Deep-Sea Research Part II 135 (2017) 27–39

Contents lists available at ScienceDirect

Deep–Sea Research II

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

Spatial heterogeneity in zooplankton summer distribution in the eastern Chukchi Sea in 2012–2013 as a result of large-scale interactions of water masses

Alexei I. Pinchuk[a,*], Lisa B. Eisner[b]

[a] College of Fisheries and Ocean Sciences, Fisheries Division, University of Alaska, 17101 Pt. Lena Loop Rd, Juneau AK 99801, USA
[b] Alaska Fisheries Science Center, NOAA, 7600 Sand Point Way, Seattle, WA 98115, USA

ARTICLE INFO

Keywords:
Arctic
Advection
Thermal regime
Zooplankton

ABSTRACT

Interest in the Arctic shelf ecosystems has increased in recent years as the climate has rapidly warmed and sea ice declined. These changing conditions prompted the broad-scale multidisciplinary Arctic Ecosystem integrated survey (Arctic Eis) aimed at systematic, comparative analyses of interannual variability of the shelf ecosystem. In this study, we compared zooplankton composition and geographical distribution in relation to water properties on the eastern Chukchi and northern Bering Sea shelves during the summers of 2012 and 2013. In 2012, waters of Pacific origin prevailed over the study area carrying expatriate oceanic species (e.g. copepods *Neocalanus* spp., *Eucalanus bungii*) from the Bering Sea outer shelf well onto the northeastern Chukchi shelf. In contrast, in 2013, zooplankton of Pacific origin was mainly distributed over the southern Chukchi shelf, suggesting a change of advection pathways into the Arctic. These changes also manifested in the emergence of large lipid-rich Arctic zooplankton (e.g. *Calanus hyperboreus*) on the northeastern Chukchi shelf in 2013. The predominant copepod *Calanus glacialis* was composed of two distinct populations originating from the Bering Sea and from the Arctic, with the Arctic population expanding over a broader range in 2013. The observed interannual variability in zooplankton distribution on the Chukchi Sea shelf may be explained by previously described systematic oceanographic patterns derived from long-term observations. Variability in oceanic circulation and related zooplankton distributions (e.g. changes in southwestward advection of *C. hyperboreus*) may impact keystone predators such as Arctic Cod (*Boreogadus saida*) that feed on energy-rich zooplankton.

1. Introduction

Interest in the Arctic shelf has increased in recent years as the climate has rapidly warmed and sea ice declined. These changes may lead to potential increases in shipping, resource extraction (e.g. oil and gas) and commercial fishing (Moran and Farrell, 2011) which could affect Arctic ecosystems. A greater understanding of lower trophic level functioning including zooplankton ecology is needed to characterize these Arctic shelf habitats and monitor future changes relating to climate and/or anthropogenic impacts.

The northern Bering and Chukchi seas connect the Pacific and Arctic oceans. The majority of the area consists of shallow (< 60 m depth) shelves lacerated with Herald and Barrow underwater canyons in the northwest and northeast respectively, while Herald and Hanna shoals separated by the moderately deep Central Channel dominate the underwater landscape in the north (Fig. 1). The Chukchi Sea is not strictly bounded by land and it does not have a gyre-type circulation characteristic of the neighboring Bering and Okhotsk seas (Stabeno et al., 1999; Ohshima et al., 2004). Instead, primarily one-directional currents flow northward due to differences in sea level between the Pacific and the Arctic (Aagaard et al., 2006; Coachman et al., 1975; Stigebrandt, 1984). The bottom topography defines three major pathways of the Pacific Water across the Chukchi shelf splitting the incoming flow into Herald, Central and Alaska Coastal outflows (Weingartner et al., 1998; Woodgate et al., 2005). Because the northern Bering and Chukchi shelves are shallow, local winds play a major role in the redistribution of water properties. Wind can retard the general south to north flow through the Bering Strait, sometimes entirely blocking or reversing it (Panteleev et al., 2010). Similarly, westward oriented winds can divert the Bering inflow onto the western Chukchi shelf, and weaken or reverse flow over the northeastern Chukchi shelf (Weingartner et al., 1998; Pisareva et al., 2015). As a result, the

