7. Succession of the Calanoid Copepod Community in Funka Bay during Spring Phytoplankton Bloom

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Abstract

Calanoid copepod succession in Funka Bay, Hokkaido, was investigated during the spring phytoplankton bloom, from December 1993 to April 1994 and from February to March 1995. The chlorophyll *a* concentration in the bay increased from February to March in both years, although the biomass was greater in 1995. The total number of calanoid copepods increased from January to February, and the species composition changed from a *Calanus pacificus, Paracalanus*, and *Clausocalanus*-dominated community to one dominated by *Pseudocalanus newmani.* This shift in species composition may be associated with the inflow of Coastal Oyashio Water. The increase in *P. newmani* is attributed to recruitment from outside the bay, due to inflow of the Coastal Oyashio Water, rather than that from in situ reproduction taking advantage of the phytoplankton bloom.

Introduction

Two major water masses occupy Funka Bay on the Pacific coast of southern Hokkaido periodically throughout the year - one is the cold and less saline Coastal Oyashio Water through spring to summer, and the other is the warm and salty Tsugaru Warm Water, originating from the Tsushima Warm Water, through summer to winter (Ohtani and Akiba, 1970; Murakami, 1984). Succession in zooplankton species composition in the bay is associated with the exchange of the two water masses (Hirakawa, 1984). The spring phytoplankton bloom occurs in mid-February to mid-March (Odate, 1992) when Coastal Oyashio Water intrudes into the bay (Ohtani, 1971). However, it is still not clear how the copepod community in the bay is influenced by this inflow of Coastal Oyashio Water and how it responds to spring phytoplankton bloom, because frequent observations have not been previously made during winter to spring.

In this study, we sampled in Funka Bay for examining numbers and composition of calanoid copepod species at the frequency of once or twice a week from January to March, to clarify the effects of the intrusion of Coastal Oyashio Water on the calanoid community and the response of the copepods to the phytoplankton bloom.

Materials and Methods

Sampling was carried out at St. 30 (41°58'N, 140°36'E; ca. 90 m deep) in the central portion of Funka Bay eight times from 16 December 1993 to 25 April 1994 and eleven times from 25 January to 27 March 1995. Zooplankton was collected with a vertical haul from the bottom to the surface using a Norpac net (mouth opening, 45 cm; mesh size, 0.1 mm) with a flow meter attached to the net ring. The zooplankton samples were preserved with 4% buffered formalin. Water temperature and salinity were measured using a CTD (Sea Bird 19) in conjunction with each sampling. Water samples were also collected with a Niskin bottle from 0, 10, 20, and 30 m for chlorophyll measurements, and the chlorophyll *a* concentrations were determined fluorometrically (Parsons et al., 1984).

Each species and copepodite stage of calanoid copepods was counted under a binocular microscope in the laboratory. The *Paracalanus* and *Clausocalanus* spp. counts were combined, because their copepodite stages could not be distinguished. Naupliar stages in copepods were also counted but not identified to the species level. The number of eggs carried by and detached from *Pseudocalanus newmani* females was counted for the samples collected in 1995.

Results

Water temperature decreased gradually from January to March, 1994, although there was a rapid decline above 40 m in late February, 1995. The decline in the upper layer was attributed to the intrusion of Coastal Oyashio Water into the bay. This is also indicated by a rapid decline of salinity at the upper layer. Although there was no such clear indication of an intrusion of Coastal Oyashio Water into the bay in 1994, the decline in salinity in late February, 1994 revealed inflow of less saline water from outside the bay. Shimizu and Isoda (1997) showed that a wind-driven current played an important role in transporting walleye pollock eggs from the outside into Funka Bay prior to the intrusion of Coastal Oyashio Water. It therefore appears that inflow of Coastal Oyashio Water into the bay also occurred in 1994.

Mean chlorophyll *a* concentration in the layer above 30 m was very low, at 1.1 mg m^{-3}, until late February, when it increased to 6.1 mg m^{-3} in 1994 (Fig. 1). In 1995, it was already at 17.1 mg m^{-3} in late February more than ten times higher than in 1994 and it remained high until mid-March, then rapidly declined in late March.

