Deep–Sea Research Part II 144 (2017) 37–51

Contents lists available at ScienceDirect

Deep–Sea Research II

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

Physical control of the distributions of a key Arctic copepod in the Northeast Chukchi Sea

Stephen M. Elliott[a,*], Carin J. Ashjian[a], Zhixuan Feng[a], Benjamin Jones[a], Changsheng Chen[b], Yu Zhang[b]

[a] Woods Hole Oceanographic Institution, 266 Woods Hole Road, Woods Hole, MA 02543-1050, USA
[b] University of Massachusetts Dartmouth, 706 S. Rodney French Blvd, New Bedford, MA 02744-1221, USA

ARTICLE INFO

Keywords:
Mesozooplankton
Calanus
Advection
Distribution
Arctic Ocean
Chukchi Sea
Hanna Shoal

ABSTRACT

The Chukchi Sea is a highly advective regime dominated by a barotropically driven northward flow modulated by wind driven currents that reach the bottom boundary layer of this shallow environment. A general northward gradient of decreasing temperature and food concentration leads to geographically divergent copepod growth and development rates between north and south. The physics of this system establish the biological connection potential between specific regions. The copepod *Calanus glacialis* is a key grazer, predator, and food source in Arctic shelf seas. Its summer distribution and abundance have direct effects on much of the food web, from phytoplankton to migrating bowhead whales. In August 2012 and 2013, *C. glacialis* distributions were quantified over Hanna Shoal in the northeast Chukchi Sea. Here an individual-based model with Lagrangian tracking and copepod life stage development capabilities is used to advect and develop these distributions forward and backward in time to determine the source (production locations) and sink (potential overwintering locations) regions of the transient Hanna Shoal *C. glacialis* population. Hanna Shoal supplies diapause competent *C. glacialis* to both the Beaufort Slope and the Chukchi Cap, mainly receives juveniles from the broad slope between Hanna Shoal and Herald Valley and receives second year adults from as far south as the Anadyr Gulf and as near as the broad slope between Hanna Shoal and Herald Valley. The 2013 sink region was shifted west relative to the 2012 region and the 2013 adult source region was shifted north relative to the 2012 adult source region. These connection potentials were not sensitive to precise times and locations of release, but were quite sensitive to depth of release. These patterns demonstrate how interannual differences in the physical conditions well south of Hanna Shoal play a critical role in determining the abundance and distribution of a key food source over Hanna Shoal and in the southern Beaufort Sea.

1. Introduction

The Chukchi Sea is a dynamic, shallow, marginal sea where water masses from the Pacific, Atlantic and Arctic Oceans meet, resulting in a complex and highly productive ecosystem. Hanna Shoal in the northeastern Chukchi Sea, like much of that shallow arctic shelf sea, exhibits tight pelagic-benthic coupling and supports a rich population of pinnipeds (Hunt et al., 2013; Grebmeier et al., 2015) that provide subsistence food for Alaskan coastal communities. In recent years, climate change has dramatically modified the sea ice and ocean conditions over Hanna Shoal with changes to the ecosystem of the Shoal expected in response (Wood et al., 2015). Many aspects of the ecology of Hanna Shoal remain poorly understood, making prediction and detection of potential climate change driven ecosystem shifts difficult at best. These interests, in addition to oil and gas interests south of the Shoal, motivated a five-year project to study the ecology of Hanna Shoal in summer, including of one of the dominant copepod species *Calanus glacialis* (BOEM, 2015).

The Chukchi Sea has been described as a flow-through shelf, with plankton populations in the region greatly influenced by the predominant advective pathways of the region (e.g., Carmack and Wassmann, 2006; Wassmann et al., 2015). The mean circulation of the Chukchi Sea is generally northward, primarily along one of three pathways: Eastern Chukchi and Barrow Canyon, the Central Channel, and Herald Valley (e.g., Weingartner et al., 2005, 2013; Brugler et al., 2014) (Fig. 1). Annual mean transport through the Chukchi is estimated to be of order 0.8 Sv, although recent measurements have indicated that this transport is increasing (Woodgate et al., 2005, 2012, 2015). Mean north-

* Corresponding author.
E-mail addresses: stephenmelliott@gmail.com (S.M. Elliott), cashjian@whoi.edu (C.J. Ashjian), zfeng@whoi.edu (Z. Feng), btjones@mit.edu (B. Jones), c1chen@umassd.edu (C. Chen), yzhang3@umassd.edu (Y. Zhang).

