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In situ observations on the surface swarm of *Euphausia pacifica* in Sendai Bay in early spring with special reference to their biological characteristics*

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Abstract: During early stage of the surface swarming of a euphausiid, *Euphausia pacifica*, swarming individuals were studied on their biological characteristics. The euphausiids do not seem to come to the surface to feed, because the stomach fullness is low and their probable food is not plentiful at the surface layer. Forty-six percent of the stomachs contained crystalline cones of euphausiid eye and 90 % contained crustacean spines, perhaps of thoracic legs of euphausiids. Cannibalism may take place during swarming. While all the males were in breeding condition, no females attached spermatophore. Although swarming of *E. pacifica* seems to be related to breeding behavior, mating would occur in the later period of the swarming season.

1. Introduction

Underwater observations on the behavior of euphausiid swarming at the sea surface are very important for understanding their swarming mechanism (HAMNER et al., 1983). We made observations on a swarm of *Euphausia pacifica* HANSEN by SCUBA diving on March 27, 1983 and reported the results (HANAMURA et al., 1984). Dimension and density of the swarm and orientation of individuals within the swarm, as well as their swimming speed were described. We could not observe feeding, defecation, mating or molting behavior in situ, contrary to the observation of HAMNER et al. (1983). The last authors observed mass molting in *E. superba*, which may act as decoys.

In this paper, we report the biological characteristics which were examined later on the euphausiid specimens collected from the same swarm to supplement in situ observations. This may provide detailed information to discuss the characteristic swarming behavior of dense aggregation of *E. pacifica* at the sea surface during daylight.

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2. Materials and methods

The swarm we observed was nearly circular in shape and about 20 m in diameter. The main body of the swarm lay below about 50 cm depth when diving operation started at 0900 hrs. Some small upward protrusions from the main body of the swarm, however, reached the surface, where euphausiids were jumping up into the air. Underwater observations of one particular swarm lasted about one hour at the location about 42.6 km SSW of Kinkazan Island. Water temperature was 6.7°C from the surface down to 23 m depth (HANAMURA et al., 1984).

A hand net, 23 cm in mouth diameter and 2.5×3.0 mm mesh aperture was used to collect *E. pacifica* from the upper surface of the swarm. Specimens were preserved in ca. 5 % formalin.

Measurements of body size were made using a Kogakusha® micrometer (precision: ±0.01 mm). The length of the sixth abdominal segment along the dorsal margin of each individual was measured, and converted to body length for each sex using equations derived by ENDO (1984). Body length denotes the length between the anterior tip of the rostrum and the posterior limit of the telson.

In *E. pacifica*, mating is performed by transfer of spermatophore from male to female.

Spermatophore transfer is inferred by examining either male ejaculatory ducts or female thelycum.

Stomach fullness and gut fullness were examined to assess the feeding activity of swarming individuals. Stomachs from 100 specimens randomly selected were removed and examined under a dissecting microscope to estimate fullness. Stomach fullness was scored into four classes (PONOMAREVA, 1971). Those 0-25 % full were placed in class I, those 25-50 % full in class II, 50-75 % full in class III and 75-100 % full in class IV. The stomach was then placed on a glass slide and dissected and its contents examined under a microscope. Gut fullness was also examined under a dissecting microscope by a little modified method of PAVLOV (1969). The gut was divided into seven sections corresponding to the six segments of the abdomen and that part of the body below the carapace. In each specimen the number of segments was counted which contained faecal matter.

After underwater observation, in order to compare the species composition of stomach contents of *E. pacifica* in the swarm with that outside the swarm, 1-*l* water samples were collected with Van Dorn water bottles at 0, 10 and 20 m depths, 24 km NNE of the location where the swarm was observed by SCUBA diving. When water sampling was tried at the same location where the swarm was found, the swarm had disappeared. At least in water temperature, no change was detected between these two locations. The water was preserved by adding ca. 10 m*l* of borax neutralized formalin just after sampling. The fixed samples were concentrated by a settling method to about 10 m*l* in the laboratory on land. Phytoplankton, microzooplankton and faecal pellets, etc. were counted under a Nikon MSDR inverted microscope.

