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Climate-related variability in abundance of mesozooplankton in the northern Gulf of Alaska 1998–2009

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ABSTRACT

Significant changes in fisheries resources have occurred in the Gulf of Alaska (GOA) in the mid 1970s, with an increase in groundfish and a decrease in crab and shrimp populations. Increased fishing pressure and such events suggest that the GOA is susceptible to climate variation; however the mechanistic links between ecosystem change and climate remain unclear. At-sea surveys were undertaken during the month of May from 1998 to 2009 to collect data on zooplankton abundance and water mass properties in the northern GOA. Significant changes in temperature, salinity and zooplankton abundance were identified during this period. The euphausiid *Thysanoessa inermis* and the copepod *Calanus marshallae* had increased abundances in years when there was a strong phytoplankton spring bloom preceded by anomalously cold winters. The euphausiid *Euphausia pacifica* and the copepods *Pseudocalanus* spp., *Neocalanus plumchrus/flemingeri*, and *Oithona* spp. were more resilient to relatively high mean water temperatures. High zooplankton abundances in years of substantial cross-shelf mixing suggest that iron and nutrient transport between the shelf and oceanic domains are essential for sustaining high zooplankton populations via phytoplankton blooms. The abundance of zooplankton in the northern GOA is highly influenced by advective processes and changes in temperature. Further understanding of biological and physical mechanisms that control the GOA ecosystem are of major importance to predict the response of zooplankton communities to environmental changes.

1. Introduction

The northern shelf of the Gulf of Alaska (GOA) is a rich and diverse ecosystem, which sustains a number of important fisheries resources such as crustaceans, salmon, halibut, pollock and sablefish (Ware and McFarlane, 1989; Weingartner et al., 2002; Willette et al., 2001). Mesozooplankton are a critical trophic link between these commercial target species and microplankton (both primary producers and microheterotrophs) (Armstrong et al., 2005; Dagg et al., 2006; Liu et al., 2008; Sigler et al., 2001), such that high zooplankton abundance may increase the probability of survival of juvenile salmon (Willette et al., 2001) and suppress the increase in biomass of microzooplankton (Strom et al., 2007). Therefore, it is important to better understand the variations in zooplankton abundance and their associations with physical changes in the marine environment.

The zooplankton community in the northern GOA is mainly composed of copepods, euphausiids, chaetognaths, pteropods, larvaceans and cnidarians (Coyle and Pinchuk, 2003). The biomass in the zooplankton community is usually dominated by large oceanic copepods, such as *Neocalanus cristatus, Neocalanus plumchrus, Neocalanus flemingeri* and *Eucalanus bungii*, which are responsible for the annual biomass peak during spring and early summer (Coyle and Pinchuk, 2003, 2005). This seasonal biomass peak is related to life cycle timing of these dominant copepod species, which over-winter in deep waters below the pycnocline and their nauplii migrate above the pycnocline in spring and early summer to feed and complete their somatic growth (Kobari and Ikeda, 2001a; Miller and Clemons, 1988; Tsuda et al., 1999). Subsequently, the rapid summer decline in biomass in surface waters occurs mainly because these four species migrate to diapause in deep waters (Coyle and Pinchuk, 2005; Kobari and Ikeda, 2001b; Tsuda et al., 2004). Conversely, smaller more neritic copepods, such as *Metridia pacifica, Pseudocalanus spp.* and *Oithona spp.*, are the most populous species in the zooplankton community, which have their annual abundance peak in summer. Therefore, the biomass and abundance peaks in zooplankton species in the GOA

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are mainly represented by oceanic and neritic copepod species, respectively (Coyle and Pinchuk, 2003).

Zooplankton species may respond differently to changes in temperature and food concentration, and their abundance may also change as a result of vertical and cross-shelf mixing that may affect dispersal of organisms in the water column (Coyle and Pinchuk, 2005; Mackas and Coyle, 2005; Pinchuk et al., 2008). Species that are abundant in the upper mixed layer such as *N. plumchrus* and *N. flemingeri* are more likely to be advected onshore by Ekman transport, while species that are abundant below the mixed layer such as *N. cristatus* and *E. bungii* are less likely to be advected onshore by surface currents (Coyle and Pinchuk, 2005). Taxa that undergo diel vertical migration such as *Metridia* spp. and euphausiids will be influenced by Ekman transport at night and subsurface flow during the day. Mixing processes can influence the distribution of zooplankton species, such that oceanic species are advected into the coastal habitat and neritic species towards the slope (Coyle and Pinchuk, 2005; Mackas and Coyle, 2005; Pinchuk et al., 2008). These processes include seasonal changes in cyclonic winds and Ekman transport and interaction of currents with the complex coast and bathymetry that can generate eddies and meanders that enhance cross-shelf transport of water masses (Okkonen et al., 2003; Weingartner et al., 2005; Janout et al., 2009). The shelf ecosystem in the GOA undergoes shifts in crustacean and fin-fish populations. In the mid-1970s, salmon and ground fish populations increased, while crab and shrimp populations decreased, and these changes corresponded to a strong regime shift in 1976–77 (Anderson and Piatt, 1999; Francis and Hare, 1994; Mantua et al., 1997). Later in the 1980s, marine mammal and seabird populations also declined, while the ground fish populations continued to increase (Hatch and Sanger, 1992; Merrick et al., 1987; Springer, 1998). The mechanism linking oceanographic regime shifts to the response by fisheries populations remains unclear, but the link is likely to involve shifts in the abundance, biomass and species composition of primary producers and secondary consumers. Long-term observation programs may help identify vulnerable populations and their response to changes in the physical environment. This paper outlines the response of major mesozooplankton taxa to changes in the environment of the GOA shelf and investigates the following hypotheses: (1) interannual variability in zooplankton abundance is influenced by changes in water mass properties, and (2) zooplankton species in the GOA will respond differently to changes in water mass properties according to their distribution along the shelf (neritic and oceanic) and within the water column (mixed layer, below and within the pycnocline).

