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ICE ALGAE AS FOOD OF AN ANTARCTIC ICE-ASSOCIATED COPEPOD, *PARALABIDOCERA ANTARCTICA* (I. C. THOMPSON)

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Abstract: To investigate the food source of an Antarctic ice-associated copepod, *Paralabidocera antarctica* (I. C. THOMPSON), the gut contents of the nauplius, copepodite and adult of this species were observed with a scanning electron microscope. Materials observed were collected in the ice-covered sea near Syowa Station (69°00′S, 39°35′E), Antarctica. Remains in the gut consisted of ice-associated diatom frustules, their fragments, and siliceous cyst-like organisms. This indicates that *P. antarctica* utilizes ice biota which consisted mainly of diatoms as the main food source.

1. Introduction

The importance of ice algae as the primary producers in the marine Antarctic ecosystems has been emphasized since the 1960's. It has been generally thought that ice-associated animals feed directly on ice-algae, zooplankton eat ice algae which were released into sea water from the sea ice and also benthic animals utilize sedimented ice algae as the food along with other organic matters. However, few reports have dealt with the relationship between ice algae and their consumers in the Antarctic.

RICHARDSON and WHITAKER (1979) clarified the dietary relation of an amphipod, *Pontogeneia antarctica* CHEVREUX to the ice algae in Signy Island. Based on the observation that the nauplii (stages I to VI) and copepodites (stages I to III) of *Paralabidocera antarctica* (I. C. THOMPSON) are distributed mainly in the interstices between ice crystals in the bottom of sea ice between autumn and early spring and, at the stage of copepodite IV they shift into the sea water, HOSHIAI and TANIMURA (1986) suggested that *P. antarctica* possibly fed on ice algae. In this report, we give a result of a floristic survey of the gut remains of *P. antarctica* of all developmental stages in conjunction with the flora of their habitat.

2. Materials and Methods

Nauplius and copepodite stages I to III specimens used in the present study were sorted from the copepod samples obtained from the bottom part of ice cores. The ice cores were taken with a SIPRE ice auger in the vicinity of Syowa Station (69°00′S, 39°35′E) in 1970 and 1975. Specimens of copepodite stages IV, V and VI (=adult) were sorted from the copepod samples which were collected from the sea water just

Table 1. List of gut contents of P. antarctica *collected from the bottom layer of the sea ice.*

Date	1970 Apr 9	1975 May 1		1975 July 3		1975 Aug 31		
Stages	N I	N II	N III	NIV	N V	N IV	N V	N VI
Ind. no. observed	31	31	42	42	32	31	37	26
Amphiprora kufferathii					+		+	+
Berkeleya rutilans				+	+			
Navicula directa				+?				
Navicula glaciei								
Nitzschia cylindrus				+	+			
Nitzschia obliquecostata								
Pinnularia quadratarea						+?	+	+
Pleurosigma directa								
Amphora sp.								
Gomphonema sp.				+	+	+	+	
Navicula spp.				+	+	+	+	+
Nitzschia spp. (sec. Fragilariopsis)				+	+			+
Nitzchia spp. (other secs.)				+	+			+
Synedra spp.						+		+
Unidentified Pennate spp.				+	+	+	+	+
Porosira pseudodenticulata								
Tharassiosira australis								
Tharassiosira spp.							+	+
Unidentified Centric spp.				+	+	+		+
Siliceous cyst-like organisms								

Table 1 (continued).

Date	1975 Oct 2				1975 Nov 7	
Stages	N V	N VI	C I	C II	C II	C III
Ind. no. observed	33	28	4	6	4	3
Amphiprora kufferathii	+	+	+	+	+	+
Berkeleya rutilans		+				
Navicula directa						
Navicula glaciei			+	+	+	+
Nitzschia cylindrus	+?		+	+	+	
Nitzschia obliquecostata						+
Pinnularia quadratarea	+?	+				
Pleurosigma directa						+
Amphora sp.						
Gomphonema sp.					+?	+?
Navicula spp.					+	
Nitzschia spp. (sec. Fragilariopsis)						+
Nitzschia spp. (other secs.)						+
Synedra spp.	+?	+?			+	+
Unidentified Pennate spp.	+	+			+	+
Porosira pseudodenticulata						
Tharassiosira australis					+	
Tharassiosira spp.		+				
Unidentified Centric spp.	+					
Siliceous cyst-like organisms					+	+

+: present.

