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**Continental Shelf Research** 



# Seasonal dynamics of zooplankton in the southern Chukchi Sea revealed from acoustic backscattering strength



CONTINENTAL SHELF RESEARCH

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### ARTICLE INFO

Keywords: Acoustic backscattering strength Chukchi Sea Moored echo-sounder Pelagic-benthic coupling Seasonal changes Zooplankton

## ABSTRACT

To understand the seasonal dynamics of zooplankton in the southern Chukchi Sea, we use observations from a moored multi-frequency echo-sounder from July 2012 to July 2014. Zooplankton biomass, as indicated by area backscattering strength, was high during autumn and low in early spring; the seasonal peak in zooplankton biomass did not coincide with the spring phytoplankton bloom. This suggests that the seasonal zooplankton dynamics in the southern Chukchi Sea are less influenced by local growth of zooplankton during the spring phytoplankton bloom and more influenced by advection of zooplankton from the Bering Sea. The differences between volume backscattering strengths at 200 and 125 kHz suggest that the main acoustic scatterers are large zooplankton (euphausiids and *Neocalanus cristatus*) in late summer and autumn and small zooplankton form winter to early summer also suggests the unsuccessful overwintering of advected Pacific zooplankton. The temporal mismatch between zooplankton and phytoplankton production suggests that there is still tight pelagic–benthic coupling in the southern Chukchi Sea.

#### 1. Introduction

The influence of climate change on the oceanic environment (e.g., increase of water temperature, shrinking ice cover, higher acidity, freshening) is evident in the Arctic Ocean (Comiso, 2011; Steele et al., 2008; Yamamoto-Kawai et al., 2009a, b). These changes affect oceanic biota in a variety of ways, such as increasing annual primary production (Arrigo et al., 2008), increasing macroalgal cover or changes in bivalve growth (Carroll et al., 2011; Kortsch et al., 2012), a northward shift of boreal fish distributions (Fossheim et al., 2015), and increasing numbers of killer whales using the Arctic as a hunting ground (Darnis et al., 2012). Such taxon-specific responses lead to speculation that the Arctic ecosystem is also changing. Tight pelagic-benthic coupling, that is, a direct connection between water-column primary production and the benthic carbon cycle resulting from low biomass in the pelagic community, is one of the characteristic features of the Arctic marine ecosystem, including the Bering Sea (Grebmeier et al., 1988; Renaud et al., 2008). The ecosystem in the northern Bering Sea, however, is shifting away from this coupling (Grebmeier et al., 2006b), whereas tight coupling is still observed in the coastal area of the Canadian Arctic (Darnis et al., 2012). It is not clear whether this coupling is still tight in other areas of the Arctic Ocean.

Low zooplankton biomass is one of the key factors contributing to tight pelagic-benthic coupling (e.g., Grebmeier et al., 1988), and zooplankton biomass is expected to be influenced by climate change. However, the number of documented changes in Arctic zooplankton is surprisingly low, and the baseline information for Arctic zooplankton is poorly understood (Wassmann et al., 2011). The seasonality of zooplankton populations-especially the timing of population increases and decreases-is one of the baseline characteristics needed to discuss whether there is still tight pelagic-benthic coupling because it will directly influence export production of organic carbon to the underlying benthos (Grebmeier, 2012). Previously, Hamilton et al. (2013) acoustically observed the seasonality of zooplankton biomass in Barrow Strait, in the eastern Canadian Arctic Archipelago. Ashjian et al. (2003) conducted yearlong zooplankton sampling to describe its abundance near ice camp SHEBA, which drifted from the Canadian Basin over the Northwind Ridge and Chukchi Plateau. However, there have been no descriptions of zooplankton seasonality in the Chukchi Sea.

In this study, we observed the seasonality of zooplankton biomass over a period of two years in the southern Chukchi Sea, which is the most productive area in the Pacific Arctic (Grebmeier et al., 2006a). To investigate any correspondence or offset in the timing of zooplankton biomass and phytoplankton blooms, observations should comprise a

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http://dx.doi.org/10.1016/j.csr.2016.12.009

Received 21 April 2016; Received in revised form 7 December 2016; Accepted 17 December 2016 Available online 20 December 2016 0278-4343/ © 2016 The Authors. Published by Elsevier Ltd.

