

Surface Swarm and Shore Stranding of the Euphausiid *Euphausia nana* in the Seto Inland Sea, Japan

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Abstract The occurrence of a surface swarm and a subsequent stranding event of *Euphausia nana* Brinton, 1962, is reported for the first time from the western Seto Inland Sea, Japan. The euphausiid swarm consisted of fully mature adults, ranging in body length from 9.0 to 13.5 mm for both sexes. The swarm is considered a breeding population as over 60% of females were fertilized and almost all males had fully developed spermatophores either in the ejaculatory ducts or on the appendages or branchiae. The sex ratio was unbiased. Foregut analyses showed that the euphausiids had nearly empty stomachs, indicating low feeding activity during swarming behaviour at the sea surface. We assume that the swarming individuals of *E. nana* in the western Seto Inland Sea were transported from the Bungo Channel with the intrusion of a deeper water mass.

Key words: surface swarm, shore stranding, Crustacea, Euphausiacea, *Euphausia nana*, Seto Inland Sea

Euphausiid crustaceans play a key role in the oceanic ecosystem due to their abundance. They are primarily inhabitants of the meso- and bathypelagic zones, but some species occasionally occur in shallow waters, forming dense swarms at the sea surface. *Euphausia nana* Brinton, 1962, *E. pacifica* Hansen, 1911, and *Thysanoessa inermis* (Krøyer, 1846), are the species well known to form surface and subsurface swarms (or aggregations) seasonally in coastal waters of Japan. Swarming euphausiids have often been commercially exploited, particularly in northern Japan (Komaki 1967, Endo 1984, Hanamura *et al.* 1989, Hirota & Kohno 1992, Kuroda 1994, Nicol and Endo 1999).

On 30th March 2000, a surface swarm by numerous planktonic crustaceans was observed by local fishermen early in the morning in the inshore waters of Suo-nada, Seto Inland Sea (Fig. 1). Subsequently, a mass stranding of the euphausiid, *Euphausia nana*, was observed on a beach of Nagai-hama, Fukuoka Prefecture (Fig. 2).

Euphausia nana is distributed in the subtropical coastal waters of the western North Pacific, mainly occurring at depths of 200-400 m during the daytime and migrating to the upper 200 m at night (Hirota and

Kohno 1992, Sawamoto 1997). This species occurs in great abundance in the waters close to the west coast of Ehime Prefecture in the Bungo Channel during spring and summer. Euphausiid fisheries, based upon shallow water aggregations, have occurred under electric lights since the 1970s or before in Ehime Prefecture and the maximum landing was 5000 metric tons in 1988 (Hirota and Kohno 1992, Nicol and Endo, 1999).

Although *Euphausia nana* is sometimes found in the Seto Inland Sea (Kohno *et al.* 1996, Shibata pers. com.), euphausiids are not a major component of the marine community of the Inland Sea due to the shallow waters (average depth 38 m). Indeed, no literature has hitherto reported such a phenomenon.

This paper reports an unusual surface swarm and a subsequent stranding of *Euphausia nana* in the Seto Inland Sea, and includes biological information on the stranded population. The factors relating to this particular phenomenon are discussed.

Numerous individuals were obtained from euphausiids stranded on Nagai-hama beach, Fukuoka Prefecture, on the afternoon (around 14.00 hrs) of 30th March 2000. There is no doubt that the stranded euphausiids and those of the surface swarm had the