In order to collect the eggs and larvae of euphausiids which might occur in the plankton, a Norpac net, 45 cm in diameter, 180 cm long and 0.35 mm mesh aperture, was hauled vertically from 20 m depth to the surface at the same location where the water samples were collected.

3. Results

Two hand net samples taken from different parts of the swarm revealed that the percentages of male were 61.9 and 63.4 %, which were significantly greater than 50 % ($p<0.01$).

Frequency of length of the sixth abdominal segment of each sex is shown in Fig. 1. The histograms somewhat skewed to right indicating that smaller individuals were undersampled.

Body length of males calculated ranged from 12.8 to 18.7 mm with a mean of 16.0 mm and that of females from 13.6 to 20.6 mm with a mean of 17.0 mm. As male *E. pacifica* carry spermatophores when they reach 8.5 mm and females larger than 9.5 mm have spermatophores attached in the Sanriku waters (ENDO, 1981), these individuals are mature. Neither eggs nor larvae of euphausiids were collected by the Norpac net.

All the males had developed spermatophores except those which had extruded both spermatophores recently. Seventeen percent of males were extruding or had extruded one or two spermatophores. No females, however, attached spermatophore.

Stomach fullness of swarming euphausiids was low. Seventy percent of them were in classes I and II. Gut fullness showed a parallel pattern with stomach fullness (Table 1). Weighted average of the number of gut segments which contain faecal matter increased with increasing stomach fullness. The same result was shown by PAVLOV (1969) in *E. superba*.

Table 1. Stomach fullness in 100 euphausiid specimens in the surface swarm. Number of intestinal segments which contain faecal matter was also tabulated with the weighted average for each stomach fullness.

Stomach fullness	n	No. intestinal segments which contain faecal matter							Weighted average
		1	2	3	4	5	6	7	
I	50	6	11	11	14	5	3	0	3.2
II	20	1	2	6	5	5	1	0	3.7
III	7	1	0	2	2	1	0	1	3.9
IV	23	3	3	2	3	6	3	3	4.2

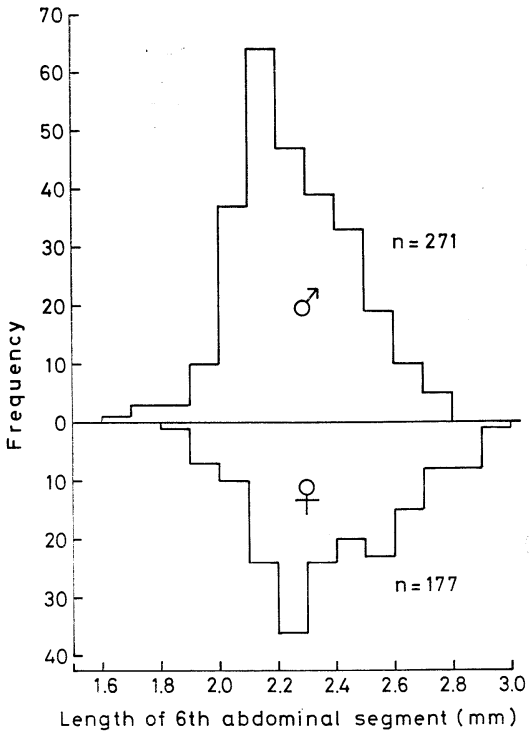

Fig. 1. Length-frequency histograms of 6th abdominal segment of male and female euphausiids collected from the surface swarm by a hand net.

Table 2. Frequency of occurrence of food items in stomachs of 100 euphausiids in the surface swarm.

Food item	Frequency
Detritus	95
Diatoms	2
Dinoflagellates	1
Foraminifera	12
Tintinnids	5
Acanthostomella norvegica	1
Parafavella sp.	2
Ptychocylis obtusa	1
Ptychocylis sp.	1
Crustaceans	90
Copepod abdomen	1
Copepod mandible	1
Crustacean spines	90
Crystalline cones of euphausiid eye	46
Crustacean fragment	5

Table 3. Plankton and other constituents identified in 1-*l* water samples collected at 0, 10 and 20 m depths by Van Dorn water bottles in Sendai Bay. Numbers of each category in 1-*l* water samples were shown.

