

# Feeding Rates of Dominant Copepods on Phytoplankton in the Coastal Area of the Southwestern Okhotsk Sea

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## ABSTRACT

Copepods mainly plays a role of the secondary producers, who transfers energy and materials from the phytoplankton such as diatoms to higher trophic levels. Copepod feeding contributes to transferring them. Feeding experiments of dominant copepods *Pseudocalanus newmani* and *Neocalanus plumchrus* collected from the coastal area of the southwestern Okhotsk Sea on large phytoplankton were done by using the food removal method. Feeding rates of *P. newmani* were higher than those of *N. plumchrus* when Chl-*a* concentrations was same level. Our results suggest that *P. newmani* plays potentially an important role for linking between large phytoplankton and higher trophic organisms during highest phytoplankton production period in the coastal area of the southwestern Okhotsk Sea.

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## Introduction to the subject

Okhotsk Sea is one of the highest productivity seas of higher trophic levels, such as walleye pollock, herring and Pacific salmon, all over the world's ocean (Radchenko *et al.*, 2010). In general, it is considered that higher fish production is supported by higher production of lower trophic levels, such as plankton, short trophic levels between food chain, such as large phytoplankton (diatoms)–copepods–fish, and higher ecological efficiency between trophic levels (Ryther, 1969). In Okhotsk Sea, plankton productivities are also high (Sorokin & Sorokin, 1999). In the southwestern Okhotsk Sea, large phytoplankton with >10 µm showed important primary producers during May to September (Shiimoto, 2011). Thus, higher productivity in Okhotsk Sea could be caused by higher production of large phytoplankton and higher ecological efficiency from large phytoplankton to copepods.

Copepods predominates marine zooplankton assemblages both in number and biomass over the world oceans (Hardy, 1965; Longhurst, 1985). Copepods mainly plays a role of the secondary producers, who transfers energy and materials from large phytoplankton such as diatoms to higher trophic levels such as carnivorous zooplankton and fishes (Runge, 1985; Lali & Parsons, 1993). Their grazing also enhances downward flux of organic materials from planktonic to benthic ecosystems (Taguchi & Saino, 1998; Ducklow *et al.*, 2001). In the coastal area of the southwestern Okhotsk Sea, calanoid copepods, *Pseudocalanus newmani* and *Neocalanus plumchrus*, dominated during ice-free

season (Asami *et al.*, 2007; Nakagawa *et al.*, 2016). Therefore, to utilize sustainably the fishery resources in both the pelagic and benthic ecosystems, it is essential prerequisite to understand feeding ecology, especially feeding on large phytoplankton, of dominant copepods, *P. newmani* and *N. plumchrus*, in the coastal area. *Pseudocalanus* spp. ingested efficiently larger particles with  $>8 \mu\text{m}$  (Corkett & McLaren, 1978). Feeding of *Neocalanus* spp. in the subarctic Pacific Ocean also preferred on large sized prey including phytoplankton and ciliates (Dagg *et al.*, 2009). However, there is no information on their feeding properties using copepods distributed in Okhotsk Sea. The present study was aimed to examine feeding rate of dominant copepods on large phytoplankton in the southwestern Okhotsk Sea.

## Methodology

### *Collection of Copepods*

Copepods were collected by a vertical haul with a ring net (60 cm in diameter, 150 cm long and 0.20 mm mesh size) from 30 m depth at a sampling site (44°8'57.0"N, 144°14'48.0"E) fixed to the coastal area of southwestern Okhotsk Sea from April 2014 to June 2015.

### *Feeding experiments*

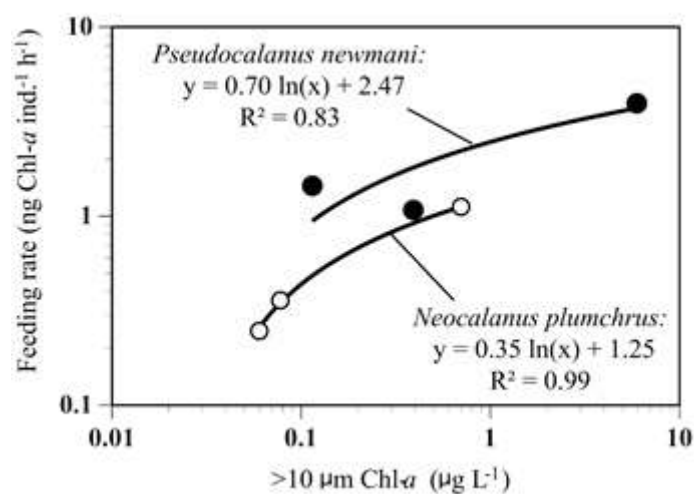
Feeding experiments of copepods on large phytoplankton were done by using the food removal method (Båmstedt *et al.*, 2000) in six 2-L polycarbonate bottles—three with copepods and three control bottles without copepods. All bottles were filled with the surface seawater, which was removed larger zooplankton with 160  $\mu\text{m}$  mesh filter, at a sampling site. Lively 3-5 mixture copepodites of *Pseudocalanus newmani* or *Neocalanus plumchrus*, which selected randomly from the collected samples and identified under a microscope, were transferred gently into 3 experimental bottles by a glass pipet. Feeding experiments were carried out 24 h under the dark condition. The bottles were kept in water bath with surface water temperature at sampling time. Water samples of 200 mL were collected from each bottle at the start and end of the experimental period, and were filtered through a 10- $\mu\text{m}$  polycarbonate filter. The plant pigments of  $>10 \mu\text{m}$  phytoplankton on the filter were extracted in 7 mL N, N-dimethylformamide. Concentrations of chlorophyll *a* were determined following Welschmeyer (1994) using a fluorometer (10-AU; Turner Designs). The feeding rates of copepods on chlorophyll *a* (Chl-*a*) of large phytoplankton were calculated with a modification of Frost's (1972) equation (Båmstedt *et al.*, 2000).