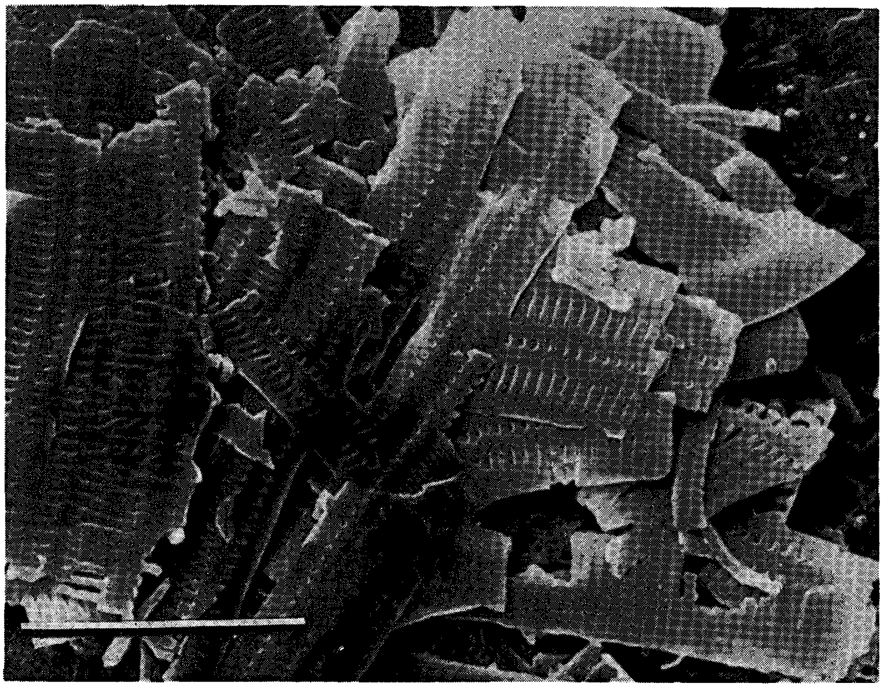

Fig. 1. Fragments of pennate diatom species, A. kufferathii, *in the gut of copepodite stage II collected from sea ice on October 2, 1975. Scale bar=10 μ.*

Table 2. List of species in ice algal assemblage in the bottom layer of the sea ice in the 1975 winter.

Date	1975 July 3	1975 Aug 31	1975 Oct 2	1975 Nov 7
Amphiprora kufferathii	++	∘	+++	++
Berkeleya rutilans	+	∘	++	+++
Navicula directa			∘	
Navicula glaciei	∘		∘	∘
Nitzschia cylindrus	∘			∘
Nitzschia obliquecostata		∘		∘
Pinnularia quadratarea		++	∘	∘
Pleurosigma directa		∘		
Amphora sp.				
Gomphonema sp.		∘		
Navicula spp.	∘			
Nitzschia spp. (sec. Fragilariopsis)	∘		∘	
Nitzschia spp. (other secs.)	+	∘	∘	∘
Synedra spp.	∘		∘	∘
Unidentified Pennate spp.				
Porosira pseudodenticulata	∘			∘
Tharassiosira australis	∘	+	+	∘
Tharassiosira spp.				∘
Unidentified Centric spp.				
Siliceous cyst-like organisms				

+++: abundant, ++: frequent, +: common, ∘: rare.

beneath the sea ice with a NIPR-I sampler (FUKUCHI *et al.*, 1979) at the same locality as above in the 1982/83 summer.

For the scanning electron microscopic (SEM) observation oı gut contents of the copepod, three to 42 individuals of nauplius and copepodite which belong to one developmental stage were selected in proportion to their numbers in samples. After repeating careful rinse with fresh water, copepods were melted in the heated conc. sulfuric acid. The whole liquid was filtered through a Nuclepore filter. The remains on the filter were rinsed with distilled water, sputter-coated with Au and examined with a scanning electron microscope (JEOL, T-100). Floristic observation of diatom in the bottom part of sea ice was also made with the above SEM, after cleaning diatom frustules (SIMONSEN, 1974) and the sputter coating.

