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Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Fluorescence, pigment and microscopic characterization of Bering Sea phytoplankton community structure and photosynthetic competency in the presence of a Cold Pool during summer

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ARTICLE INFO

Available online 17 December 2013

Keywords:

Bering Sea
Phytoplankton
Taxonomy
Diversity
Sea-ice
Salinity
Temperature
Nutrients

ABSTRACT

Spectral fluorescence measurements of phytoplankton chlorophyll *a* (Chl *a*), phytoplankton phycobilipigments and variable fluorescence (Fv/Fm), are utilized with High Performance Liquid Chromatography (HPLC) estimates of phytoplankton pigments and microscopic cells counts to construct a comprehensive picture of summer-time phytoplankton communities and their photosynthetic competency in the eastern Bering Sea shelf. Although the Bering Sea was ice-free during our study, the exceptionally cold winter that preceded the summer of 2008 when our cruise took place, facilitated the formation of a “Cold Pool” ($< 2^{\circ}\text{C}$) and its entrapment at depth in the northern middle shelf. The presence of a strong pycnocline over the entire middle and outer shelves restricted inorganic nutrient fluxes into the surface waters resulting in phytoplankton populations that were photo-physiologically stressed due to nutrient limitation. Elevated Chl *a* concentrations recorded in the Green Belt along the shelf edge of the Bering Sea, were due to *Phaeocystis pouchetii* and nano-sized cryptophytes. Although inorganic nutrients were not limiting in the Green Belt, Fv/Fm values were low in all probability due to iron limitation. Phytoplankton communities in the low biomass surface waters of the middle shelf were comprised of prasinophytes, haptophytes, cryptophytes and diatoms. In the northern part of the middle shelf, a sinking bloom made up of the centric diatoms *Chaetoceros socialis*, *Thalassiosira nordenskiöldii* and *Porosira glacialis* was located above the Cold Pool. The high biomass associated with this senescent bloom and its accretion above the pycnocline, suggests that the Cold Pool acts as a barrier, preventing sinking phytoplankton from reaching the bottom where they can become available to benthic organisms. We further posit that if summer-time storms are not energetic enough and the Cold Pool is not eroded, its presence facilitates the transfer of the large spring phytoplankton bloom to the pelagic ecosystem.

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1. Introduction

The eastern Bering Sea shelf is one of the most productive marine ecosystems in the world. From an ecosystem perspective, its most defining feature is its highly productive phytoplankton bloom which forms in spring and supports extraordinarily rich stocks of fish, migratory marine birds and mammals (Hunt et al., 2011). Sea food landings from the Bering Sea are extremely large

and have been estimated to account for more than 10% of the world's and about 55% of the U.S. annual seafood harvest (NOAA, 2013).

As with most high-latitude oceanic regions, sea-ice is a key component of the Bering Sea shelf ecosystem. It provides the seed population for the spring bloom and is also responsible for introduction of dissolved iron into the water column which is especially beneficial to the Fe limited High Nutrient Low Chlorophyll (HNLC) waters of the offshore Bering Sea (Aguilar-Islas et al., 2007). Sea-ice also has a huge impact on the upper ocean circulation processes (Zhang et al., 2012) that aid in the advection of nutrients on to the shelf, and in the release of freshwater from

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sea-ice which affects the static stability of the surface ocean and the formation of thermal structures and fronts on the eastern Bering Sea shelf (Kachel et al., 2002). These fronts which start developing in spring, create three distinct hydro-chemical domains, i.e. the inner-shelf, the middle-shelf and the outer-shelf that have been widely used in describing various aspects of the ecosystem of the eastern Bering Sea shelf (Coachman, 1986; Kachel et al., 2002; Sullivan et al., 2008). Phytoplankton growth over the eastern Bering Sea shelf is restricted to an extremely short season, and generally begins when sea-ice begins to retreat. Although growth occurs over a limited period, it is rapid, and greatly favored by increased stability of the water column induced by sea-ice melt water during cold years and thermal stratification during warm years. With the increase in solar radiation, spring-time phytoplankton are able to take advantage of extremely high concentrations of inorganic nutrients to form massive blooms over the wide expanse of the eastern Bering Sea shelf. In cold years, with significant sea-ice after mid-March, there can be two blooms, an early bloom in March–April, and a second bloom in May or June (Stabeno et al., 2010, 2012a) that can result from storm-driven injections of new nitrogen into the upper-water column (Sambrotto et al., 1986). This largely sea-ice dependent explosive growth of phytoplankton strips the entire Bering Sea shelf water column of all its nutrients in a short time. Since nutrient replenishment by vertical transport from the deep is severely constrained by a strong halocline (Aagaard et al., 1981; Woodgate et al., 2005), further biomass accumulation of phytoplankton in summer, especially in the southeastern Bering Sea is generally restricted (Whitledge et al., 1986; Rho et al., 2005). Summer phytoplankton population photosynthesis and growth are thus largely dependent on cross-shelf advective processes including mesoscale eddies that introduce nutrients on to the shelf (Springer et al., 1996; Mizobata and Saitoh, 2004; Okkonen et al., 2004).

