



Biophysical ocean observation in the southeastern Bering Sea

Kathleen M. Stafford,¹ Sue E. Moore,² Phyllis J. Stabeno,³ D. V. Holliday,⁴ Jeffrey M. Napp,⁵ and David K. Mellinger⁶

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[1] Integrated ocean observation, from physical and atmospheric forcing mechanisms to the distribution and abundance of top-level predators, is critical to the investigation of marine ecosystems and the impact of climate change on them. We integrated data from a biophysical mooring in the southeast Bering Sea to create a one-year snapshot of ocean dynamics in this remote large marine ecosystem. Distinct patterns in production (chlorophyll), zooplankton biovolume (copepods and euphausiids) and the occurrence of zooplankton predators (fin and right whales) were defined and related to discrete features in the annual physical cycle. Peaks in prey and predator cycles were linked to spikes in fluorescence that occurred at the onset of water column stratification in late spring 2006 and the appearance of sea ice in late winter 2007. These data illustrate the capability and potential of integrated ocean observing systems (IOOS) to describe seasonal variability and linkages in a remote marine ecosystem. **Citation:** Stafford, K. M., S. E. Moore, P. J. Stabeno, D. V. Holliday, J. M. Napp, and D. K. Mellinger (2010), Biophysical ocean observation in the southeastern Bering Sea, *Geophys. Res. Lett.*, 37, L02606, doi:10.1029/2009GL040724.

1. Introduction

[2] Rapid changes in global climate are particularly manifest in polar and sub-polar seas, but their effects on ecosystems are poorly understood. The southeastern Bering Sea is a region that has demonstrated remarkable variability in temperature and seasonal sea ice cover over the past decade [Stabeno *et al.*, 2007]. Understanding connectivity between these physical patterns and biological production is essential to predict impacts of climate variability on all trophic levels in this ice-driven ecosystem. Although some marine ecosystem models include higher trophic-level predators (e.g., salmon, pinnipeds), few have incorporated large whales as significant grazers of secondary production (zooplankton). Here, as a demonstration of ocean observation capability, we present a year-long record from a biophysical mooring

in the southeastern Bering Sea that integrates measures of large whale occurrence, zooplankton biovolume, phytoplankton biomass and hydrography, including ice cover.

2. Ocean Observation in the Southeastern Bering Sea

[3] Biophysical moorings have been deployed on the middle shelf of the southeastern Bering Sea since 1995 [Stabeno *et al.*, 2002]. The moorings measure temperature, salinity, nutrients, fluorescence, oxygen, and currents, and are serviced in spring and fall. In April 2006, a passive acoustic recorder and a TAPS-8 multi-frequency zooplankton acoustic profiling system were added to the mooring deployed at the M2 site (Figure 1). The recorder sampled continuously at 2 kHz for an effective bandwidth of 1–970 Hz. Acoustic data were archived *in situ* and were recovered in April 2007. The program XBAT (eXtensible BioAcoustic Tool, <http://xbat.org>) was used to automatically detect diagnostic fin and right whale calls over the one year deployment period. Two types of fin whale calls were modelled for automatic detection: one that swept down from 31.4 to 8.4 Hz over 2.3 s and the other from 40.9 to 23.6 Hz over 2.0 s. Right whale “gunshot” calls were typified as sweeps from 425 Hz to 20 Hz over 3.6 s. All of these call types have been associated with the male of the species [Watkins *et al.*, 1987; Croll *et al.*, 2002; Parks *et al.*, 2005].

[4] The TAPS-8 instrument transmitted data in near-real time to a surface mooring that then communicated via satellite to laboratory. It could not be left over winter, so was recovered in September 2006. The TAPS-8 measures volume backscatter at 8 frequencies from 104–3000 kHz and was programmed to sample every 20 minutes [Holliday *et al.*, 2009; Medwin and Clay, 1998; Simmonds and MacLennan, 2005].

[5] The device was deployed at 18 m, in the surface mixed layer, with the transducers pointed sideways away from the mooring. Daily averages of biovolume ($\text{mm}^3 \text{m}^{-3}$) of scatterers as a function of size (length) were estimated by applying an inverse solution to the matrix of volume backscatter as a function of frequency for two different scattering models, one for copepods (truncated, fluid sphere model) and the other for euphausiids (distorted-wave, Born approximation) [Holliday, 1977; Costello *et al.*, 1989]. Biomass was then estimated by multiplying the biovolume of the scatterers by an appropriate mean density for the individual organisms.

3. Integrated Biophysical Measurements

[6] To integrate the biophysical data we used measures of large whale occurrence (from detections of fin and right

¹Applied Physics Laboratory, University of Washington, Seattle, Washington, USA.

²Office of Science and Technology, NMFS, NOAA, Silver Spring, Maryland, USA.

