decomposed, releasing ammonium (Whitledge, personal communication). Spring resuspension of that material during storms could lead to distribution of ammonium throughout the water column (Smith et al., 2002).

Geographic and temporal changes in the $\delta^{13}\text{C}$ of zooplankton and bowhead whale baleen has been attributed to geographic (Schell et al., 1998) and temporal (Schell, 2000) changes in the $\delta^{13}\text{C}$ of phytoplankton in the Bering Sea, which in turn were attributed to changes in primary productivity or phytoplankton species composition. Smaller or more slowly growing phytoplankton exhibit greater ^{13}C fractionation, or lighter (more negative) $\delta^{13}\text{C}$, other factors being equal (Laws et al., 1995; Popp et al., 1998). The $\delta^{13}\text{C}$ of sediment trap samples was heavier in 1997-98 than during summer 1999 or 2000-01 (Fig. 3). On the other hand, copepod and euphausiid $\delta^{13}\text{C}$ was heaviest in 1999 (Fig. 4). While the lack of consistency could indicate that $\delta^{13}\text{C}$ is controlled by factors other than phytoplankton composition, sediment traps, collecting biweekly year round, and zooplankton, sampled mainly in spring, reflect different time frames. The annual pattern of $\delta^{13}\text{C}$ in sediment trap samples (Fig. 3) is consistent with a relationship to phytoplankton growth rate, in that $\delta^{13}\text{C}$ tends to be higher during spring and, usually, fall than during the summer when nutrients are usually depleted over the Bering Sea shelf (Stabeno et al., 2002). The $\delta^{13}\text{C}$ values during winter are scattered, probably because resuspended bottom sediment is sometimes present. Our data show that copepods were isotopically lighter from 1997-2001 than those analyzed by Schell et al. (1998), which were sampled during 1985-1990 and 1993-95 (Smith et al. 2002).

This is consistent with the 30-year decrease in $\delta^{13}\text{C}$ of bowhead whale baleen reported by Schell (2000), which he attributed to a decrease in Bering Sea primary productivity.

During fall, the amount of organic matter accumulated by the Site 2 trap showed substantial maxima, comparable to those in spring, which were closely linked in time to increasing wind velocities that resulted in a breakdown of the summer stratification and new nutrient supplies to the photic zone. This observation is consistent with fall fluorescence maxima recorded by the biophysical mooring (Stabeno et al., 1999; Stabeno and Hunt, 2002). Hence, the data so far indicate that the spring bloom may not be the predominant source of organic matter to the benthos of the middle shelf.

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