	0 m	10 m	20 m
Diatoms	2,000	2,496	1,444
Asterionella glacialis	18	20	28
Bacteriastrum spp.		4	
Chaetoceros spp.	10	66	8
Corethron criophilum	14	74	20
Cylindrotheca closterium	60		
Denticulopsis seminae	4	4	6
Licmophora sp.	6	10	20
Melosira spp.	110	236	44
Nitzschia longissima	84	512	336
Nitzschia spp.	1,220	1,012	578
Paralia sulcata		4	180
Rhizosolenia sp.		6	
Thalassionema nitzschioides	20		
Thalassiosira spp.	124	68	14
Other centric diatoms	46	90	58
Other pennate diatoms	284	390	148
Dinoflagellates	56	60	110
Ceratium spp.		4	4
Peridinium sp.		2	
Podolampas sp.			2
Prorocentrum sp.		2	
Pyrocystis lunula	2		
Naked dinoflagellates	44	50	92
Others	10	2	12
Silicoflagellates	8	6	2
Coccolithophorids			52
Radiolarians			2
Tintinnids	8	4	6
Acanthostomella norvegica		2	
Helicostomella subulata	2		
Ptychocylis obtusa			2
Stenosemella pacifica			2
Tintinnopsis beroidea	6		
Tintinnopsis sp.		2	2
Naked ciliates	1,164	1,154	386
Crustaceans	10	46	22
Copepod nauplii	2	14	14
Copepodites			2
Copepods		6	4
Crustacean spines	6	6	
Crustacean fragments	2	20	
Crystalline cones of euphausiid eye			2
Faecal pellets	46	268	154

Unidentified detrital material with or without crustacean spines, perhaps from euphausiid, were the main constituent of the contents in volume in all but one case. In the latter case, only crystalline cones of euphausiid eyes were found. Among other components, foraminifera were rather frequently found, although only one or two individuals were found in a stomach (Table 2).

It is noticeable that 90 and 46 out of 100 specimens respectively fed on the crustacean spines and crystalline cones. Noticeable is also that a number of euphausiids (15.6 %) had broken eye.

Plankton in the water samples are listed in Table 3. Diatoms were most dominant in number in samples from all depths in spite of the fact that only 2 % of *E. pacifica* fed diatoms. Naked ciliates were also numerous. Foraminifera which were found in 12 % of stomachs could not be found in the water samples.

Two kinds of parasites were found: the ellobiopsid, *Thalassomyces* sp. (possibly *T. fagei*) and the suctorian, *Ephelota* sp. Infection rates of *E. pacifica* by *Thalassomyces* sp. and *Ephelota* sp. were 2.0 and 67.0 %, respectively.

4. Discussion

There have been several hypotheses concerning the causes of the daytime surface swarming of euphausiids as reviewed by KOMAKI (1967) and BROWN et al. (1979), i.e., (1) predators may drive euphausiids to the surface, (2) euphausiids may come to the surface to feed, (3) conditions of current and tide may accumulate euphausiids, or stimulate them to swarm at the surface, and (4) some internal demands related to maturation may drive euphausiids to the bright sea surface. Only first two hypotheses could be tested in the present study, because no observations on tide or current were made. The last hypothesis can not be proved without extensive laboratory experiments.

Although many sea gulls afloat above the swarm were feeding on euphausiids, no predators such as fishes were observed below the swarm. This was confirmed not only by direct observation of divers but also by the echogram (HANAMURA et al., 1984). The first hypothesis that the predators which hunt and pursue euphausiids from depths (cf. KOMAKI, 1967) was not applicable to this case.

Stomach fullness of swarming *E. pacifica* was apparently low compared with that in non-swarming ones. For example, more than 70 % of the population showed class IV stomach fullness at night in summer in the same area (ENDO, 1981). Although low stomach fullness does not necessarily mean non-feeding, *E. pacifica* in the present swarm might not come to the surface for feeding. Chlorophyll *a* crops and cell number of diatoms and ciliates were not largest at the surface layer where *E. pacifica* swarmed, but most abundant below the swarm (10 m). Only 2 diatom cells were found in 100 stomachs of euphausiids, although diatoms were the most plentiful organisms in the water.