2. Methods

2.1. Study area

The northern GOA is a very dynamic environment, and has a complex bathymetry with many canyons, troughs and a deep shelf (Weingartner et al., 2005). During fall and winter, strong westward alongshore winds cause onshore Ekman transport and coastal downwelling. During spring and summer downwelling diminishes as winds relax (Stabeno et al., 2004; Weingartner et al., 2005). The main currents in this region are the Alaska Coastal Current (ACC), which flows westward within 20–50 km of the coast (Royer, 1982; Weingartner et al., 2005), and the Alaska Current seaward of the shelfbreak, which narrows and intensifies west of Kodiak Island to become the Alaskan Stream, a western boundary current of the Subarctic Gyre (Fig. 1) (Reed, 1984; Reed and Stabeno, 1989).

The study area was divided into three zones: the inner and middle shelves and the oceanic domain (Fig. 2). Here the shelf is broad (160 km wide) and deep, with bottom depths exceeding 150 m. Irregular bathymetry characterizes the shelf; water shoals from 250 m on the inner shelf to 150 m in the middle shelf before deepening again (Fig. 2). The inner shelf is highly influenced by freshwater runoff, and in late spring and summer, high salinity oceanic waters penetrate the sub-surface waters of the inner and middle shelves, which have a mixture of neritic and oceanic waters (Coyle and Pinchuk, 2005). The oceanic domain has high salinity basin waters, and can be subject to mesoscale anticyclonic eddies propagating westward along the shelfbreak and slope (Janout et al., 2009; Okkonen et al., 2003).

Surveys were conducted along the Seward line (~220 km) during May from 1998 to 2009 (Fig. 2) as part of the Global Ocean Ecosystems Dynamics (GLOBEC) Long Term Observation Program (LTOP) in the northern GOA, Rough weather precluded a complete coverage of the Seward line in 2008; hence, this survey year was not included in the analyses. Data from May were chosen for analysis because zooplankton biomass peaks during this month (Coyle and Pinchuk, 2003, 2005) and because continued sampling in May has provided an uninterrupted time series from 1998 to 2009.

2.2. Data collection

From 1998 to 2004 large zooplankton and micronekton (*N. cristatus*, *E. bungii*, *C. marshallae*, *Metridia* spp., *N. plumchrus*, *N. flemingeri*, *Thysanoessa inermis*, *E. pacifica*, *Thysanoessa spinifera*, Pterapods and Chaetognatha) were collected with a 1 m^2 Multiple

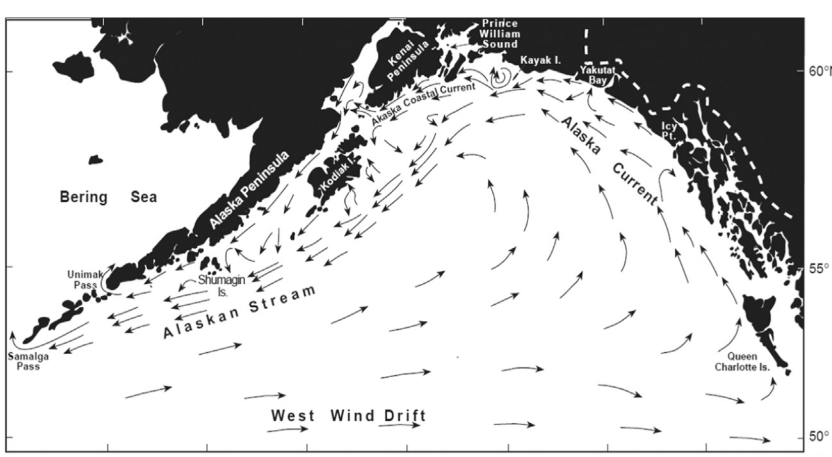

Fig. 1. Map of the Gulf of Alaska. The flow of the Alaska Coastal Currents and Subarctic Gyre are indicated as are several geographic place names (after Reed and Schumacher, 1986).