http://dx.doi.org/10.1016/j.dsr2.2016.10.001

Available online 15 October 2016

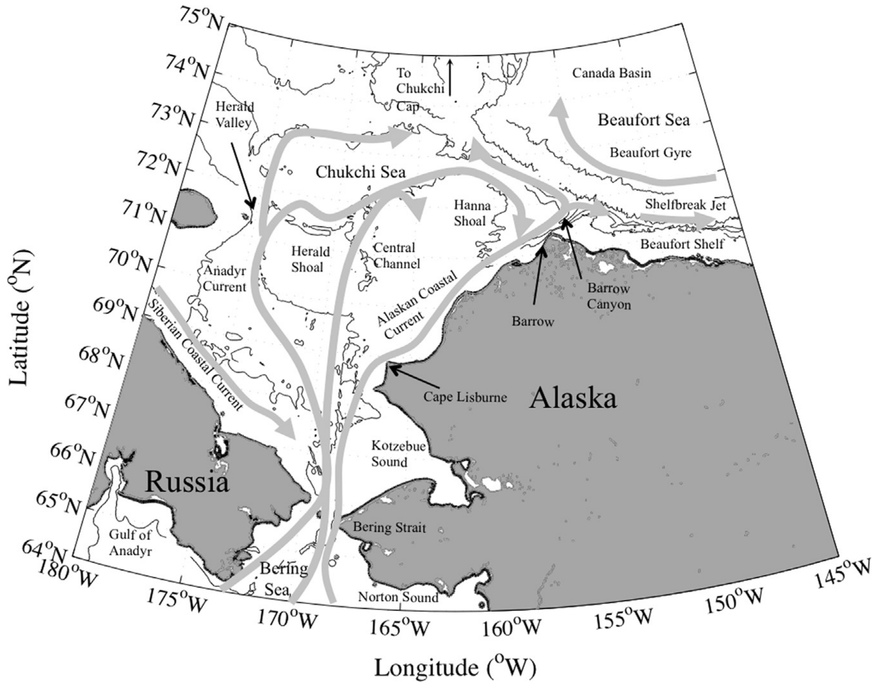

Fig. 1. Chukchi Sea geographic features and dominant advective pathways (adapted from Brugler et al., 2014). Only the southern portion of the Beaufort Gyre is shown.

ward flow in this shallow shelf sea is modulated by wind-driven circulation that can cause local flow reversals and variability in circulation pathways (Weingartner et al., 2005, 2013). Residence time in the Chukchi Sea was estimated to be between one and six months with the lowest values expected in late summer and the highest values expected in late winter, when conditions are the least variable and surface winds have the least effect on circulation (Woodgate et al., 2005). These circulation pathways carry plankton from the northern Bering Sea through the Chukchi to the Arctic Ocean (e.g., Hopcroft et al., 2010). Hanna Shoal, in the northeastern Chukchi Sea, lies at the convergence of the three northward advection pathways and thus should be notably influenced by input of Bering Sea planktonic populations as well as those endemic to the Chukchi Sea and those that are moved onto the shelf, by upwelling for example, from the adjacent Arctic Basin. The exact route followed by the Bering Sea Water arriving in the Chukchi is variable from year to year which appears to drive much of the interannual variation in zooplankton populations (Day et al., 2013).

There are few studies of zooplankton on Hanna Shoal proper, with most work being conducted on the adjacent Chukchi and Beaufort Sea shelf breaks/slopes or in Barrow Canyon (e.g., Lane et al., 2008; Campbell et al., 2009; Llinás et al., 2009; Day et al., 2013; Questel et al., 2013). At present, the zooplankton community, including *C. glacialis,* only grazes a small proportion of the total primary production, leaving the remainder to sink to the seafloor where it supports a rich and abundant benthos (e.g., Campbell et al., 2009; Grebmeier et al., 2015). The copepod community is numerically dominated by small copepods such as *Oithona similis* and *Pseudocalanus* spp. and in terms of biomass by the larger *C. glacialis* (a shelf/slope species). *C. glacialis* is a key species in the Arctic zooplankton community in terms of biomass, and its role as an energy concentrator is essential for ecosystem function (Falk-Petersen et al., 2009). This relatively long-lived planktonic crustacean is present over Hanna Shoal in August in all of its life stages and may serve as an important food source for migrating bowhead whales in the fall (Quakenbush et al., 2010). In the highly advective western Arctic, *C. glacialis* populations in the Arctic basin are impacted by the success of populations in the adjacent Chukchi Sea, while populations in the Chukchi Sea are dependent on the success of populations in the Anadyr Gulf and the rest of the northern Bering Sea. The physical processes that mediate these connections remain poorly understood. To predict the strength of the *C. glacialis* population over Hanna Shoal and the effects of this population on those in the western Arctic, it is necessary to identify the strongest upstream sources and strongest downstream sinks. Sources are the locations where the individuals were hatched and sinks are the locations where individuals are competent to diapause at the beginning of the winter.

The remote and harsh nature of the northeast Chukchi Sea makes long-term spatially widespread data difficult and expensive to obtain, thus using direct observation to find source and sink regions is currently impractical. Coupling field observations with oceanographic models is an effective way to extrapolate on the limited data that can be collected in order to make broader conclusions. Here a physical ocean model is coupled to an individual-based copepod development model to explore the sources and sinks of the *C. glacialis* populations on Hanna Shoal. Observed copepodid life stage (C1-C6) specific distributions of *C. glacialis* in August of 2012 and 2013 were used as initialization for the simulations. Five overarching hypotheses or expectations were identified: (1) When the observed *C. glacialis* populations are advected forward in time, much of the population will leave the Shoal and enter diapause along the shelf break north of Alaska. (2) When the observed *C. glacialis* populations are advected backwards in time, much of the population will be found to originate in the southern Chukchi Sea. (3) Interannual variability will result from small variations in the advective pathways. (4) The source and sink regions could be sensitive to the depth of release, since the copepods are held at the depth of release during the simulations, but given the small range of release depths the impact should be modest, particularly for copepods that leave Hanna Shoal. (5) Given the spatial and temporal scales of the physical model, the source and sink regions should be fairly insensitive to the exact time and location of release.

2. Materials and methods

2.1. Physical ocean model

The physical ice-ocean model is the Arctic Ocean Finite Volume Community Ocean Model (AO-FVCOM) (Chen et al., 2016; Zhang