Spines and crystalline cones of euphausiid were found in most stomachs. In a different swarm 42 % of stomachs also contained euphausiid spines, although no crystalline cone was found (ENDO, 1984). These results suggest that the cannibalism took place during swarming behavior of *E. pacifica*. FISHER and GOLDIE (1959) suggested that *Meganyctiphanes norvegica* eat the eye of its neighbor when the proportion of euphausiids to other organisms in the plankton is high. It is well known that euphausiid eyes are rich in vitamin A and astaxanthin (MAUCHLINE and FISHER, 1969).

Males slightly outnumbered females. Sex ratio of *E. pacifica* in swarms does not differ so greatly from unity (TERAZAKI, 1981; ENDO, 1984), as in *E. superba* (e.g. MARR, 1962) and *M. norvegica* (CASANOVA-SOULIER, 1970; BROWN et al., 1979; NICOL, 1984a), which exhibit highly variable sex ratios. BYRON et al. (1983) showed that the swarms of a copepod, *Diaptomus tyrreli*, were predominately composed of adult males. They suggested that these swarms have mating purpose and that males were predominate because mated females had dropped out as in the insect swarms. Such may also be the case with *E. pacifica* swarms, because males outnumbered females and the percentage of males tended to increase at the end of the swarming season (ENDO, 1984).

Males were fully mature. The percentages of males which were extruding or had extruded one or two spermatophores is 17.4 %, being

less than 47.8 %, the average value obtained in the 1978 swarming (ENDO, 1984). The difference may come from the methods by which euphausiids were collected. Specimens were scooped by a small hand net in 1983, while they were commercially caught by a bow mounted trawl in 1978. In the latter case much larger amount of euphausiids were caught at a time, many of which were exposed to damage and might be forced mechanically to extrude their spermatophores.

Fifteen out of 271 males (5.5 %), not females, attached spermatophores mainly to their gill. More than half of these males possibly attached their own spermatophores, considering the fact that 53 % of males with attached spermatophores had one or two empty ejaculatory ducts.

Sixty-seven percent of *E. pacifica* examined were infected by *Ephelota* sp. This suctorian was found also abundantly on *M. norvegica* from surface swarms in the Bay of Fundy (NICOL, 1984b). As suggested by NICOL, however, it is unlikely that the suctorian is the cause of surface swarming. We examined swarming *E. pacifica* collected in 1978–1983 for the presence of parasites. Percentage of *E. pacifica* infected by *Thalassomyces* sp. is rather constant, ranging from 0.6 % in 1978 to 5.5 % in 1982. More variable is that by *Ephelota* sp., ranging from 0 % in 1978 up to 67.0 % in 1983.

ENDO (1984) suggested that surface swarming of *E. pacifica* in the Sanriku coastal waters is related to breeding behavior, because the maturation of ovarian eggs and fertilization occur during the swarming season and eggs and early larvae of the species occurred most frequently about one month after the swarming season ended. In the present study, no females with attached spermatophore occurred. This is not incompatible with ENDO's hypothesis, because the present sampling was made in the middle of the swarming season. NICOL (1984a) suggested that *M. norvegica* swarming in the Bay of Fundy is related to reproductive activity by examining biological characteristics of swarming individuals.

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仙台湾で観察されたツノナシオキアミ (*Euphausia pacifica*) 濃密浮上群の生物学的特性

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要旨: 仙台湾でツノナシオキアミ *Euphausia pacifica* の濃密浮上群を潜水観察した際に採集した個体の生物学的特性を調べた。胃の充満度は全体に低く，現場海域の植物プランクトンは群が見られた表層よりも 10 m 層で多かったことから，摂餌のために表層で成群していたとは考えにくい。採集された個体の 46 % の胃中にオキアミ複眼の円錐晶体が，また 90 % の胃中にオキアミ胸脚の刺毛が見出された。共食いしている可能性がある。浮上群は成体だけから成り，雄の精莢は成熟していたが，精莢を付着させた雌は存在しなかった。成群浮上現象は繁殖行動と関係があると考えられるが，交尾は成群期間の後半に行われるのであろう。