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Swarming of Thecosomatous Pteropod *Cavolinia uncinata* in the Coastal Waters of the Tsushima Strait, the Western Japan Sea[1),2)]

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Abstract

The swarming of *Cavolinia uncinata* (RANG) was first observed in the coastal waters of the Tsushima Strait, the western Japan Sea in June 1990. The occurrence of swarming seemed to be independent of the configuration of seashore, although the swarming was localized and patchy. The pteropods were crowded in high densities (>100 individuals m^{-2}), especially in the lee side of inlets and fishing ports. Some pairs ceased swimming for copulation and continued copulating for a few minutes on the sea bottom in shallow waters. A few days after swarming, a great number of dead pteropods was found on shallow sea bottoms and on strand lines. The pteropod spawned an egg mass soon after being accommodated in a laboratory aquarium. The eggs developed to the veliger stage in the egg capsules, and the juveniles hatched out as early as the third day after spawning. All of the juveniles died, however, within two days after hatching. In the latter half of June 1990, the surface temperature increased to ca. 23℃ which was much higher than in other years. *C. uncinata* might be transported from the tropical and/or subtropical habitat to the coastal waters of the Tsushima Strait by the Kuroshio and the Tsushima Warm Currents, which seemed to be more prevalent in June 1990.

Keywords: *Cavolinia uncinata*, swarming, spawning, development, temperature, Japan Sea

Thecosomatous pteropods are present in all the world seas. However, the majority of species are restricted to the circumglobal warm-water area (VAN DER SPOEL 1967). *Cavolinia uncinata* (RANG) is one of the most abundant thecosomatous pteropods in the tropical and subtropical oceans, and they occasionally form swarms in tropical waters (LALLI & GILMER 1989). *C. uncinata* is rarely fround in the Japanese warm waters (YAMAZI 1958), and a swarm has not been reported there. Mass occurrences of other thecosomatous pteropods, *Cavolinia* cf. *tridentata* and *Creseis acicula*, have been hitherto reported in Suruga Bay (NAKAZAWA 1915) and in the coastal waters of the eastern Japan Sea (NISHIMURA 1960, MORIOKA 1980), respectively.

We encountered the swarming of *C. uncinata* in the Japanese coastal waters of the Tsushima Strait. This paper is the first report on a swarm accompanying the spawning of *Cavolinia uncinata* in the Japanese coastal waters.

1) Received 27 August, 1993, Accepted 11 January, 1994
2) 響灘およびその周辺域でのクリイロカメガイ *Cavolinia uncinata* のスウォーミング
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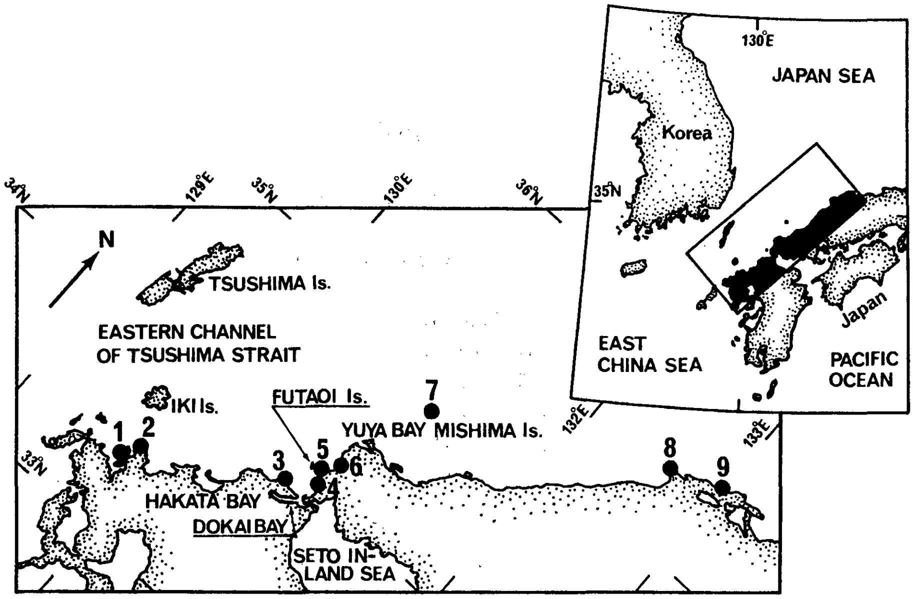

Fig. 1. Location of samplings. 1: Takashima Is., 2: Hato-misaki, 3: Iwaya, 4: Yoshimi, 5: Yoshimo, 6: Kogushi, 7: Mishima Is., 8: Hino-misaki, 9: Etomo.