While the areal extent and rate of retreat of sea-ice are important determinants of the magnitude of spring phytoplankton blooms, they can also influence environmental conditions that develop over the Bering Sea shelf in the following summer, such as the formation of the Cold Pool (Zhang et al., 2012; Stabeno et al., 2012a,b) and the degree of stratification (Ladd and Stabeno, 2012). The formation of the Cold Pool or bottom waters with temperatures $< 2\text{ }^{\circ}\text{C}$, is tied to the process of stratification which begins in April or May. Once the water column over the middle shelf of the Bering Sea begins to stratify, the warmer surface waters insulate the bottom water layer from warming as the season progresses. The temperature of the bottom layer depends on sea-ice conditions in winter and the temperature of the water column at the onset of stratification in spring (Stabeno et al., 2002, 2007). In cold years (with extensive sea-ice through April), temperatures in the bottom layer or the Cold Pool usually remain below $2\text{ }^{\circ}\text{C}$ throughout summer.

Sea-ice conditions over the Bering Sea are extremely sensitive to small changes in wind velocities and air temperatures. Since the Bering Sea comes under the influence of storms and climatic patterns such as ENSO (Overland et al., 2012), PDO, NAO and the AO (Overland et al., 1999), sea-ice conditions can vary greatly over seasonal, annual, interannual and decadal cycles (Stabeno et al., 2001) and influence phytoplankton communities and the food chain of the Bering Sea. A turning point in the cyclical pattern of Bering Sea sea-ice behavior (Stabeno and Overland, 2001; Overland and Stabeno, 2004) was the onset of the El-Niño in 1997 which had a huge impact on the ecosystem. Following this event, the Bering Sea experienced a rapid melt back of its sea-ice (Stabeno et al., 2001). Anomalous cloud-free conditions, increased solar heating, decreased onshore transport of slope water and reduced number of energetic storms (Stabeno et al., 2001) all acting in consonance during that year, contributed to the

formation of a warm ($\sim 12\text{ }^{\circ}\text{C}$) and stable water column on the shelf in which few nutrients remained to support diatoms (Egge and Aksnes, 1992). These conditions caused a dramatic switch in phytoplankton populations, with profound effects on the rest of the food chain (Baduini et al., 2001; Stockwell et al., 2001). Diatoms were replaced by coccolithophore (i.e. *Emiliana huxleyi*) blooms, which occupied almost the entire continental shelf of the Southeastern Bering Sea (Broerse et al., 2003). The warming ($\sim 3\text{ }^{\circ}\text{C}$) trend persisted into the 2000s and was marked by significant decreases in sea-ice concentrations, ice duration, maximum ice extent and large crustacean zooplankton. This warm period was followed from 2008 to 2011 by a series of cold years, characterized by high ice extent, increases in large copepods and euphausiids, and improved recruitment of pollock and cod (Stabeno et al., 2012a,b). No comparable information is available on phytoplankton communities that would have taken place during the transition from a warm to a cold year. Such information is essential if we are to understand the influence of changing sea-ice patterns on the primary producers and the production pathways of organic matter which support the valuable fisheries of this extensive high-latitude continental shelf (Moran et al., 2012; Lomas et al., 2012).

Here we use high-resolution fluorescence-based estimates of phytoplankton chlorophyll *a* (Chl *a*), three spectral types of phycoerythrin (PE) and phytoplankton photosynthetic competency, coupled with microscopy and High Performance Liquid Chromatography (HPLC) measurements of diagnostic pigment biomarkers of phytoplankton groups for detailed characterization of phytoplankton community structure during the summer of 2008 which was characterized by the presence of a Cold Pool. Hydrographic and chemical data obtained during the cruise are utilized to describe the data in relation to the environmental conditions, in particular, in relation to the Cold Pool that prevailed during the summer of 2008.

This study was part of a NASA supported International Polar Year study on the impacts of sea-ice changes on the bio-optical properties of high-latitude oceans, and allowed us to participate in a Bering Sea Ecosystem Study-Bering Sea Integrated Ecosystem Research Program (BEST/BSIERP) cruise in the summer of 2008. Although there was no sea-ice during our study, residual effects of the cold winter were obvious from the presence of a Cold Pool and remnants of low salinity surface water in the northern regions of the eastern Bering Sea shelf. The ecological role of the Cold Pool is significant for higher trophic organisms and fisheries (Stabeno et al., 2012a). While it can obstruct cross shelf migration of subarctic fish (Kotwicki et al., 2005; Ciannelli and Bailey, 2005), it can act as a corridor for migration of Arctic species to the southeastern shelf (Stabeno et al., 2012a,b). The Cold Pool can possibly affect cross shore transport of nutrients, but its overall impacts on biomass and composition of phytoplankton within and outside of the pool remain unknown.

2. Materials and methods

The data presented in this study were collected on board the US Coast Guard Cutter *Healy* from the 1st to 31st July 2008. The cruise was part of the BEST/BSIERP study of the Bering Sea, a partnership project between the US National Science Foundation and the North Pacific Research Board, Alaska. Continuous hydrographic profiles were obtained at 177 oceanographic stations along a cruise track shown in Fig. 1, using a Sea-Bird Electronics[®] Conductivity–Temperature–Depth (CTD) rosette fitted with $12 \times 30\text{ l}$ Niskin bottles. The cruise track in Fig. 1 is overlaid on 16 marine regions recently delineated by the BEST/BSIERP research community based on a large

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