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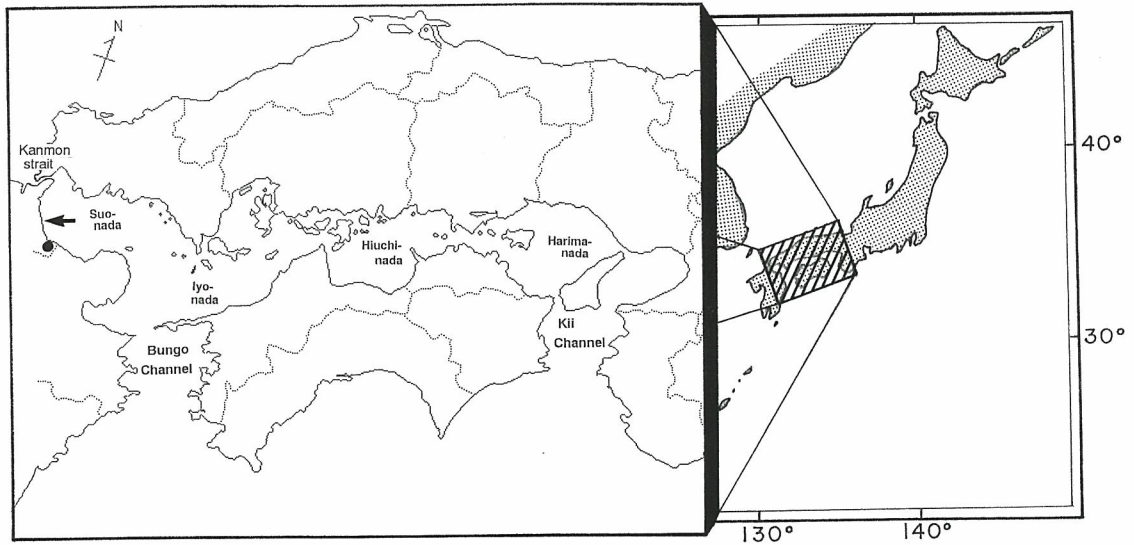


Fig. 1. Map of the Seto Inland Sea. Arrow indicates the stranding site and the Buzen-kai Laboratory in filled circle.

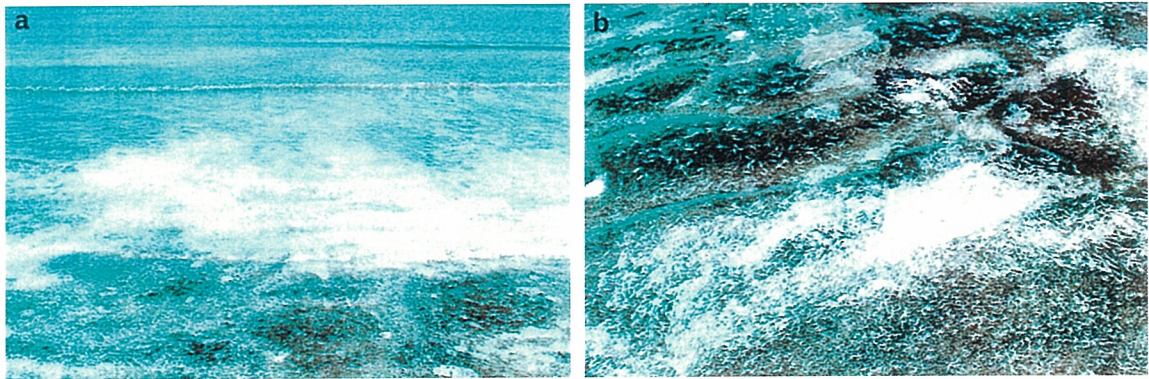


Fig. 2. Mass stranding of *Euphausia nana* in the Seto Inland Sea: a, strand line on a sandy beach (at 14:00 hrs); b, close-up of the strand line.

same origin. The sample was preserved immediately in 10% formalin and seawater. For each individual, the body length, from the rostrum to the median telson spine, was measured. The sex, presence or absence of an attached spermatophore, and external parasites were also noted. Stomach (= foregut) contents were analyzed for 30 selected specimens and gut fullness was determined on a scale of I to IV: (I) empty to 1/4 full, (II) half full, (III) 3/4 full and (IV) completely full (see Endo 1984).

Hydrographic and meteorological data were available from monitoring stations at the Buzen-kai Laboratory, located about 15 km SSE of the stranding site.

The observed euphausiids were all adults. The body size ranged from 9.0 to 12.2 mm (mean \pm SD = 11.0 ± 0.71 mm; $N = 84$) for males and from 9.3 to 13.5 mm (11.6 ± 0.73 mm; $N = 66$) for females, with females slightly larger ($p < 0.05$) (Fig. 3). The swarm was believed to be a breeding population as 61.2% females had a spermatophore at their thelycum

(fertilized). Furthermore, most males possessed spermatophores either in the ejaculatory ducts or on the pleopods or sometimes on the posterior branchiae. Unlike *Thysanoessa inermis* (see Hanamura *et al.* 1989), females of *Euphausia nana* consistently had only one spermatophore attached to their thelycum. The spermatophore is approximately 0.9 mm in length, 0.3 mm wide at the middle of the distal trunk, and also has a slightly narrow, short stalk and a massive basal disk. The spermatophores carried by males were filled with spermatomass, while those attached to a female thelycum contained only a small quantity of spermatomass.

