

Diets of Three Copepods (Poecilostomatoida) in the Southern Taiwan Strait

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Cheng-Han Wu, Jiang-Shiou Hwang and Jui-Sen Yang (2004) Diets of three copepods (Poecilostomatoida) in the southern Taiwan Strait. *Zoological Studies* 43(2): 388-392. Gut contents of 3 copepods including *Oncaea venusta*, *O. mediterranea*, and *O. conifera*, of the southern Taiwan Strait were picked out using a fine needle under a stereomicroscope and then examined with scanning electron microscopy (SEM). The major components of the diets of the 3 copepods were the diatoms *Chaetoceros* sp. and *Thalassiothrix* sp., although radiolarian, microzooplanktonic, and copepod debris was also found in the gut contents. The 3 copepods seemed to feed non-selectively, as the diets were determined to be diverse. The technique of examining the picked-out gut contents with SEM was developed and determined to be useful in studying the diets and feeding ecology of copepods. <http://www.sinica.edu.tw/zool/zoolstud/43.2/388.pdf>

Key words: Diet, Copepod, Taiwan Strait, Gut content, SEM.

Copepod diets have been studied to understand copepod significance in terms of secondary production in ocean environments (Kleppel et al. 1991, Irigoien et al. 2002). Poecilostomatoida copepods have been considered to be mainly omnivorous or carnivorous (Go et al. 1998). However, the question of whether copepods feed selectively or non-selectively has not been resolved due to difficulties in identifying the diets of copepods and is still being debated (Kleppel 1993). Dinoflagellates, diatoms, and microzooplankton were reported in copepod diets through examination of fecal pellets (Stoecker and Capuzzo 1990, Turner 1991, Turner et al. 2001).

Feeding studies are considered a possible method to characterize the copepod diet. Copepod feeding behavior was consistent with the predictions of optimal foraging theory (DeMott 1989) in 1 feeding study. However, in the ocean, the taxonomic and biochemical complexity of the food environment makes it difficult to apply the theory to copepod feeding (Kleppel 1992). To study copepod feeding, a technique to investigate the details of the diet is necessary. Much previous

work on copepod feeding ecology examined fecal pellets by scanning electron microscopy (Turner 1978, 1984a b 1986 1987 1991 2002), although some copepodologists have directly examined copepod diets in the gut (Decho and Fleeger 1988, Ohtsuka et al. 1993, Nishida and Ohtsuka 1996, Go et al. 1998). Apparently, it is not easy to determine the composition of copepod food through analysis of fecal pellets, the products remaining after digestion. As the technology with electron microscopy became available, more-realistic, complex, and revealing studies were feasible. In the present work, we attempted to establish a method to directly investigate copepod diets in the gut. Reliable in situ information on the content of the copepod gut is presented by a method using scanning electron microscopy.

MATERIALS AND METHODS

Copepods were collected during the day and at night using a multiple plankton sampler (MPS 92B, Hydro-Bios, Kiel-Holtenau, Germany). The

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multiple plankton sampler consisted of a deck command unit and an underwater unit with 5 plankton net bags of 300- μ m mesh size. Samples were taken at 22°N, 119°E, and 22°N, 120°E during 16 to 24 Apr. 1996 and at 22°N, 120°E during 1 to 4 Nov. 1997 in the southern Taiwan Strait. The MPS was loaded vertically at depths of 100, 200, 300, 400, and 500 m beneath the sea surface. With the research vessel moving at around 1 m/s (2 knots) the net was hauled horizontally at each depth. To collect copepods on the sea surface, a zooplankton net with a 1.0-m mouth diameter, a 4.5-m length, and with a 300- μ m mesh was used. As soon as the samples were collected from the ocean, specimens were placed in fixatives consisting of 3% glutaraldehyde and 3% paraformaldehyde in phosphate buffer (pH 7.2, 0.2 M). Specimens in the fixative were kept in a refrigerator (4°C) in the research vessel for transport back to the laboratory. With a stereomicroscope, *Oncaea venusta*, *O. mediterranea*, and *O. conifera* were identified, selected, and separated into different vials for further fixation.

