Deep-Sea Research II ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Deep-Sea Research II

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

Euphausiids in the eastern Bering Sea: A synthesis of recent studies of euphausiid production, consumption and population control

George L. Hunt Jr.[a,*], Patrick H. Ressler[b], Georgina A. Gibson[c], Alex De Robertis[b], Kerim Aydin[b], Michael F. Sigler[d], Ivonne Ortiz[e], Evelyn J. Lessard[f], Benjamin C. Williams[g], Alexei Pinchuk[g], Troy Buckley[b]

[a] School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195, USA
[b] Alaska Fisheries Science Center, National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), 7600 Sand Point Way N.E., Building 4, Seattle, WA 98115, USA
[c] International Arctic Research Center, University of Alaska Fairbanks, PO Box 757340, Fairbanks, AK 99775-7340, USA
[d] Alaska Fisheries Science Center, National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), 17109 Point Lena Loop Road, Juneau, AK, USA.
[e] Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Box 355672, Seattle, WA 98195, USA
[f] School of Oceanography, University of Washington, Box 357940, Seattle, WA 98195-7940, USA
[g] University of Alaska, Fairbanks, School of Fisheries and Ocean Sciences, Fisheries Division, 17101 Point Lena Loop Road, Juneau, AK 99801-8344, USA

ARTICLE INFO

Keywords:
Bering Sea
Euphausiids
Krill
Thysanoessa
Walleye Pollock
Gadus chalcogrammus
Top-down/bottom-up control

ABSTRACT

Euphausiids are an important component of the eastern Bering Sea marine ecosystem. We synthesized information on the ecological roles of two species, *Thysanoessa raschii*, which predominates over the Middle and Inner Shelf Domains, and *Thysanoessa inermis*, which predominates over the Outer Shelf Domain. Although estimates of euphausiid biomass across the shelf are not well constrained, we estimated that, between April and July, 2004–2010, euphausiid biomass was 3.08–5.25 g C m^{-2} on the outer shelf and 1.95–3.92 g C m^{-2} on the middle shelf. Modeled estimates of euphausiid production, for spring and summer combined, varied between 0.043 g C m^{-2} d^{-1} and 0.051 g C m^{-2} d^{-1}, depending on location, with a mean of 0.048 g C m^{-2} d^{-1}. Recently reported field measurements of annual primary production over the southeastern Bering Sea in 2008–2009 vary between 0.06 and 6.65 g C m^{-2} d^{-1}, with a mean of 1.262 g C m^{-2} d^{-1} ± 2.049 g C m^{-2} d^{-1} in spring and summer combined, a level sufficient to support euphausiids, at least on an annualized basis. Walleye pollock (*Gadus chalcogrammus*, hereafter pollock) is the single most important consumer of euphausiids over the eastern Bering Sea shelf. We estimated that pollock consumed between 0.0042 and 0.019.7 g C m^{-2} d^{-1} of euphausiids, depending on year, with a mean of 0.011 g C m^{-2} d^{-1} in summer averaged over 1999–2009. This consumption is equivalent to between 17% and 29% of summer euphausiid production, depending on location.

Over the period for which data were available (2004–2012), we observed a strong negative relationship between euphausiid biomass as determined in acoustic surveys and pollock biomass as estimated in the eastern Bering Sea pollock stock assessment (r^2=0.82). During this time period, sea-surface temperature was the second strongest predictor of euphausiid biomass, (r^2=0.63). However, for the period 2004–2010, bottom temperature (r^2=0.94) was the strongest predictor, followed by pollock biomass from the pollock stock assessment (r^2=0.82), and sea-surface temperature (r^2=0.81). Mean pollock density in the acoustic surveys was not a powerful predictor of euphausiid biomass during either period. In spatially explicit multiple regression analyses for the periods 2004–2012 and 2004–2010 those formulations that included sea-surface and bottom temperatures as well as survey estimates of pollock had the greatest explanatory value. However, when either or both temperature terms were dropped, the explanatory value of the models dropped considerably. When pollock biomass was dropped from the models, there was little change in explanatory value compared to the full model. Euphausiid production and pollock consumption data coupled with a negative relationship between euphausiid biomass and stock assessment estimates of pollock biomass indicate a top-down predation effect. However, strong negative relationships between euphausiid biomass and water temperatures indicate the influence of a bottom-up mechanism. The apparent differences in these results may relate to the different spatial and

* Corresponding author. Tel.: +1 206 441 6109, +1 360 378 6748.

http://dx.doi.org/10.1016/j.dsr2.2015.10.007

temporal scales used to assess the pollock biomass used in the analyses. Alternatively, euphausiid biomass may be strongly controlled during a restricted portion of the year, such as spring, if critical food needs are not met in some years. We lack the data necessary to resolve these alternative hypotheses.

1. Introduction

Euphausiids (also known as krill) play a central role in the pelagic food-web of the eastern Bering Sea marine ecosystem. They consume phytoplankton, micro-zooplankton, and detritus, and "repackage" these small particles into lipid-rich bodies that then become an important source of energy for fish, seabirds and baleen whales (Hunt et al., 1996; Aydin and Mueter, 2007). Despite their central role in the pelagic food web, Bering Sea euphausiids have remained little studied, perhaps because they are sufficiently large and fast swimmers to avoid most scientific plankton nets, and small enough that they are not sampled during fishery surveys using either bottom or mid-water trawls. In recent years, acoustic methods for estimating their abundance in the Bering Sea have been developed, and these have allowed improved estimates of euphausiid distribution and abundance (De Robertis et al., 2010; Ressler et al., 2012, 2014a). In this contribution, we consider both new data and information from the literature on the ecology of euphausiids in the eastern Bering Sea (Fig. 1). These new data were obtained in the Bering Ecosystem Study (BEST), and the Bering Sea Integrated Ecosystem Study (BSIERP), which together are now known as the Bering Sea Project (http://www.nprb.org/bering-sea-project). We focus primarily on synthesizing the new information available on euphausiid population biology to assess the factors that control euphausiid abundance in the region.