* Corresponding author.
E-mail address: aipinchuk@alaska.edu (A.I. Pinchuk).

http://dx.doi.org/10.1016/j.dsr2.2016.11.003

Available online 11 November 2016
0967-0645/

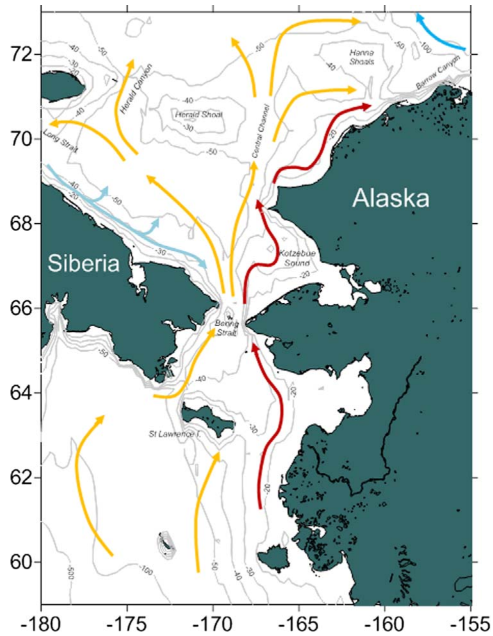

Fig. 1. A schematic diagram water circulation on the Northern Bering – Chukchi shelf (red – Alaska Coastal Current, yellow – Bering Shelf, Anadyr and Chukchi Shelf Water pathways, light blue – Siberian Coastal Current, deep blue – Beaufort Gyre) (after Danielson et al., this volume, modified). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

variability in the pelagic environment can be large and difficult to assess, especially when using datasets collected over short temporal and spatial scales. Recent analyses of Chukchi Sea thermal conditions based on basin-wide observations conducted during the last six decades reveal multi-year fluctuations between two opposite ("cold" vs "warm") states during summer months (Luchin and Panteleev, 2014). In the eastern Chukchi Sea, the contrast between the thermal states was strongly manifested north of 70 °N, where difference in mean temperature amounted to 5 °C (Luchin and Panteleev, 2014). Temperature distributions for each state suggested intensified flow of the Pacific Water along the Alaskan coast towards Barrow Canyon during "warm" states, while during the "cold" states most of the Pacific Water is deflected westward, to be funneled through Herald Canyon (Luchin and Panteleev, 2014). Such shifts in the magnitude and distribution of fundamental physical properties directly affect pelagic communities, including zooplankton.

Due to geographical proximity, water masses in the northern Bering and Chukchi seas are formed by similar processes (Luchin and Panteleev, 2014) and typically have distinct temperature and salinity characteristics. Water masses entering the Chukchi Sea through the Bering Strait include warmer, fresher Alaska Coastal Water flowing along the eastern shore and Anadyr/Bering Summer Water with moderate temperatures and salinities. Upon entering, the latter eventually transforms into Chukchi Summer Water with similar properties. In contrast, Melt Water is colder fresher water in the surface layer formed by melting of sea ice and is restricted to the northernmost Chukchi Sea during summer. Finally, near-bottom cold and salty Bering and Chukchi Winter Waters are remnants of the previous winter cooling and considered resident to the corresponding shelves. The contrasting properties of these water masses restrict mixing and promote a tendency for water masses to overlay each other along their boundaries, even in the vicinity of constricted and turbulent Bering Strait (Pinchuk, 1993). These water masses also contain different nutrient concentrations, phytoplankton biomass and primary productivity (Danielson et al., 2016; Eisner et al., 2013; Springer and McRoy, 1993; Grebmeier et al., 2006) providing diverse habitats for zooplankton and their predators (e.g. fish, marine mammals and seabirds).