The separated copepods in different vials were re-fixed in a new solution of glutaraldehyde (3%) and paraformaldehyde (3%) fixatives for an additional 2 h. After being washed in phosphate buffer 5 times for 20 min each time, specimens were postfixed in 1% osmium tetroxide for 2 h, washed with phosphate buffer 5 times and then dehydrated in an ethanol series (50%, 75%, 85%, 95%, 100%, and 100%) for 20 min each step. After dehydration, specimens were placed in amyl acetate for 30 min and dried using a critical point dryer (Hitachi HCP-2, Japan). With a stereomicroscope and a fine needle (0.1 mm in diameter), the gut contents were picked out from the fixed, dried

copepods. The contents of the guts were placed on stubs and then coated in a sputter-coater (Hitachi E101). Gut contents were investigated using a scanning electron microscope (Hitachi 2400).

RESULTS AND DISCUSSION

Copepods were fixed very well with the primary fixative consisting of formaldehyde and glutaraldehyde and the post-fixative of osmium tetroxide, and showed very good features (Fig. 1). Gut contents were successfully picked out with a fine needle under a stereomicroscope. The gut contents were placed on stubs for investigation with a scanning electron microscope. The results showed the ecological and physiological significance of dietary diversity.

In the gut contents of *Oncaea venusta*, the diatoms *Chaetoceros* sp. (Fig. 2) and *Thalassiothrix* sp. (Table 1) were commonly found. Debris of zooplankton was also found in the copepod guts. *Oncaea mediterranea*, *O. conifera*, and *O. venusta* all exhibited a consistent pattern with respect to gut contents (Figs. 3, 4). Radiolarian and copepod debris also observed in the gut con-

Table 1. Organisms in the gut contents of the 3 copepods, *Oncaea venusta*, *O. mediterranea*, and *O. conifera*

	Average diameter (μ m)	Average length (μ m)	Percent (%)
Diatoms			
<i>Chaetoceros</i> sp.	9.9	1.4	27.5
<i>Thalassiothrix</i> sp.	3	11.2	3.8
Unidentified	3.3	7.4	55.1
Radiolarians	11	15	5.1
Copepod debris	18.4	56	8.5

^aThe gut contents of 71 copepods were examined by scanning electron microscopy.

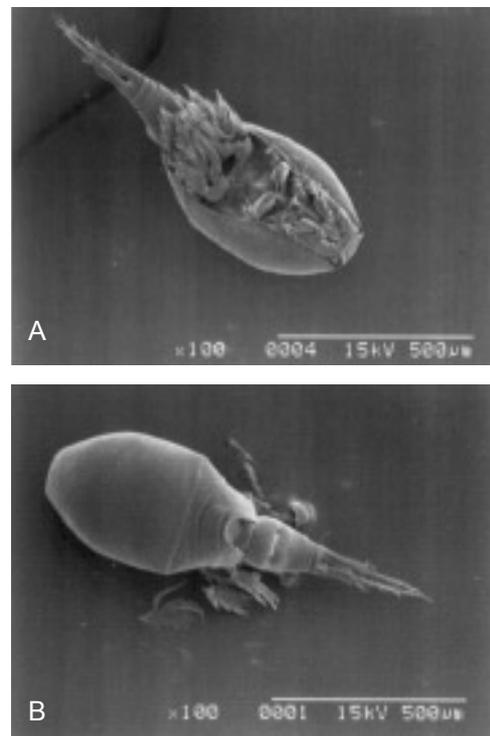


Fig. 1. SEM micrographs of copepod. A: ventral view of *Oncaea venusta*. B: dorsal view of *O. venusta*.

tents (Fig. 5). However, in the southern Taiwan Strait, the major contents found in the gut of copepods were diatoms, which are plentiful in ocean.

Particle sizes of gut contents ranged from 0.16 to 18.4 μm in diameter and from 2 to 56 μm in length. Spine debris of the diatoms *Chaetoceros*

sp. in the gut was 1.37 μm in diameter x 9.92 μm in length (Fig. 6). The biggest particle found in the gut was debris of copepods with a size of 18.4 μm in diameter with 56 μm in length (Fig. 7). Gut contents of copepods in a natural ocean environment seem to have considerable diversity in particle size



Fig. 2. Contents of the gut of *Oncaea venusta* collected in the daytime at 22°N, 119°E, 100 m beneath the sea surface. ch, *Chaetoceros* sp. spine; D, diatom unidentified; cr, copepod debris.