In particular, our investigation examines the relative importance of top-down and bottom-up factors (Hunt and McKinnell, 2006) in the control of euphausiid biomass. The general consensus has been that most secondary production in the eastern Bering Sea is consumed by predators (Smith, 1991; Springer, 1992; Aydin et al., 2007). Springer (1992) and Ressler et al. (2012) have suggested that the biomass of euphausiids in the eastern Bering Sea could be determined in part through top-down control by walleye pollock (*Gadus chalcogrammus,* hereafter, pollock) predation. Ressler et al. (2012) used biomass data from a new acoustic-trawl survey of euphausiids, as well as acoustic-trawl and bottom trawl surveys of pollock, to demonstrate a negative correlation between pollock and euphausiid biomass. They hypothesized that pollock predation, in addition to forcing by water temperature or ice cover as suggested by other work (e.g., Coyle et al., 2011; Hunt Jr. et al., 2011), might provide a significant control of eastern Bering Sea euphausiid standing stocks.

Predation by pollock is a key focus of our investigation because this species contributes the largest source of planktivorous fish

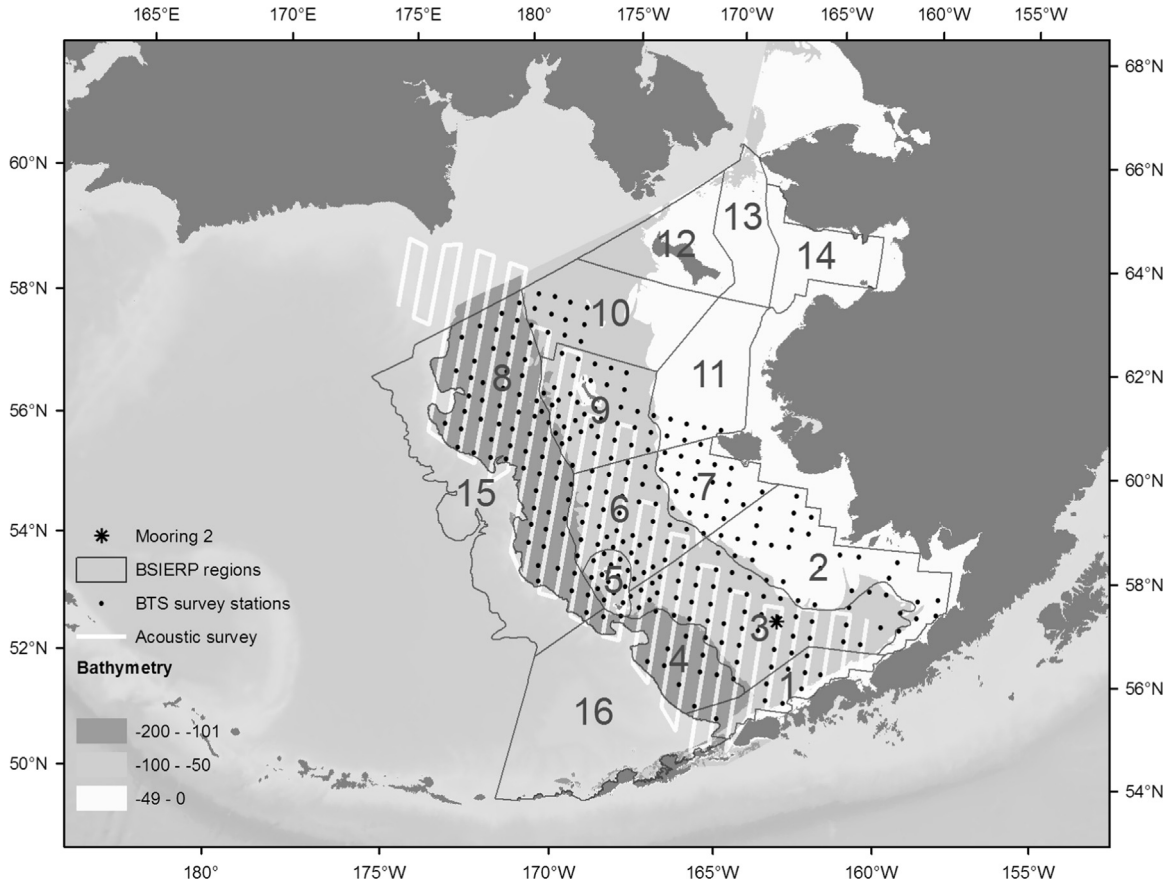

Fig. 1. The eastern Bering Sea shelf with the BSIERP regions (numbered 1–16), the stations for the NOAA bottom trawl survey (dots), and the track line of the acoustic trawl survey (white lines). Bathymetry is indicated in shades of white (0–49 m, Inner Shelf Domain), light grey (50–100 m, Middle Shelf Domain), and dark grey (101–200 m, Outer Shelf Domain. The Shelf slope domain is a narrow strip just seaward of the Outer Shelf Domain.

Please cite this article as: Hunt, G.L. Jr., et al., Euphausiids in the eastern Bering Sea: A synthesis of recent studies of euphausiid production, consumption and population control. Deep-Sea Res. II (2015), http://dx.doi.org/10.1016/j.dsr2.2015.10.007