Materials and Methods

Field observations of *C. uncinata* were carried out along the Japanese coast of the Tsushima Strait in June, 1990 (Figure 1). The pteropods were collected with buckets and nets. The shell length and shell width were measured using a stereoscopic microscope and ocular micrometer. The maximum distance between the anterior margin of dorsal lip and the posterior end of caudal spine was taken as shell length. Shell width was measured at a right angle to shell length, not including the lateral spines.

Living pteropods for the observation of spawning were caught with a bucket in the shallow waters of Yoshimo beach on June 6. About 50 specimens were kept in a 60cm×30cm×35cm glass aquarium containing ca. 30 liters seawater in the laboratory at a room temperature around 22℃. The specific gravity of the seawater was 24.1 at 15℃. Aeration was performed, but no diet was supplied for them.

Seawater temperature was monitored at intervals of 30 minutes with an electric thermometer set five meters below the sea surface off Futaoi Island (Figure 1). The time series data of water temperature were smoothly averaged over a 24 hour period.

Results

Water Temperature

The seawater temperature in June 1990 ranged between 19.1℃ and 23.0℃ (Figure 2). The temperature rapidly increased by nearly 1℃ at the end of May 1990. Then, it gradually rose to above 21℃ in the middle of June, higher than in other years. On June 23, it suddenly increased to ca. 23℃, much higher than others.

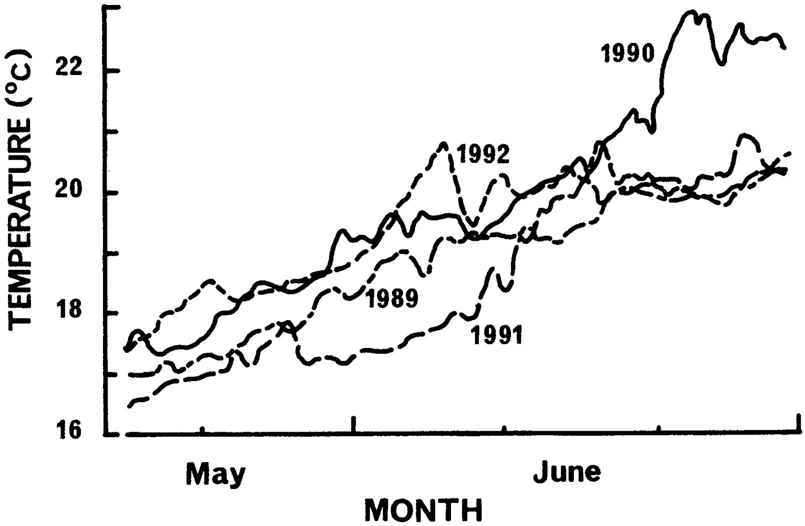

Fig. 2. Seawater temperatures (℃) monitored at five meters below the sea surface in the coastal waters near Futaoi Island in the latter half of May and June, 1989–1992.

Table 1. Observation records of the swarming of *Cavolinia uncinata* and configuration of the seashore.

Date	Locality	Configuration
June 6	Yoshimo	sandy beach
June 9	Hato-misaki	rocky shore
June 11	Takashima Is.	rocky shore
June 11	Kogushi	rocky shore
June 17	Yoshimo	sandy beach, fishing port
June 19	Mishima Is.	rocky shore
June 19	Hino-misaki	rocky shore
June 22	Etomo	fishing port
June 24	Yoshimi	rocky shore

The magnitude of the sudden increase was ca. 2℃.

Swarming

The swarming of *C. uncinata* was observed in the coastal waters along the Japanese coast of the Tsushima Strait in June 1990 (Table 1). At first, the swarming was found at Yoshimo beach on June 6. The water temperature was ca. 20℃. The swarming occurred on sandy beaches (Yoshimo), near rocky shores (Takashima Is., Hato-misaki, Yoshimi, Kogushi, Mishima Is. and Hino-misaki), and in fishing ports (Yoshimo and Etomo). It seemed to be independent of the configuration of the seashore. But, the swarming was sporadic and localized. No occurrence was observed in the Seto Inland Sea and in Hakata, Dokai and Yuya Bays, which are rather enclosed and eutrophic.