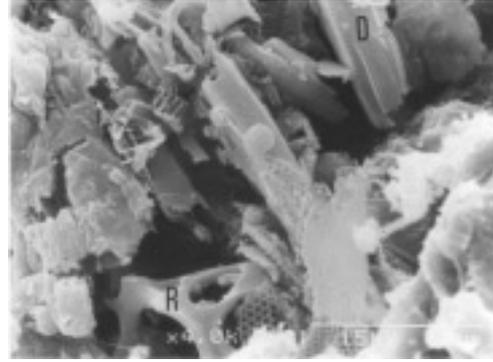


Fig. 5. Contents of the gut of *Oncaea conifera* collected in the nighttime at 22°N, 120°E, 100 m beneath the sea surface. D, diatom unidentified; R, radiolarian; F, food chyme.

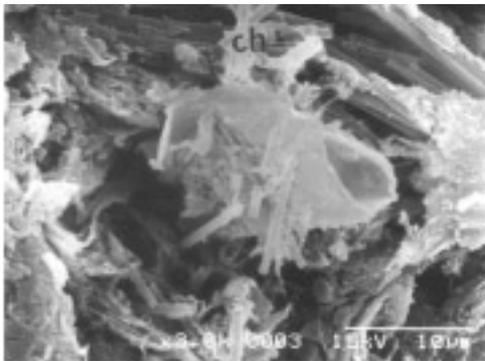


Fig. 3. Contents of the gut of *Oncaea mediterranea* collected in the daytime at 22°N, 119°E, 300 m beneath the sea surface. ch, *Chaetoceros* sp. spine;

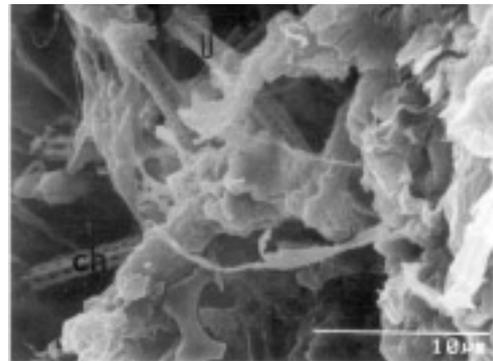


Fig. 6. Contents of the gut of *Oncaea conifera* collected in the daytime at 22°N, 119°E, 100 m beneath the sea surface. ch, *Chaetoceros* sp. spine; u, unidentified debris.

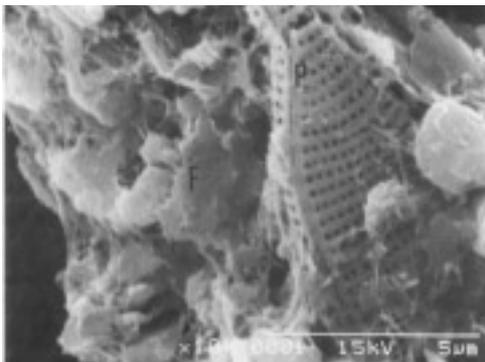


Fig. 4. Contents of the gut of *Oncaea conifera* collected in the daytime at 22°N, 119°E, 200 m beneath the sea surface. P, diatom unidentified; F, food chyme.

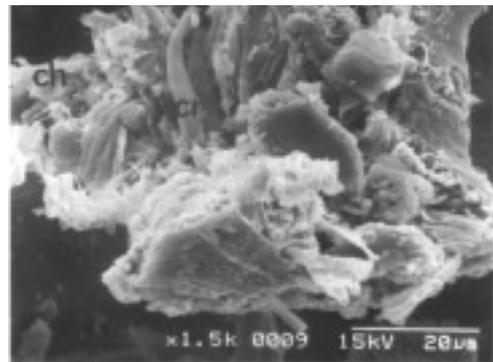


Fig. 7. Contents of the gut of *Oncaea venusta* collected in the daytime at 22°N, 119°E, 200 m beneath the sea surface. ch, *Chaetoceros* sp. spine; cr, copepod debris.