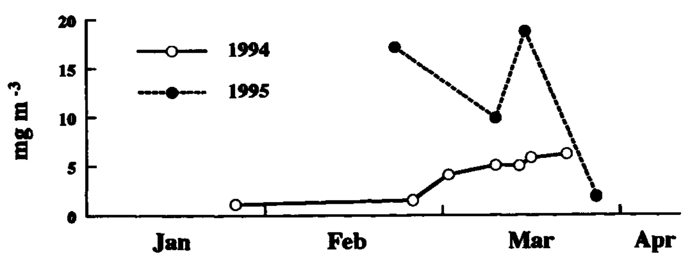

Fig. 1. Mean chlorophyll *a* concentration in 0-30 m water column at St. 30 in Funka Bay from late January to late March 1994 and from late February to late March 1995.

The total number of copepodites of calanoid copepods increased gradually from late February to mid- and late March in 1994 and 1995 (Fig. 2). Peaks of abundance were 1,800 and 2,600 m^{-3} in 1994 and 1995, respectively. Copepod nauplii were relatively constant at low numbers, 1,000-2,000 m^{-3}, and gradually decreased until late March in 1994, whereas they increased rapidly up to 10,000 m^{-3} by late March in 1995.

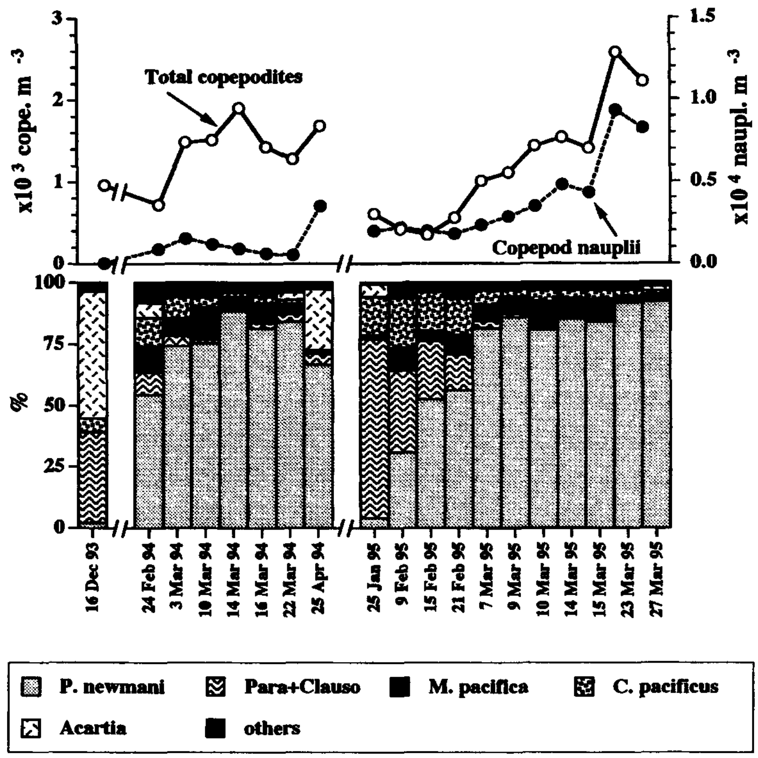

Fig. 2. Abundances of total copepodites and nauplii in calanoid copepods and the species composition at St. 30 in Funka Bay from 16 December 1993 to 25 April 1994 and from 25 January to 27 March 1995.

From January to March, the numerically-dominant copepodites belonged to four taxa: *Pseudocalanus newmani, Paracalanus-Clausocalanus* group (*Para + Clauso*), *Metridia pacifica*, and *Calanus pacificus* (Fig. 2). In December 1993 and April 1994, *Acartia* spp. also dominated. These five taxa comprised more than 90% of total calanoids. An increase in the proportion of *P. newmani* rather than a decrease in number of *Para + Clauso* and *C. pacificus* from January to February, 1995 was responsible.

P. newmani accounted for more than 80% of total calanoids during phytoplankton bloom as indicated by chlorophyll *a* concentrations. Although the stocks were less abundant, large oceanic copepods, such as *Neocalanus plumchrus* and *N. cristatus*, also increased from late February to March in both years.

All copepodite stages of *P. newmani*, including adult, simultaneously increased from mid-February to late March in both years, although early and late copepodites declined by mid-March in 1994 (Fig. 3). In 1995, *P. newmani* eggs were counted. Numbers gradually increased from late February to mid-March and then promptly declined.