³Pacific Marine Environmental Laboratory, NOAA, Seattle, Washington, USA.

⁴Graduate School of Oceanography, University of Rhode Island, San Diego, California, USA.

⁵Alaska Fisheries Science Center, NMFS, NOAA, Seattle, Washington, USA.

⁶Cooperative Institute for Marine Resources Studies, Oregon State University and Pacific Marine Environmental Laboratory, NOAA, Newport, Oregon, USA.

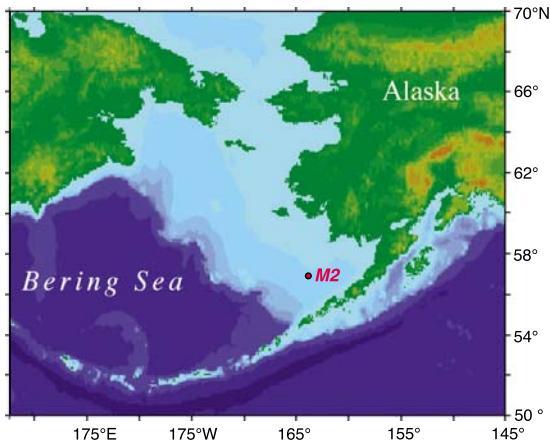


Figure 1. Location of bio-physical mooring in the Bering Sea (M2: 56°40 N, 163°52 W).

whale calls), zooplankton biovolume (acoustic estimates for particles with shapes of euphausiids and copepods), phytoplankton (chlorophyll a, from fluorescence) and hydrography including ice cover from temperature all of which were recorded on instrumentation deployed on long-term moor-

ings in the Bering Sea. The seasonal hydrography on the Bering Sea middle-shelf in 2006/07 was typical, whereby a cold well-mixed ocean gave way to stratification in May (Figure 2, top). The sharp, two-layered system warmed from June through early September, becoming well-mixed again in late October. The water column then became progressively colder from late October through February with sea-ice-returning in March 2007 (indicated by temperatures $< -1^{\circ}\text{C}$). Peaks in chlorophyll fluorescence were associated with late-spring stratification, fall mixing, and late-winter ice formation. The high chlorophyll fluorescence at the advent of sea-ice was likely a result of phytoplankton associated with the sea-ice that activated the sensor positioned at 11 m. Interestingly, peak measures of copepod biovolume occurred in advance of the springtime bloom, with persistence through the warm summer period, while the biovolume of euphausiid-like particles occurred at lower levels through the spring with a peak in mid-summer (Figure 2, middle). The relatively high biovolume preceding the bloom was most likely due to overwintering stages of the copepod *Calanus marshallae* and euphausiid *Thysanoessa raschii*, although our measurements were from a single location and the increases we observed could also have been due to advection of plankton from another part of the shelf where the bloom began earlier. Similarly, an alterna-