3. Results

Although no remains of diet appeared from the gut of nauplius stages I, II and III, diatom frustules and/or their fragments were found in the gut of nauplius stages IV, V and VI and copepodite stages I, II and III, all of which were collected from the sea ice (Table 1). The occurrence of diatom species is shown with a cross in Table 1 regardless of their abundance. The majority of frustules and their fragments that appeared were of pennate diatoms. Common species found from nauplii were *Am-*

Table 3. List of gut contents of P. antarctica *collected from the water layer just beneath the sea ice.*

Date	1982 Nov 15		1982 Dec 2		1982 Dec 17		1983 Jan 15	
Stage	C IV (♀)	C IV (♂)	C V (♀)	C V (♂)	C VI (♀)	C VI (♂)	C VI (♀)	C VI (♂)
Ind. no. observed	4	4	4	5	5	5	12	12
Amphiprora kufferathii	+	+	+		+	+	+	+
Berkeleya rutilans								
Navicula directa		+?						
Navicula glaciei	+	+	+		+	+	+	+
Nitzschia curta							+	+
Nitzschia cylindrus		+						
Nitzschia obliquecostata	+	+		+?				
Pinnularia quadratarea			+	+	+	+		+
Pleurosigma directa	+	+	+	+				
Amphora sp.								+?
Gomphonema sp.			+	+				+
Navicula spp.		+				+	+	+
Nitzschia spp. (sec. Fragilariopsis)	+	+				+		
Nitzschia spp. (other secs.)	+		+			+	+	+
Synedra spp.	+		+		+	+		+
Unidentified Pennate spp.	+	+	+				+	+
Porosira pseudodenticulata	+?							
Tharassiosira australis						+?		
Tharassiosira spp.			+					+
Unidentified Centric spp.				+		+		+
Siliceous cyst-like organisms						+	+	+

+ : present.

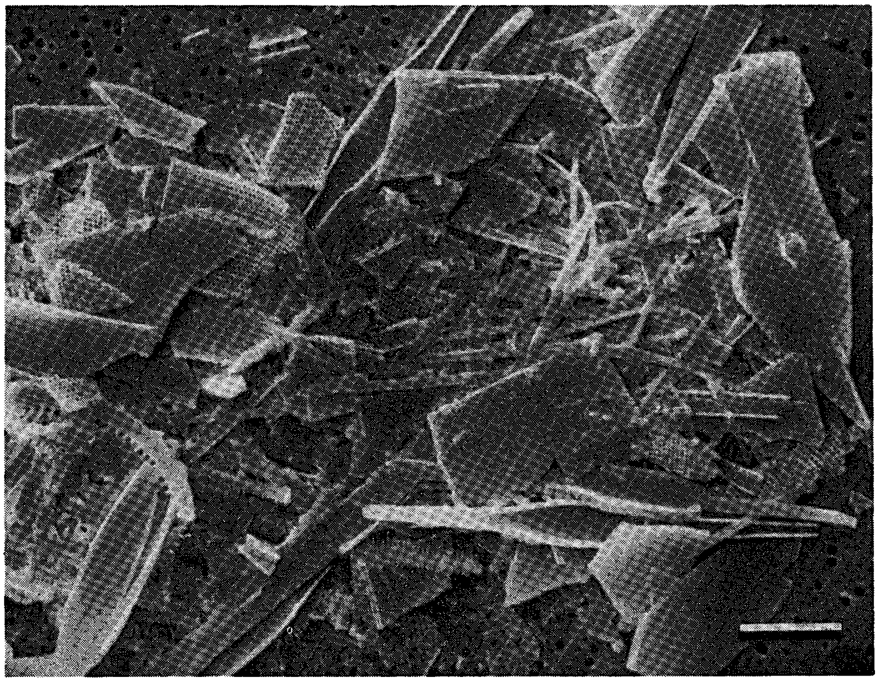

Fig. 2. Fragments of pennate species, P. directum, Synedra *sp., etc., in the gut of copepodite stage IV collected from sea water on November 15, 1982. Scale bar=10 μ.*

phiprora kufferathii, *Pinnularia quadratarea* and *Gomphonema* sp., followed by *Berkeleya rutilans* and *Nitzschia cylindrus*. *A. kufferathii*, *Navicula glaciei* and *N. cylindrus* were commonly observed from copepodites (Fig. 1). In addition to the above species, fragments of species of *Navicula*, *Nitzschia*, *Synedra* and other pennates were contained in the copepodite guts except for the copepodites collected on October 2. The abun-