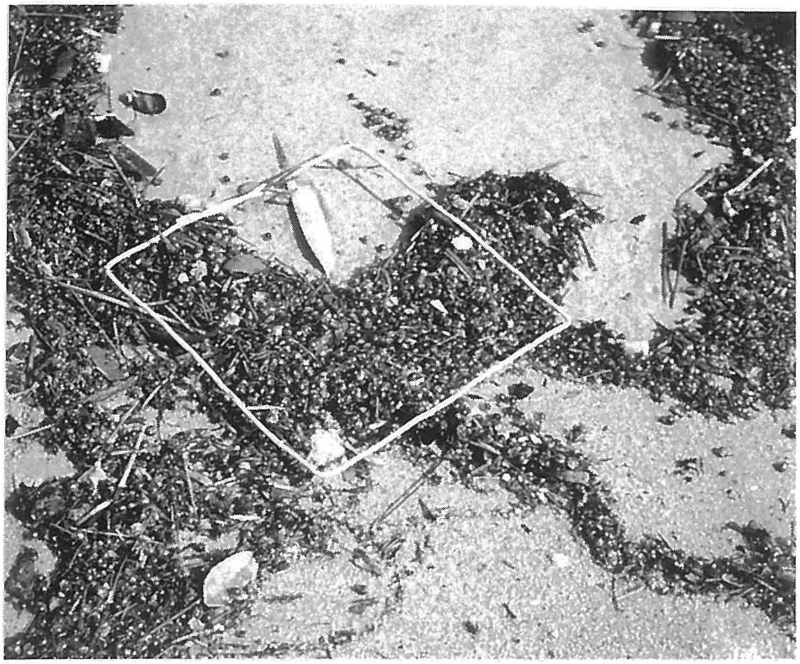

Fig. 3. A mass stranding of *Cavolinia uncinata* on the strand line of Kogushi beach on June 14, 1990. The quadrat in the photograph is a square 20 cm×20 cm.

Fig. 4. A spawning *Cavolinia uncinata*, swimming and trailing an egg mass.

Table 2. Shell width and length of *Cavolinia uncinata*.

Date	Locality	Shell Width(mm)				
		n	Mean	Min.	Max.	SD
Jun 19	Iwaya*1	53	6.1*3	5.6	6.9	0.3
Jun 17	Kogushi*1	53	6.1*3	5.3	6.7	0.3
Jun 22	Etomo*2	35	6.4*3	5.7	7.3	0.4
Date	**Locality**	**Shell Length(mm)**				
		n	Mean	Min.	Max.	SD
Jun 19	Iwaya*1	53	7.9*3	7.0	8.8	0.4
Jun 17	Kogushi*1	53	8.1*3	7.2	9.1	0.4
Jun 22	Etomo*2	35	8.4*3	7.5	9.6	0.5

*1 dead specimens stranded on beach.
*2 living specimens caught by bucket.
*3 the means of both width and length were significantly different between Etomo and the other two localities (*t*-test, $p<0.01$), but not significantly different between Iwaya and Kogushi (*t*-test, $p>0.05$).

The swarms were patchy in distribution, presenting various forms. The patch size ranged from about two meters to more than 10 meters across. The pteropods were crowded in densities greater than 100 individuals m^{-2}, especially in the lee side of inlets and fishing ports. When a seaward wind was blowing and the surface water was flowing offshore, however, the swarming diminished and almost disappeared in the nearshore waters. The swarm formation appeared to be strongly dependent on wind direction that affected water movements.

The vertical distribution was almost uniform in shallow waters less than a few meters in depth. *C. uncinata* swam actively, beating a pair of well-developed muscular wings. Some pairs ceased swimming for copulation and continued copulating for a few minutes on the sea bottom in shallow waters. The frequency of copulation was less than a few per cent of the swarming population. A few days after swarming, a great number of dead pteropods were found on shallow sea bottom and on strand line (Figure 3).

The shell size was not significantly different between the dead pteropods collected on Iwaya beach and those on Kogushi beach (Table 2). However, the swarming population in Etomo fishing port was significantly larger than the former two populations.

Spawning and Early Development

The pteropod, captured alive at Yoshimo on June 6, began to spawn a mucous egg mass soon after being accommodated in an aquarium. About 10% of the spawning individuals were counted. The pteropod was swimming, trailing an egg mass ca. 5 cm long like a ribbon (Figure 4). The egg mass appeared to be slightly heavier than seawater because it was hanging down from the body and sank slowly after detachment. The eggs were enveloped in a zigzag row within the transparent mucus. One egg mass contained 400-500 eggs. All of the pteropods kept in an aquarium died by the next day.