Distinct zooplankton taxa assemblages in the Chukchi Sea and their affinity to certain water masses have been reported by multiple studies as early as the 1930s (e.g. Stepanova, 1937; Brodsky, 1950; Wirketis, 1952; Pavshtiks, 1984). Those pioneering studies agreed that the Bering Sea Shelf (including Anadyr) waters, while also populated with wide-spread shelf species (e.g. *Calanus glacialis*) among others, are, nevertheless, best characterized by large (> 4 mm) oceanic copepods *Neocalanus* spp. and *Eucalanus bungii*, which originate from the Bering Sea outer shelf and are excellent tracers of Pacific intrusion into the high Arctic. In contrast, the large copepods *Calanus hyperboreus, Pareuchaeta glacialis* and *Metridia longa* originate from the Arctic Basin, and, thus serve as reliable indicators of Arctic-derived waters in the Chukchi Sea (Brodsky, 1950). It has been noted that, spatially, these two groups are somewhat distinctive and are likely reflective of complex local interactions between the water masses they inhabit (Wirketis, 1952). The neritic assemblage associated with Alaska Coastal Water typically is composed of small (< 2 mm) copepods and, in addition to the widespread *Oithona* spp., *Pseudocalanus* spp. and *Acartia longiremis*, is best characterized by nearshore *Centropages abdominals, Epilabidocera amphitrites, Tortanus discaudatus, Acartia clausi* and cladocerans *Evadne* spp. and *Podon* spp. (Wirketis, 1952).

Since these early studies, numerous attempts have been made to clarify the taxonomic composition of zooplankton communities in the Chukchi Sea and to quantify these distributional patterns at various scales, resulting in one fundamental conclusion: Chukchi Sea zooplankton are largely comprised of Bering Sea zooplankton with only a relatively minor contribution of resident Arctic fauna (Hopcroft et al., 2010; Eisner et al., 2013; Questel et al., 2013; Ershova et al., 2015a, b). However, most surveys were restricted to the short ice-free period and were conducted along a handful of transects typically running from nearshore onto the shelf. It comes as no surprise that high variability was observed along discrete sampling locations over the years (Questel et al., 2013; Ershova et al. 2015a), thus limiting our understanding of zooplankton dynamics at basin-wide scales. Recent changes in the extent and duration of ice cover resulted in a number of surveys covering substantial parts of the Chukchi shelf with sampling grids, allowing comparisons on a quasi-synoptic scale (Eisner et al., 2013; Slabinsky and Figurkin, 2014; Matsuno et al., 2016).

The Arctic Ecosystem integrated survey (Arctic Eis) program was launched in 2012 to document the zooplankton, bottom and pelagic fish and invertebrates, understand the environmental forcing that impacts northern Bering and Chukchi Sea ecosystems and predict the future effects of reduced sea ice and warming on these ecosystems. This survey covered most of the northern Bering and Chukchi seas east of the international border and extended as far north as 72.5°N. The 2012/2013 project was a natural experiment displaying the interplay between two years with contrasting oceanographic conditions on the eastern Chukchi shelf resulting from differences in prevailing wind fields (Danielson et al., 2016). We hypothesized that shifts in water mass distribution markedly affected the distribution of expatriate and resident zooplankton taxa both in terms of spatial coverage and relative abundance/biomass, altering the role of Arctic species on the northeastern Chukchi shelf. Our study is unique in combination of high spatial resolution and broad spatial coverage extending to the understudied northeastern-most Chukchi Sea shelf.

2. Methods

Samples were collected in the Chukchi and northern Bering seas between 8 August and 24 September in 2012 and 2013.The sampling design was based on a square grid pattern with stations located 56 km apart, resulting in a total of 139 and 134 sampling locations in 2012 and 2013, respectively. Sampling started in the Bering Strait and continued northward along zonal (east-west) transects up to 72.5°N