## Result and discussion

Feeding of copepods is influenced by physiological and environmental factors (Thompson *et al.*, 1994). Among their factors, food concentration has a huge effect on copepod feeding rate (Paffenhöfer & Harris, 1976). In the present study, feeding rates of *Pseudocalanus newmani* ranged from 1.4–4.0 ng Chl-*a* ind. L<sup>-1</sup> h<sup>-1</sup>, while >10 µm Chl-*a* concentration were from 0.11–5.95 µg L<sup>-1</sup> (Table 1).

**Table 1.** Feeding rates on large phytoplankton and experimental conditions.

Species	Date	Temp. (°C)	>10 µm Chl- <i>a</i> (µg L <sup>-1</sup> )	Feeding rate (ng Chl- <i>a</i> ind. L <sup>-1</sup> h <sup>-1</sup> )
<i>Pseudocalanus newmani</i>	Apr. 16-17, 2014	4.0	0.11	1.4
	Nov. 10-11, 2014	8.0	0.39	1.1
	Apr. 1-2, 2015	2.3	5.95	4.0
<i>Neocalanus plumchrus</i>	Jun. 23-24, 2014	8.6	0.06	0.2
	May 11-12, 2015	4.9	0.08	0.4
	Jul. 7-8, 2015	12.0	0.70	1.1



**Figure 1.** Relationship between feeding rates of dominant copepods *Pseudocalanus newmani* (closed circle) and *Neocalanus plumchrus* (open circle) on large phytoplankton and its abundance.

Highest rate of *P. newmani* was found in April of 2015 (Table 1). *Neocalanus plumchrus* feeding rates ranged from 0.2–1.1 ng Chl-*a* ind. L<sup>-1</sup> h<sup>-1</sup>, while Chl-*a* were from 0.06–0.70 µg L<sup>-1</sup> (Table 1). Highest rate of *N. plumchrus* was in November of 2015 (Table 1). Feeding rates of *P. newmani* and *N. plumchrus* on >10 µm Chl-*a* as a large phytoplankton increased with increasing Chl-*a* concentration in the experimental bottles (Figure 1). In the coastal area of the southwestern Okhotsk Sea, *P. newmani* and *N. plumchrus* are dominant species during ice-free season (Nakagawa *et al.*, 2016). In

this area including lagoons connected to the Okhotsk Sea, large phytoplankton standing stocks, mainly diatoms, increased and dominated during April to June (Shiomoto, 2011; Nishino *et al.*, 2014; Nakagawa *et al.*, 2015). Also >10 µm Chl-*a* concentration in April of 2015 was highest value in the present study (Table 1). During this period, juvenile chum salmon, *Oncorhynchus keta*, occupy the coastal area around their natal rivers (Bradford, 1995). Juvenile chum salmon utilized *P. newmani* and *N. plumchrus* as one of the main prey in the coastal area (Nagata *et al.*, 2007). In the present study, feeding rates of *P. newmani* were higher than those of *N. plumchrus* when Chl-*a* concentrations were same level (Figure 1). Our results suggest that *P. newmani* potentially plays an important role for linking between large phytoplankton and higher trophic organisms during highest phytoplankton production period in the coastal area of the southwestern Okhotsk Sea.

### Conclusion

Feeding experiments of dominant copepods collected from the coastal area of the southwestern Okhotsk Sea on large phytoplankton were done by using the food removal method. Feeding rates of *P. newmani* were higher than those of *N. plumchrus* when Chl-*a* concentrations was same level. Our results suggest that *P. newmani* plays potentially an important role for linking between large phytoplankton and higher trophic organisms during highest phytoplankton production period in the coastal area of the southwestern Okhotsk Sea.

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