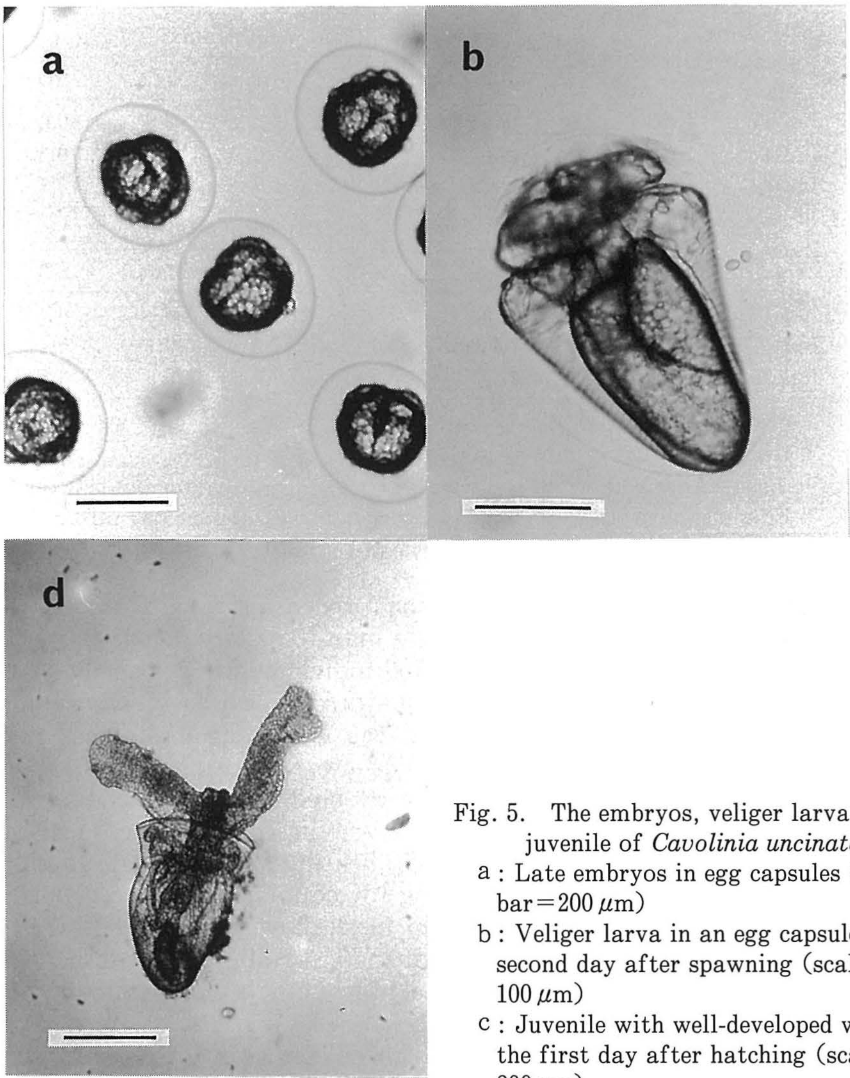

Fig. 5. The embryos, veliger larva and juvenile of *Cavolinia uncinata*.
a : Late embryos in egg capsules (scale bar=200 μm)
b : Veliger larva in an egg capsule at the second day after spawning (scale bar=100 μm)
c : Juvenile with well-developed wings at the first day after hatching (scale bar=200 μm)

The embryos developed to the veliger larvae in egg capsules (Figure 5a and 5b). The juveniles hatched out as early as the third day after spawning at 22℃ and began to swim freely with two well-developed wings (Figure 5c). All of the juveniles died within two days after hatching.

Discussion

According to VAN DER SPOEL (1967), *C. uncinata* is a tropical pteropod and occurs north to 35°N in the western North Pacific. In the Tsushima Strait, which is practically located at the northern boundary of the distribution, the swarm of *C. uncinata* accompanying the spawning is an extraordinary phenomenon.