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continuous timeseries that includes spring data. Because we had no opportunity to collect continuous and springtime data by shipboard observations, we collected data using moorings with an attached echosounder together with environmental sensors. There have been several sets of biological observations in the Arctic Ocean and its marginal seas using a moored acoustic device owing to its usefulness in barely accessible areas such as seasonal ice zones. However, most of these studies focused on the diel vertical migration of zooplankton (Berge et al., 2009, 2015; Cottier et al., 2006; Fisher and Visbeck, 1993; Wallace et al., 2010); descriptions of zooplankton seasonality are still rare.

Although our acoustic data include diel vertical migration signals. we do not discuss diel vertical migration in this paper. Our goals were to describe the present state of the seasonality of zooplankton biomass as baseline information and to discuss the influence of zooplankton on pelagic-benthic coupling in the southern Chukchi Sea. Acoustic backscattering strength from zooplankton and fish is known to be dependent on target size, anatomical characteristics and orientation, and the frequency of the incident sound (Lavery et al., 2007; Stanton et al., 1994). These dependences can be used to make inferences about the classification of target organisms and their size distribution (De Robertis et al., 2010; Holliday et al., 1989). Recent studies have used the differences in backscatter measurements at multiple frequencies to attempt to identify the scatterers (e.g., De Robertis et al., 2010; Lavery et al., 2007). In this study, we attempted to identify the dominant scatterers in the southern Chukchi Sea and how they are affected by the seasonal dynamics of the zooplankton community.

#### 2. Material and methods

#### 2.1. Study site

The Chukchi Sea is a shallow, marginal Arctic sea connected to the Bering Sea and strongly influenced by Pacific waters. Generally, the Pacific waters in the Chukchi Sea can be classified into two water types: Alaskan Coastal Water and Bering Sea Water (Coachman et al., 1975). The former is relatively warm, less saline, and more nutrient-limited, flowing on the eastern side of the Chukchi Sea with several branches flowing into the central Chukchi Sea. Bering Sea Water originates from a mixture of more saline, nutrient-rich Anadyr Water and Bering Shelf Water with intermediate salinity, entering the Chukchi Sea through the Bering Strait. The northward transport of these waters at the Bering Strait is strongest in summer and weakest in winter (Hunt et al., 2013). Along the western edge of the Chukchi Sea, the fresh, cold Siberian Coastal Current flows southward in some years and is deflected into the central Chukchi Sea (Weingartner et al., 1999). A water mass with extremely low temperature ( < -1.6 °C) during winter is known as Pacific Winter Water (Pisareva et al., 2015).

Regional hydrography and marine organisms are also influenced by sea-ice dynamics. Satellite data from the Special Sensor Microwave/ Imager (SSM/I) (see next section) over the last decade (2004–2014) revealed that ice melting at our mooring site starts between May and early June, whereas ice formation begins from mid-November to mid-December. Recent airborne surveys showed a mean sea-ice thickness of 2 m although extremely thick ice (>5 m) was sometimes observed in the Chukchi Sea (Hass et al., 2010).

#### 2.2. Mooring observations and satellite-derived data

Mooring observations were conducted at station SCH in Hope Valley in the southern Chukchi Sea from July 2012 to July 2014 (Fig. 1). To monitor the dynamics of sound scatterers, we deployed a multifrequency upward-looking echo-sounder (Acoustic Zooplankton Fish Profiler [AZFP]; ASL Environmental Sciences, Victoria, British Columbia, Canada; see Lemon et al., 2012) 7 m above the sea bottom (Table 1). To ensure continuous data collection, two identical AZFPs

were deployed alternately. Although our AZFPs collected data at 125, 200, 455, and 769 kHz, we were not able to use acoustic data from 455 or 769 kHz because of mechanical problems with the transducers.