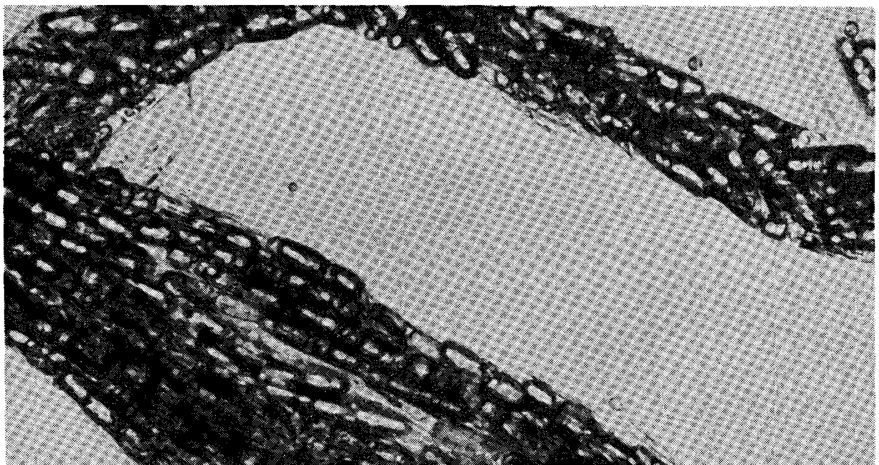

Fig. 3. A colony of tube-dwelling pennate diatom species, B. rutilans, *collected from undersurface of fast ice near Syowa Station. Scale bar=100 μ.*

dance of frustules and their fragments was high in the copepodite in comparison with the nauplius, though the exact enumeration of the copepodite gut contents could not be done because of overlapping on the filters used for SEM observation.

Compositions of ice algal assemblages in the bottom sea ice sampled in 1975 are shown in Table 2. They were composed of, primarily, pennate diatoms and, secondarily, centric species. The species which appeared as the numerical dominants were *A. kufferathii*, *B. rutilans* and *P. quadratarea*. There is a good agreement in the species composition of diatoms in the dietary remains in the gut of *P. antarctica* and of the ice algal assemblages, except for *B. rutilans* which was not commonly found from the gut of copepods in spite of its abundance in the sea ice.

Gut contents of copepodite stages IV, V and VI collected from the water layer in the 1982/83 summer are shown in Table 3. The species identified were principally common to those of gut contents of nauplii and copepodites inhabiting sea ice and also of ice algae (Fig. 2). Because *P. antarctica* at these stages feed in the water layer, phytoplankton collected with a plankton net from November 1982 to January 1983 were coarsely examined. The species composition of phytoplankton was generally similar to that of ice algae.

4. Discussion

HOSHIAI and TANIMURA (1986) reported that *P. antarctica* survived through the winter season in the sea ice and the growth of its juveniles occurred in May–June and October–November. At these times, the ice algal concentration in the sea ice bottom is high (HOSHIAI, 1981) but the phytoplankton standing crops is low (FUKUCHI *et al.*, 1985). They suggested that of *P. antarctica* fed on ice algae. In general, the gut contents do not always reflect the composition of ingested food because of digestion. Furthermore, in the present investigation, food substances other than hard siliceous shells are decomposed by the sulfuric acid treatment. However, the common appearance of ice diatoms in the *P. antarctica* gut and the sea ice reveals that *P. antarctica* depends upon at least the diatoms and possibly other microorganisms that are either digested or decomposed by the sulfuric acid treatment.

The abundance of diatom frustules and their fragments was higher in the gut of copepodites than in the gut of nauplii. The growth of nauplius into copepodite occurred in October–November (HOSHIAI and TANIMURA, 1986) and a remarkable increase of ice algal biomass was observed in the same season (HOSHIAI, 1981). As shown in Table 2, *B. rutilans* frequently appeared as one of the dominant species of ice diatoms in the Syowa Station area. This species, however, did not occur in the gut contents of copepodites (Table 1). It seems that *P. antarctica* could not ingest *B. rutilans* because *B. rutilans* lined in a colony covered with a tube (Fig. 3).

After shifting in the sea water, the species composition of diatoms in the gut contents of *P. antarctica* reflected that in the water column, which also resembled that of species composition of diatoms in the sea ice. This indicates the close food relation of *P. antarctica* to the ice-associated species that were found in the sea water. However, whether the ice-associated species in the water column are those released from sea ice or those newly developed from the inoculum derived from sea ice is a problem to be solved in the future.

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