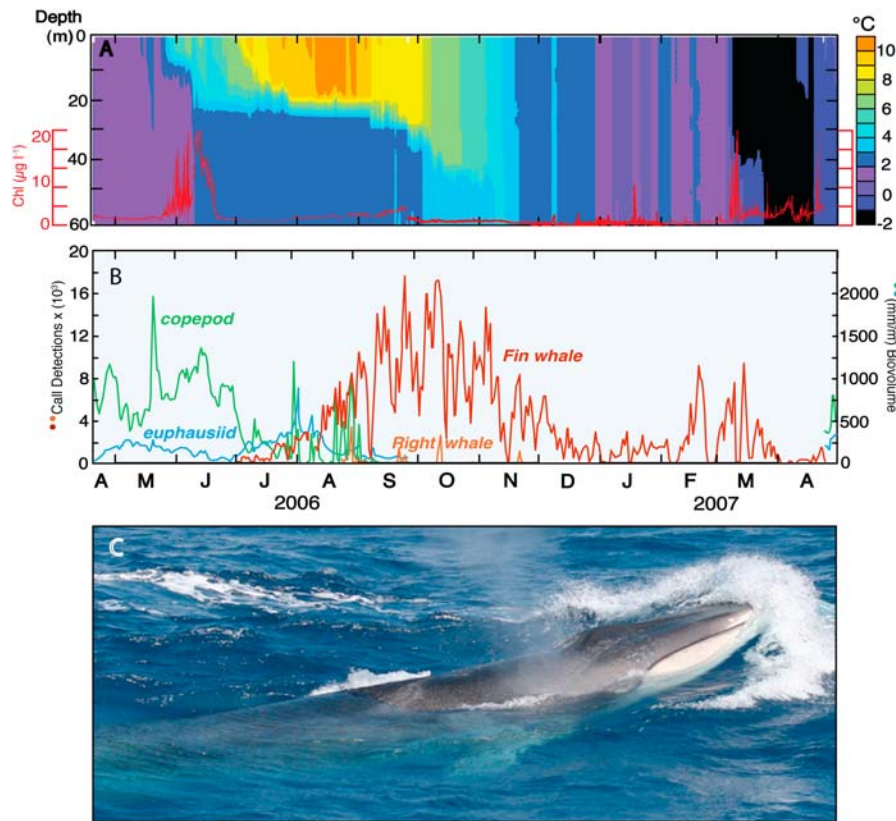


Figure 2. (top) Phytoplankton (chl a $\mu\text{g l}^{-1}$, red line, 11 m depth) and temperature ($^{\circ}\text{C}$, color contour, 11 sensors from 4 m to 60 m depths) April 2006–May 2007; ice covered the mooring when the temperature is shown as black. (middle) Fin and right whale call detections ($\times 10^3$) and biovolume of euphausiid- and copepod-like backscatterers ($\text{mm}^3 \text{m}^{-3}$). (bottom) Fin whale surfacing.

tive explanation is that the increases were due to bloom-independent reproduction by the overwintering organisms (i.e., local production).

[7] Over 1.2 million fin whale calls were detected, with signals received almost continuously from August until instrument recovery at the end of April (Figure 2, middle). There were two peaks in detections: one beginning during the second peak of the euphausiid biomass signal that extended from June to mid-December, and a second smaller peak from mid-February to the beginning of April. Seventeen thousand North Pacific right whale “gunshot” calls were recorded in distinct bouts from June to October, with most calls in August and September following the second peak in copepod biovolume (Figure 2, middle).

[8] Fin (Figure 2, bottom) and right whales were chosen for this study since euphausiids comprise a significant part of the fin whale diet in the Bering Sea, whereas right whales forage primarily on copepods [Nemoto, 1970; Baumgartner and Mate, 2003]. The difference in numbers of calls detected for each species is likely due to the disparity in estimated numbers of whales on the Bering Sea middle shelf: up to 1200 fin whales [Moore et al., 2002] and fewer than 50 right whales (P. R. Wade et al., The world’s rarest whale?, submitted to *Biology Letters*, 2009). Overall, most whale sounds were detected as copepod and euphausiid biovolume declined in late summer and fall, suggesting an increase in calling post-foraging [Payne and Webb, 1971]. While this delay in detection confounds a determination of whale residency on the Bering middle shelf, the seasonal pattern may reflect the whales’ acoustic behavioral ecology, as fin whales produce long-patterned sequences of sound more often in late summer and fall [Stafford et al., 2007]. Similarly, the seasonal pattern in euphausiid and copepod biovolume in the surface waters could be confounded by their movement in the water column away from acoustical detection. Both taxonomic groups are comprised of species that undergo a winter diapause and the apparent declines in biovolume could also reflect a migration to the sea bottom.

4. Conclusions

[9] The integration of biophysical data from hydrography to whales represents a significant step forward in our ability to observe the dynamics of the Bering Sea middle shelf ecosystem. Distinct seasonal patterns in the occurrence of predator and prey were defined, both related to discrete features of the annual physical cycle. Observing and understanding linkages among physical, production and predation cycles is fundamental to the construct of representative ecosystem models. For example, if the number of whale calls detected is used as a proxy for abundance, the strong seasonal signal of fin whales, each of which can consume up to 700–1000 kg krill/day [Hinga, 1979; Barlow et al., 2008], emphasizes the need to include these predators in ecosystem models, especially those that take a top-down approach and those where lower trophic level production is balanced by mortality from unspecified predators. Repeated integrated observations such as those reported here are essential to ecosystem-based investigations and are the hallmark of systems now being planned on national and international levels (e.g., <http://ioos.gov>). Our ability to manage ocean resources in this era of rapid climate change

depends on long-term ocean observation that integrates the system from wind to whales [e.g., Croll et al., 2005].

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- D. V. Holliday, Graduate School of Oceanography, University of Rhode Island, 5034 Roscrea Ave., San Diego, CA 92117, USA.
- D. K. Mellinger, Pacific Marine Environmental Laboratory, NOAA, 2115 SE OSU Dr., Newport, OR 97365, USA.

S. E. Moore, Office of Science and Technology, NMFS, NOAA, 1315 East-West Hwy., Silver Spring, MD 20910, USA.

J. M. Napp, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA.

K. M. Stafford, Applied Physics Laboratory, University of Washington, 1013 NE 40th St., Seattle, WA 98105, USA. (stafford@apl.washington.edu)

P. J. Stabeno, Pacific Marine Environmental Laboratory, NOAA, 7600 Sand Point Way NE, Bldg. 3, Seattle, WA 98115, USA.