Acoustic data were collected using the settings listed in Table 2. Acoustic sampling cell resolutions were  $0.5 \text{ m} \times 30 \text{ s}$  (pings) for the first deployment and  $0.2 \text{ m} \times 15 \text{ s}$  (pings) for the second and third deployments. Because the beam angle is 8°, sampling volumes were calculated as ranging from  $0.1 \text{ m}^3$  (at 5 m from the AZFP) to  $6.6 \text{ m}^3$  (at 10-m depth) for the first deployment and from  $0.1 \text{ to } 4.0 \text{ m}^3$  for the second and third deployments. The AZFPs were calibrated by the manufacturer before each deployment using a hydrophone and a secondary source (Lemon et al., 2012). Before the third deployment, a secondary calibration check in a tank (Lemon et al., 2012) was also performed using a 12.7-mm-diameter tungsten carbide sphere. The secondary calibration check showed calibration errors at 125 and 200 kHz of 0.8 and 0.0 dB, respectively.

Luo et al. (2000) and Hamilton et al. (2013) suggested that acoustic devices were capable of sensing organisms with minimum lengths of 1 and 0.5 mm at 153 and 307 kHz, respectively, or about one-tenth of the wavelengths. Following this suggestion, the lower detection limits for our 125 and 200 kHz AZFP would be approximately 1.2 and 0.8 mm, respectively. In contrast, Emery and Thomson (2001) noted that objects larger than about one-quarter wavelength will reflect sound, whereas objects smaller than this scatter the sound. The detectability of scatterers depends on the signal-to-noise ratio (SNR) (Furusawa et al., 1999), and a high population density of scatterers can produce a high SNR even if the individual scatterers are small.

A conductivity-temperature-depth sensor (SBE37-SM; Sea-Bird Electronics, Bellevue, Washington, USA) and a chlorophyll/turbidity sensor (INFINITY-CLW; JFE Advantech Co., Ltd, Nishinomiya, Hyogo, Japan) were attached to the AZFP frame. Environmental data were collected every hour using these sensors. For our purposes, the chlorophyll data were only used to show the timing of phytoplankton activity and as an indicator of relative chlorophyll concentrations.

Daily satellite-derived sea-ice concentration data from the SSM/I were obtained from the National Snow and Ice Data Center (http://nsidc.org; last accessed 7 Sep 2016). Satellite-derived sea surface temperatures (SSTs) from the Moderate Resolution Imaging Spectroradiometer were obtained from the Distributed Active Archive Center of Goddard Space Flight Center, National Aeronautics and Space Administration (http://modis.gsfc.nasa.gov/; last accessed 8 Sep 2016).

#### 2.3. Acoustic data analysis

Acoustic data were converted to volume backscattering strengths (dB re 1 m<sup>-1</sup>) by using the AzfpLink software (ASL Environmental Sciences, 2016). Volume backscattering strength is the logarithmic version of the volume backscattering coefficient,  $s_{\nu}$  (m<sup>-1</sup>), which is the sum of the backscattering cross-section of all scatteres in the ensonified volume. For this conversion, we used calibration coefficients, sound speed, and absorption coefficients specific to each deployment. The sound speed (Mackenzie, 1981) and the absorption coefficients (Francois and Garrison, 1982) were average values calculated from conductivity-temperature-depth sensor profiles obtained near each mooring site at the beginning and end of each deployment. Files with volume backscattering strength data in comma-separated-value format created by the AzfpLink software were further analyzed using MATLAB software. The volume backscattering strength obtained includes back-scatter derived from scatterers (signal) and noise as follows:

$$S_{\nu,meas} = 10\log_{10}(10^{(S_{\nu,signal}/10)} + 10^{(S_{\nu,noise}/10)}),$$
(1)

where  $S_{v, meas}$  is the volume backscatter recorded by the AZFP,  $S_{v, signal}$  is the contribution from scatterers, and  $S_{v, noise}$  is the contribution from noise (De Robertis and Higginbottom, 2007). The

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