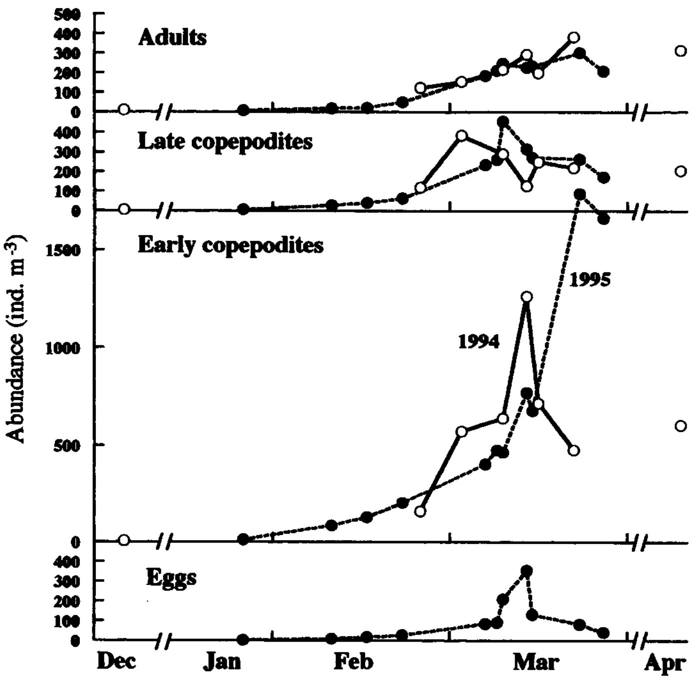

Fig. 3. Abundance of each developmental stage in *Pseudocalanus newmani* at St. 30 in Funka Bay from 16 December 1993 to 25 April 1994 and from 25 January to 27 March 1995.

Discussion

During this study, the species composition of calanoid copepods in Funka Bay changed from a *Calanus pacificus*, *Paracalanus* sp., and *Clausocalanus* spp.-dominated community to one dominated by *Pseudocalanus newmani*. Hirakawa (1984) showed such changes in the species composition in the bay, i.e., a shift from warm water species to cold water species, and suggested that this is due to the inflow of the Coastal Oyashio Water to the bay. *C. pacificus*, *Paracalanus* sp., and *Clausocalanus* spp. originate from the Tsugaru Warm Water and reproduce during summer to winter in the bay (Hirakawa, 1984). They may spill out of the bay due to inflow of the cold Coastal Oyashio Water, and/or may die as a result of the low temperature of the intruding water mass.

Copepodites of *P. newmani*, the dominant species during the phytoplankton bloom, increased in the bay during the study period, but not in synchrony with the chlorophyll *a* concentration. Copepod nauplii, considered to be mostly *P. newmani* due to its numerical dominance of the calanoid copepodites, decreased with increasing chlorophyll *a* concentration in March, 1994, but increased with the decreasing chlorophyll in March, 1995. The number of eggs of this species also did not increase in synchrony with chlorophyll, although the maximum did coincide with the second chlorophyll peak. These results suggest that the increase in *P. newmani* can be attributed to recruitment from the outside of the bay due to inflow of Coastal Oyashio Water rather than to in situ reproduction by the females in the bay.

Although trophic linkage among diatom blooms, copepod production, and fish is widely accepted as a traditional concept in pelagic food webs (e.g., Runge, 1988), recent studies found that egg production and/or hatching success of the eggs in copepods are negatively influenced by diatom diets (e.g., Ban et al., 1997). In Funka Bay, the spring phytoplankton bloom consists primarily of diatoms (Odate, 1992). Recently, we examined the hatching success of *P. newmani* eggs collected from the bay in mid-March, 1997, and found a high ratio of deformed nauplii compared with the total hatch, rather than relatively high hatching success. The same has been shown for *Calanus helgolandicus* and *Calanus pacificus* when fed on diatoms (Poulet et al., 1995; Uye, 1996). These influences on egg production, hatching success, and deformed nauplii can negatively affect copepod recruitment. The lack of a correlation between numbers of nauplii and chlorophyll *a* concentration in Funka Bay may in part result from such inhibitory effects of diatoms.

In conclusion, the shift of the species composition of calanoids from January to March may be associated with the inflow of the Coastal Oyashio Water into Funka Bay. The increase in *P. newmani* numbers in the bay can be attributed to recruitment from outside the bay through transportation in with Coastal Oyashio Water, rather than to reproduction within the bay in association with the spring phytoplankton bloom.

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