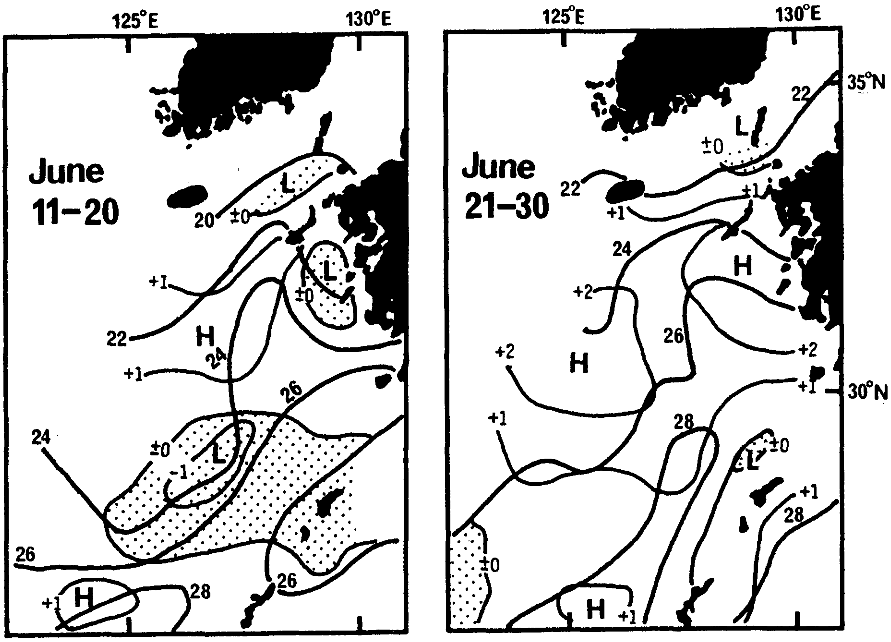

Fig. 6. Distributions of the ten-day mean of sea surface temperature (℃) and the deviation (℃) from the 30-year mean (1956–1985) in the East China Sea and the Tsushima Strait in the middle and last ten days of June, 1990. Shaded areas show the negative deviations (NAGASAKI MARINE OBSERVATORY 1990)

The transport of tropical macroplankton to the Japanese coastal waters by the Kuroshio and its branch, the Tsushima Warm Current, is well-known, e. g. an epipelagic octopod, *Argonauta argo* (OKUTANI & KAWAGUCHI 1983), and a nautiloid, *Nautilus pompilius* (HAMADA et al. 1978). OKUTANI & KAWAGUCHI (1983) reported the relation between the mass occurrence of *A. argo* and the surface water temperature in the southern Japan Sea, June-July 1982. Namely, when *A. argo* occurred there, the surface temperature was 1–2℃ higher than the mean for 1953-1980. In the present study, the water temperature was higher, especially in the latter half of June 1990, than in other years. This fact suggests that the Kuroshio and the Tsushima Warm Current, which seemed to be more prevalent in 1990, might convey *C. uncinata* to the coastal waters under survey.

TAWARA & FUJIWARA (1985) found sudden temperature increases in the Tsushima Strait during the period from late April to early July in 1982. They reported that such a sudden temperature increase was caused by an intrusion of the warm water mass from the East China Sea into the Tsushima Strait. Indeed, there was a water mass tongue extending northward from the Kuroshio area west off Kyushu in the middle of June (Figure 6) and then a remarkable increase in the temperature occurred in the latter half of June, 1990 (see Figure 2). These oceanographical facts support the above-mentioned hypothesis that *C. uncinata* might be transported to the coastal waters by the Tsushima Warm Current. However, the swarming population described in the present study probably represent a sterile expatriate assemblage of individuals, because the spawning swarm is an unusual phenomenon in the study area.

In this study the survey of the swarming was made only in the coastal waters, and no information in the offshore waters has been obtained. KAWANO (1991) found a dense population of *C. uncinata* in an area ca. 10 km off Yuya Bay in the middle of June, 1990. Thus, the swarming was not limited only to coastal waters, but it also might possibly have occurred elsewhere in the Tsushima Strait.

The shell size was significantly different between the specimens stranded on the Iwaya and Kogushi beaches and the living specimens swarming in Etomo port. The former beaches are near each other, and are much further away from Etomo port. The differences in shell size might be attributed to the difference of population and/or the growth.

The formation of the swarm appeared to be dependent on wind direction. However, wind is only considered to be a local factor affecting the swarm formation in coastal waters because there was no significant difference in the wind conditions observed by the Shimonoseki Meteorological Observatory in June, 1988–1992.

The egg mass obtained in this study was heavier than seawater, although most cavoliniids lay a free-floating egg mass (LALLI & GILMER 1989). The spawning of demersal egg mass in shallow coastal waters, which seems unusual for an epipelagic animal, would turn out to be a well-adapted behavior. Additionally, in the present study, *C. uncinata* released the egg mass while actively swimming in the laboratory aquarium. However, according to LALLI & GILMER (1989), most cavoliniids are quiescent in the water while they are releasing the egg mass from the genital opening. Thus, the spawning behavior of *C. uncinata* might be unusual.

The great many deaths on the strand line and on the bottom of shallow nearshore waters after swarming might be associated with spawning. On the other hand, the death in a laboratory aquarium within a day after the capture could be attributed to rearing conditions in the laboratory, e.g. water quality and diet. Indeed, no cavoliniid pteropod has yet been maintained in the laboratory for more than a few days (LALLI & GILMER 1989). The death of veliger would also be attributed to starvation and unfavorable environment in an aquarium.

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