Although our examination is limited, females of 11.8–12.5 mm in length had approximately 250–300 ovarian eggs. In contrast, many females carried fewer eggs than this, indicating they were probably post-spawners, or had partly shed their eggs.

Males constituted 55.6% of the sample ($N = 150$), although the proportional of males and females was not

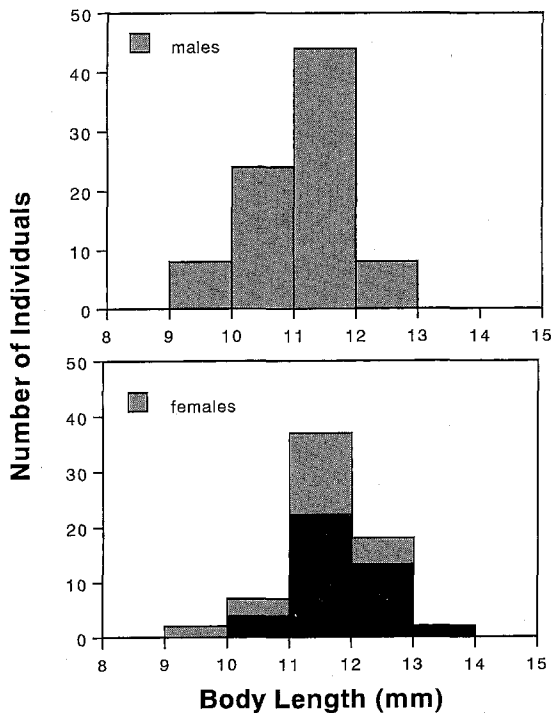


Fig. 3. Size frequency distribution of *Euphausia nana* (N = 150). Filled columns indicate females with a spermatophore on their thelycum.

significantly different (χ^2 test = 1.98, df = 1; $p > 0.05$). The sex ratio of the surface swarms of *Euphausia pacifica* in Sanriku coastal waters fluctuates around 50%, with a slight male predominance (Endo 1984), and those on the west coast of Hokkaido consists of 30–50% males (Kotori *et al.* 1995). In contrast, surface swarms of *Thysanoessa inermis* off the west coast of Hokkaido exhibit a sex ratio greatly biased towards females (65.2–96.9% females) (Hanamura *et al.* 1989).

Epibiont infestation sometimes has negative effects to crustacean host, including impair gas exchange, interfere with mobile activity and as a cause of stress. In the *Euphausia nana* sample, no external parasites were observed.

Stomach analyses revealed that approximately 70% of *Euphausia nana* had completely and/or nearly empty stomachs (Fig. 4); no clear difference between the sexes was observed (χ^2 test = 0.07, df = 1; $p > 0.05$). This indicates that the swarming *E. nana* did not engage in feeding activity. Previous observations in Japanese waters have shown similarly low gut fullness in *E. pacifica* and *Thysanoessa inermis* from daytime surface swarms, suggesting low feeding activities during swarming behaviour at the sea surface (Endo 1984, Hanamura *et al.* 1989, Kotori *et al.* 1995). Suh *et al.* (1998) also observed that individuals of *E. pacifica* from daytime swarms in the south-west Sea of Japan possessed nearly empty stomachs, in contrast to individuals from nighttime swarms which had more

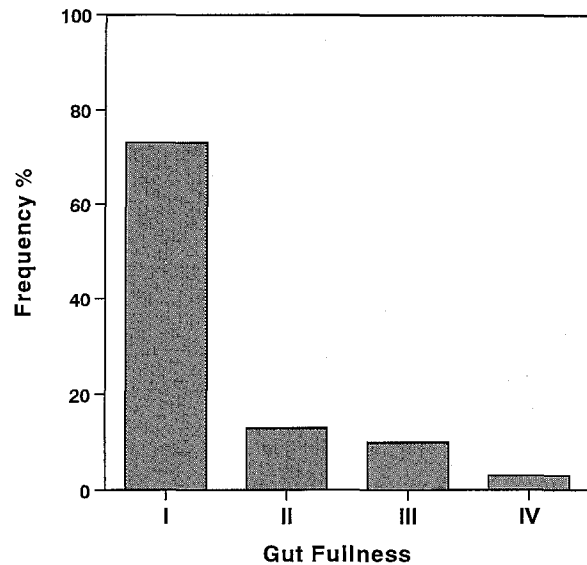


Fig. 4. Gut fullness of *Euphausia nana*: I, empty to 1/4 full; II, half full; III, 3/4 full; IV, completely full.

than half full guts. Stomach contents of *E. nana* mainly consisted of small quantities of detritus and crustacean setae. Unidentified egg-like materials were infrequently found.