(Table 1).

The diets of the 3 species of copepods were diverse. Diatoms, dinoflagellates, and radiolarian and copepod debris were found in the guts of the 3 copepods. Zooplankton was occasionally found in the gut contents of *O. venusta* and *O. mediterranea* (Figs. 7, 8). Radiolarians were only seen in the gut of *O. mediterranea* collected 100 m beneath the sea surface in the southern Taiwan

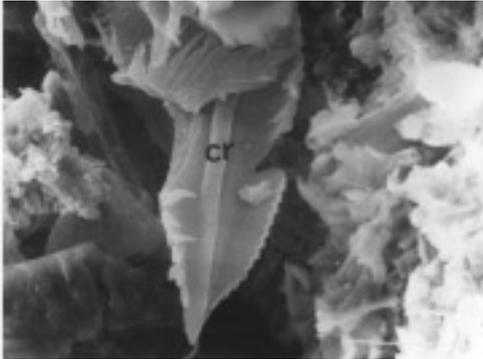


Fig. 8. Contents of the gut of *Oncaea mediterranea* collected in the daytime at 22°N, 119°E, 200 m beneath the sea surface. cr, copepod debris.

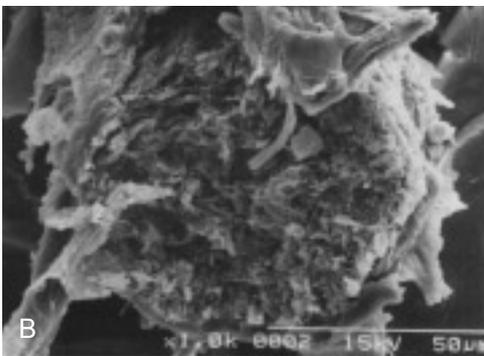
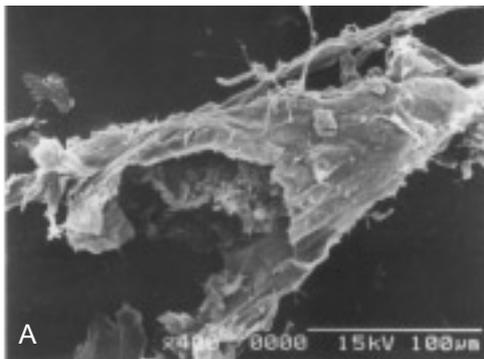


Fig. 9. A: Contents of the gut of *Oncaea conifera* collected in the daytime at 22°N, 120°E, 200 m beneath the sea surface. A half stomach and few gut content B: Contents of the gut of *Oncaea venusta* collected in the nighttime at 22°N, 119°E, 400 m beneath the sea surface. A digest tract full food debris.

Strait. Gut contents of copepods on the sea surface mostly consisted of diatoms. In the ocean, the feeding strategy of the 3 species appeared to be omnivorous, regardless of whether the strategy was selective (Go et al. 1998) or nonselective (Turner 1991). However, the 3 copepods seemingly fed non-selectively and ingested most particles that were available. Dietary diversity may enhance the nutritional value of rations (Kleppel 1993), and non-selective diverse diets have been associated with high production among copepods. In this study, most of the copepod guts examined were not fully expanded, although full guts were found in a few copepods (Fig. 9). The copepods might not feed continuously, and perhaps our sampling time was not at a feeding time. Therefore, identifying feeding times of copepods has become an interesting topic we will pursue in future work. However, in the marine ecology, feeding in the food chain is an important factor for copepod populations.

Bottle incubations have conventionally been used to study the daily ration and to objectively characterize diets of calanoid copepods (Kleppel et al. 1996). It was difficult to ascertain to what extent the food media used in incubation experiments simulated a natural situation (Escribano et al. 1997). Incubation studies do not give the true relationship between food availability and feeding by copepods, unless the contents of the gut are inspected. Light microscopy is not sufficiently detailed for examining gut contents. In the present work, a method of examining picked-out gut contents with scanning electron microscopy was developed, and the major organisms fed to the copepods were identified. This technique for examining diet contents in the copepod gut was successfully established for studying copepod diets.

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