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Benthic macrofaunal production for a typical shelf–slope–basin region in the western Arctic Ocean

Heshan Lin, Jianjun Wang*, Kun Liu, Xuebao He, Junhui Lin, Yaqin Huang, Shuyi Zhang, Jianfeng Mou, Chengxing Zheng, Yu Wang

Laboratory of Marine Biology and Ecology, Third Institute of Oceanography, State Oceanic Administration, Xiamen 361005, China

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ABSTRACT

Secondary production by macrofaunal communities in the western Arctic Ocean were quantified during the 4th and 5th Chinese Arctic Scientific Expeditions. The total production and P/B ratio for each sector ranged from 3.8 (±7.9) to 615.6 (±635.5) kJ m^{-2} yr^{-1} and 0.5 (± 0.2) to 0.7 (± 0.2) yr^{-1}, respectively. The shallow shelves in the western Arctic Ocean exhibited particularly high production (178.7–615.6 kJ m^{-2} yr^{-1}), particularly in the two "hotspots" – the southern and northeastern (around Barrow Canyon) Chukchi Sea. Benthic macrofaunal production decreased sharply with depth and latitude along a shelf–slope–basin transect, with values of 17.0–269.8 kJ m^{-2} yr^{-1} in slope regions and 3.8–10.1 kJ m^{-2} yr^{-1} in basins. Redundancy analysis indicated that hydrological characteristics (depth, bottom temperature and salinity) and granulometric parameters (mean particle size, % sand and % clay) show significant positive/negative correlations with total production. These correlations revealed that the dominant factors influencing benthic production are the habitat type and food supply from the overlying water column. In the Arctic, the extreme environmental conditions and low temperature constrain macrofaunal metabolic processes, such that food and energy are primarily used to increase body mass rather than for reproduction. Hence, energy turnover is relatively low at high latitudes. These data further our understanding of benthic production processes and ecosystem dynamics in the context of rapid climate change in the western Arctic Ocean.

1. Introduction

Marine invertebrates represent an important link in matter cycling and energy flow from primary producers to fish, even for top consumers in the marine food chain (Brey, 1990). Benthic macrofaunal production, the incorporation of organic matter or energy per unit of time and area (Cusson and Bourget, 2005), is an important pathway in the energy flow through ecosystems. As a result, production measures are more functionally-based than biomass measures and have assumed a fundamental role in the quantification of ecosystem dynamics (Tumbiolo and Downing, 1994; Bolam et al., 2010). Analyzing the different components that contribute to benthic production and how this production is affected by external factors is very important for understanding ecosystem dynamics and function under environmental and anthropogenic stress (Dolbeth et al., 2012).

A number of empirical methods have been proposed and improved to estimate benthic macrofaunal production (Robertson, 1979; Brey, 1990, 2001; Edgar, 1990; Sprung, 1993; Tumbiolo and Downing, 1994). These empirical models are largely based on population features (e.g., biomass, lifespan) and environmental variables (e.g., depth, temperature, habitat type). Recent studies have successfully predicted productivity values and spatial distribution using these empirical models (Cusson and Bourget, 2005; Bolam et al., 2010; Bolam and Eggleton, 2014; Zhang et al., 2011).

The western Arctic Ocean, including the Chukchi Sea and Beaufort Sea, is mainly influenced by seasonal ice cover and the nutrient-rich Pacific waters advected over the shelves of the Bering Strait (Grebmeier et al., 2006). The annual primary production of the western Arctic Ocean is estimated to range from <50 to 800 g C m^{-2} yr^{-1} (Hill and Cota, 2005). For secondary production in this area, there are few studies using benthic macrofaunal production. Previous studies mainly focused on pelagic production via zooplankton (Sakshaug, 2004; Slagstad et al., 2011; Leu et al., 2011; Wassmann, 2011). Slagstad et al., 2011 found that pelagic production changes were unevenly distributed spatially during future warming with the most significant increases occurring along the Eurasian shelves and the Chukchi Sea. It has been reported that the Arctic shelf exhibits very high biomass (Grebmeier

* Corresponding author.
E-mail addresses: linheshan@tio.org.cn (H. Lin), wangjianjun220@tio.org.cn (J. Wang).

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et al., 1988; Blanchard et al., 2013; Wang et al., 2014a, 2014b) due to the input of nutrient-rich seawater from the Pacific Ocean during the summer (Grebmeier et al., 2006).

Pelagic-benthic coupling is regarded as a crucial process in the Arctic ecosystem. This process determines the food supply transmitted from the overlying water column to the seabed, which directly impacts benthic macrofaunal production. Major environmental factors, including depth, water mass, food supply, organic matter, substrate type and grain size, affect the Arctic benthic ecosystem (Brockington and Clarke, 2001; Bates et al., 2005; Carroll et al., 2008). Piepenburg, 2005 noted that the major factor affecting the benthos in the Arctic deep sea is energy limitation caused by a very limited organic matter supply to the seabed.

In recent decades, the extent and thickness of ice cover in the Arctic regions have been rapidly decreasing (ACIA, 2005). Climate change may alter environmental factors (e.g., water mass, temperature, ice cover) and the pelagic-benthic coupling processes, which ultimately affect benthic production (Macdonald, 1996). In this study, we set out to answer two questions: 1) What is the spatial variability of benthic macrofaunal production in the western Arctic Ocean along a shelf–slope–basin transect? and 2) Is there a quantifiable relationship between the spatial differences in benthic macrofaunal production and environmental factors? The quantitative data on benthic macrofaunal production we obtained should enhance our understanding of benthic production processes and ecosystem dynamics in the context of rapid climate change.