Our understanding of the mechanisms which induce surface swarms of euphausiids are far from complete. Endo (1984) stated that surface swarms of *Euphausia pacifica* in Sanriku coastal waters correspond with breeding behaviour. In contrast, Kodama and Izumi (1994) suggested that surface swarms of this euphausiid are strongly related with the southward intrusion of the cold Oyashio Current. Similarly, several authors have discussed the formation of surface swarms in *E. pacifica*, giving more weight to physical rather than physiological factors as causes (Komaki 1967, Nishikawa *et al.* 1995, Kotori *et al.* 1995).

Daily meteorological data from the Buzen-kai laboratory indicated that westerly winds intensified from 28th March 2000 (Kamizono pers. obs.). In association with this, the near bottom water temperature in the coastal area of Buzen-kai noticeably decreased, reaching a minimum on 30th March, when the surface swarm of *Euphausia nana* occurred (Fig. 5). Therefore, it is unlikely that the euphausiids invaded the Inland Sea with the warm Tsushima Current via the Kanmon Strait. The westerly wind may drive water from the coast offshore, combined with the intrusion of a deeper water mass from the Bungo Channel. Moreover, *E. nana* aggregates in the Bungo Channel in this season (Hirota and Kohno 1992). The observed swarming phenomenon, however, can not be explained by the water movement alone, since similar hydrographic events frequently occur in the area.

Saito (1996) reported that shore strandings of *Euphausia similis* Sars, 1883, in Suruga Bay, central

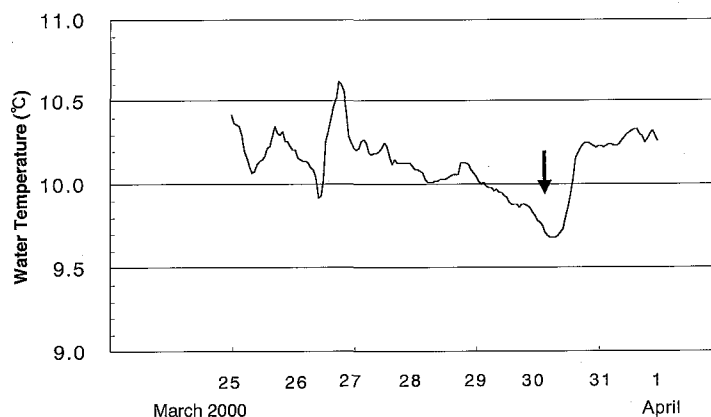


Fig. 5. Changes in the near bottom water temperature off the Buzen-kai Laboratory from 25 March to 2 April 2000. Arrow indicates the occurrence of surface swarming and stranding events of *Euphausia nana*.

Japan, are seasonal and relatively regular events. He also found that *E. similis* strandings are often accompanied by a small number of other euphausiids, *Thysanopoda monacantha* Ortmann, 1893 and *Nematoscelis difficilis* Hansen, 1911, as well as some deep-water mysid and hyperid crustaceans. O'Brien *et al.* (1986) noted that strandings of *Nyctiphanes australis* Sars, 1883, on the Tasmanian coast occur synchronously with matting behaviour. Unfortunately, no evidence is available about this particular behaviour with regard to the *Euphausia nana* stranding. Further studies should be done to better understand the combination of factors mediating such events.

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オキアミ類の一種 *Euphausia nana* の海面浮上群と海岸への打ち上げ

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オキアミ類の一種 *Euphausia nana* の海面浮上群と、それに続く海岸への打ち上げ現象を初めて瀬戸内海で確認した。オキアミ浮上群は 9.0~13.5 mm の成熟個体で構成され、雄は十分に発達した精包を持ち、また雌の60%は交尾していたことから、この群れは産卵群と考えられた。浮上群の性比はほぼ等しかった。オキアミ個体の殆どは空胃であり、海表面で索餌活動を行っていた形跡は認められなかった。環境データの時間変動とそのパターンから、瀬戸内海で確認されたオキアミ浮上群は豊後水道を起源とするものであると考えられた。