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Response of *Eucalanus bungii* to oceanographic conditions in the western subarctic Pacific Ocean: Retrospective analysis of the Odate Collections

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Abstract

To evaluate their response to oceanographic conditions, interannual variations in seasonal abundance of *Eucalanus bungii* were investigated in zooplankton samples collected from the Oyashio Current system from 1960 to 2002. Large decadal changes were observed in seasonal timing and population age-structure. During the early 1970s and 1990s, *E. bungii* were abundant until mid-summer, but during the late 1970s and early 1980s, the season of maximum abundance was limited to spring and early summer. From the late 1970s to early 1980s, spring–summer abundance of newly recruited young copepodites (C1–C2) declined significantly, and an even more pronounced decline was observed for the abundance of the late copepodite stages (C3–C5). Monthly population structure showed that young of the year stopped development at C3 during the late 1970s to early 1980s, but molted into late copepodite stages in the other decades. Seasonal weakening of the Aleutian Low Pressure System estimated from North Pacific Index (NPI) was rapid during the late 1970s to early 1980s, and the NPI was positively correlated with phosphate concentrations at sea surface, spring–summer abundance of the young copepodites stages, and the extended duration of the season of high abundance. These results suggest that the decadal decline of copepod abundance originated at the early life stages, and was associated with a shift of atmospheric and oceanographic conditions. As possible biological mechanisms, we propose reduced egg production, lower survival for the portion of the annual cohort with late birth date, and overwintering of the survivors at younger stages.

Keywords: Zooplankton; Time-series analysis; Climatic changes; Food availability; Survival; Oyashio

1. Introduction

Eucalanus bungii is abundant in the subarctic North Pacific Ocean and the neighboring Bering, Okhotsk, and Japan Seas (Fleminger, 1973; Fleminger and Hulsemann, 1973). These copepods constitute up to 31% of mesozooplankton biomass occurring in the water column above 1000 m during summer (Vinogradov, 1997). *E. bungii* preys on micro- to nanophytoplankton, microzooplankton, and sinking particles (Kobari et al., 2003b), and is a

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food resource for epipelagic, mesopelagic, and demersal fishes (Odate, 1994; Beamish et al., 1999; Yamamura et al., 2002) and seabirds (Russell et al., 1999). Therefore, this species has important roles in the energy pathway from lower to higher trophic levels in the marine ecosystem.

E. bungii undergoes an ontogenetic migration down to the mesopelagic waters (Fig. 1). Previous studies (Miller et al., 1984; Tsuda et al., 2004; Shoden et al., 2005) showed that their life histories are associated with seasonality of primary productivity. From autumn to winter, dormant populations reside below 250 m depth at copepodite stages 3–5 and as adult females. Individuals emerging from dormancy migrate upward to the surface and mature in spring. Adults spawn eggs during the period of high primary production. Newly recruited juveniles develop from egg into pre-dormant stages from spring to summer of the birth year, stop development and migrate downward during late summer for overwintering. Reflecting geographical differences in the amount, duration, and timing of primary productivity, life spans are biennial in the Alaskan Gyre (Miller et al., 1984) and annual to biennial in the Oyashio waters (Tsuda et al., 2004; Shoden et al., 2005).

An accumulation of evidence from the past decade demonstrates long-term variation in phytoplankton and zooplankton biomass in the subarctic Pacific Ocean and its neighboring waters (e.g., Brodeur and Ware, 1992; Odate, 1994; Sugimoto and Tadokoro, 1997). Various climate indices, such as the Arctic Oscillation (AO: Thompson and Wallace, 1998), North Pacific Index (NPI: Trenberth and Hurrell, 1994), and Pacific Decadal Oscillation (PDO: Mantua et al., 1997), have been suggested as descriptors of forcing factors of the interannual variability of the marine ecosystem (Polovina et al., 1995). Because responses to climate events appear species-specific through the life history, it is difficult to understand detailed mechanisms from analyses that are based only on total biomass. Species-based analyses therefore have been recommended and applied for both phytoplankton and zooplankton (Miller et al., 1992; Mackas et al., 1998; Chiba and Saino, 2002, 2003; Chiba et al., 2006; Kobari et al., 2003a; Tadokoro et al., 2005).

In the Oyashio waters, long-term changes in summer zooplankton biomass show a bi-decadal pattern with high biomass from the 1960s to 1970s and low biomass in the 1980s (Odate, 1994).

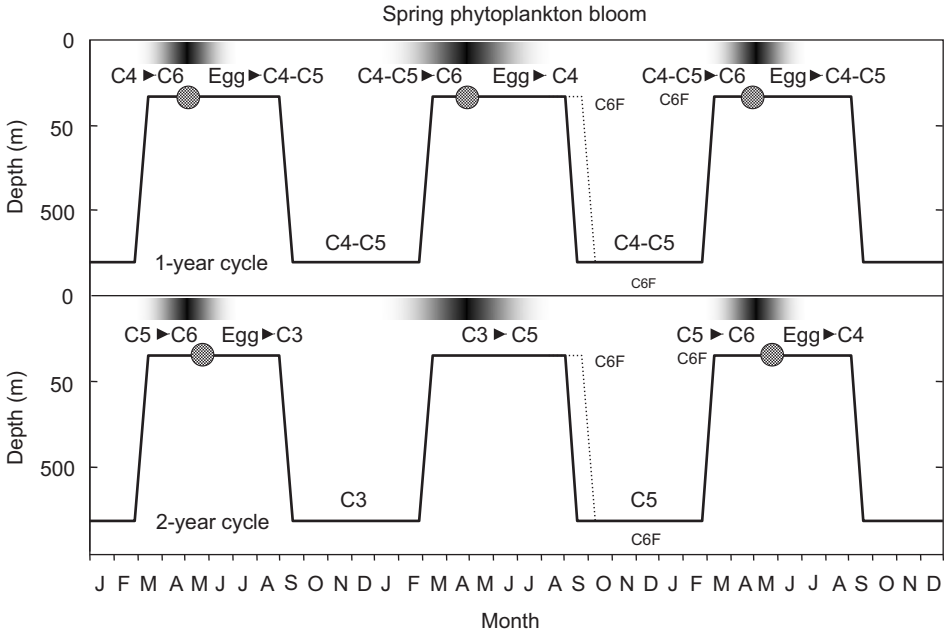

Fig. 1. Schematic diagram of annual (top panel) and biennial (bottom) life cycle patterns of *Eucalanus bungii* in the Oyashio waters proposed by Shoden et al. (2005) and Tsuda et al. (2004). Solid line indicates variation of depth during development and dormancy, shaded circles along line show mean spawning seasons, and surface layer shading shows timing and duration of the spring phytoplankton bloom.