2. Methods

2.1. Survey area

Macrofaunal samples were collected at 65 stations in the Chukchi Sea, Beaufort Sea and Arctic Ocean (Fig. 1) while aboard the R/V *Xuelong* during the 4th CHINARE (Chinese National Arctic Research Expedition, July to September 2010) and 5th CHINARE (July to September 2012). Forty stations at depths of 26–126 m were located on the Chukchi shelf, which was divided into 4 sectors comprising the southern (SC1-14), central (CC1-11), northeastern (BC1-7) and northern (NC1-8) Chukchi Sea. Five stations were located on the Chukchi slope (CS1-5), at depths of 170–809 m. Eleven stations were located on the Arctic Ocean basin (AB1-11), at depths of 2016–4000 m. The other stations were located on the Beaufort shelf (WB1), slope (BS1) and basin (BB1-7), at depths of 46–3890 m. In total, there were 9 sectors: SC, CC, BC, NC, CS, AB, WB, BS and BB. To facilitate discussion, abbreviations for specific regions were adopted (see Fig. 1).

2.2. Sampling methodology

One sample was collected at each station using a 0.25 m^2 box corer (50 cm × 50 cm × 60 cm). Each sample was rinsed through 0.5 mm mesh sieves, and the residue containing the benthic macrofauna was fixed in 7% formaldehyde for later processing in the laboratory. Macrofauna were identified to the lowest possible

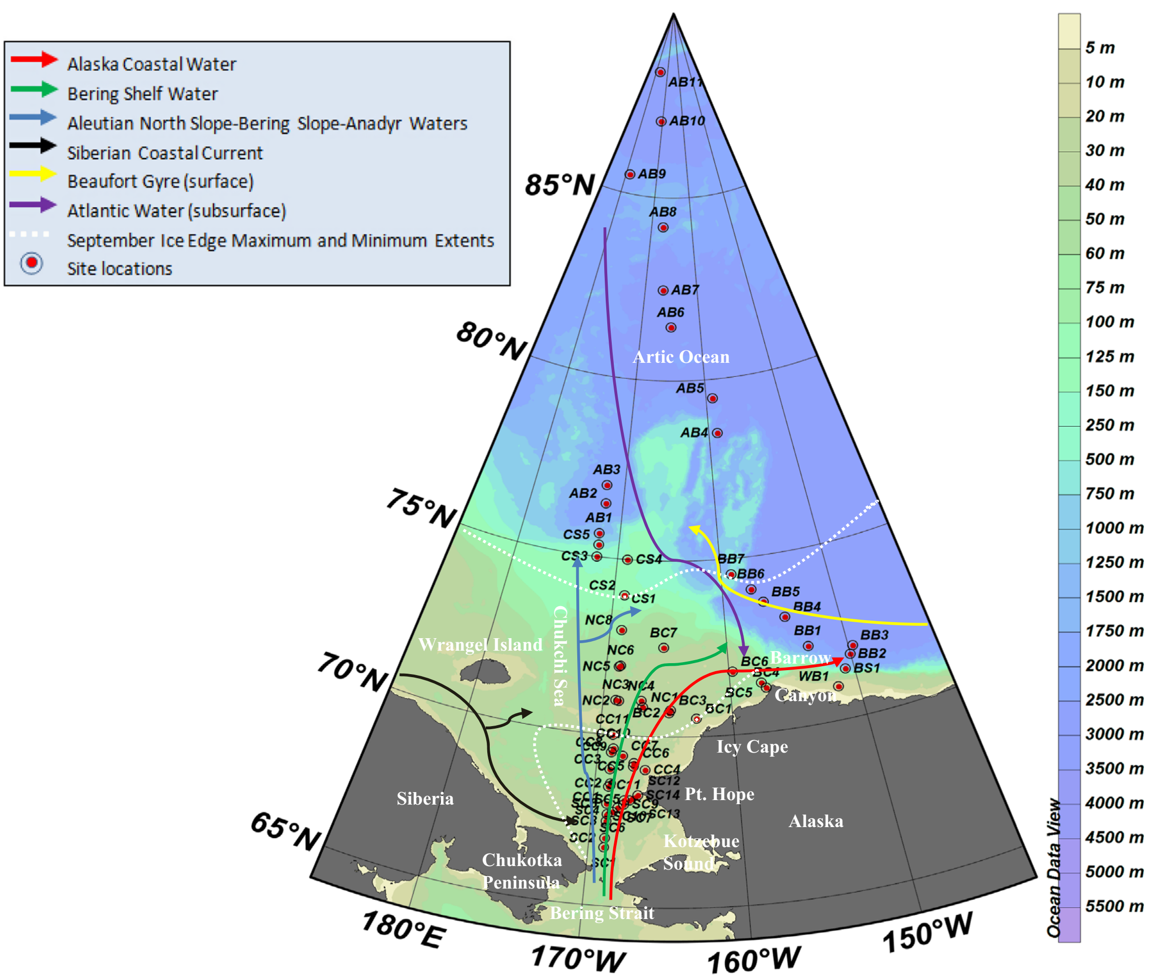

Fig. 1. Map of the western Arctic Ocean, showing sampling locations, water mass types and extent of sea ice (modified from the map provided by Tom Weingartner and Seth Danielson, University of Alaska Fairbanks). SC, southern Chukchi shelf; CC, central Chukchi shelf; BC, northeastern Chukchi shelf (Barrow Canyon); NC, northern Chukchi shelf; CS, northern Chukchi slope; AB, Arctic Ocean basin; WB, western Beaufort shelf; BS, western Beaufort slope; BB, western Beaufort basin.