Distribution of larvae and juveniles of the Japanese mantis shrimp *Oratosquilla oratoria* (De Haan, 1844) (Stomatopoda) in the Sea of Hiuchi-Nada, Japan

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*Abstract.* — The temporal and spatial distribution of larvae and newly settled juveniles of a stomatopod crustacean *Oratosquilla oratoria* (De Haan, 1844) was investigated in the eastern part of the Sea of Hiuchi-Nada, Japan. Occurrence of many larvae to the northwest of Ibuki-jima Island suggests it may be the spawning ground. Larvae are transported counterclockwise around Ibuki-jima Island by a residual current, widely settle in the bottom waters, and metamorphose to benthic juveniles. Newly settled individuals were sampled at most stations in August, but were absent in the southern waters of Ibuki-jima Island in October. Oxygen-deficient waters from August to October may be partially responsible for the distribution of *O. oratoria* juveniles in October.

Introduction

The Japanese mantis shrimp *Oratosquilla oratoria* (De Haan, 1844), the most exploited stomatopod crustacean in the world, is abundant in the eastern part of the Sea of Hiuchi-Nada of the Seto Inland Sea, Japan. Given that the annual catch of mantis shrimp by small trawl nets fluctuates on a large scale, studies into the cause of these fluctuations are necessary to manage the resource. A previous model of population dynamics was made when there was little information on the population ecology of the *O. oratoria* (Ishioka et al., 1981), and clearly overestimated the growth rate (Hamano & Morrissy, 1992). Accurate ecological data are needed to produce more realistic models.

In a previous study at Ishikari Bay in Hokkaido, Hamano & Nagai (1989) suggested the inflow of a warm current on the early larval stages played an important role in the structure of the *O. oratoria* population. Hence, the fluctuation in the annual catch in the eastern part of the Sea of Hiuchi-Nada may also be due to the survival rate of its early larval stages therefore subject to oceanographic conditions. Given this, we decided to study the temporal and spatial distribution of *O. oratoria* larvae and juveniles in the study area. Senta et al. (1969) reported that the spawning season of *O. oratoria* runs from the middle of May to late August in waters adjacent to the present study area. It is also known that eggs of this species hatch about two weeks after spawning when water temperature is 25°C, the first and the second stage larvae stay in the mother’s burrow, the third stage larvae start a planktonic life, and finally pass through eleven larval stages in one or two months before metamorphosing into a juvenile (Hamano & Matsuura, 1987). The juveniles settle from August to October, grow to 6 cm in total length in a year, and become 9 cm and 12 cm at +2 and +3 years old, respectively (Hamano & Morrissy, 1992). For these reasons, we considered that *O. oratoria* larvae mainly metamorphose into juveniles from July to
October in the present study area, therefore, sampling was conducted during this period.

**Materials and Methods**

The Sea of Hiuchi-Nada, the present study area, is located in the center of the Seto Inland Sea. The depth was less than 40 m and extensive flat bottom sediments extend over areas between 10 to 30 m depth. Bottom sediments are mainly silty clay (Iuchi, 1985).

Planktonic larvae and benthic juveniles of *Oratosquilla oratoria* were captured at twenty sampling stations around Ibuki-jima Island in the eastern part of the Sea of Hiuchi-Nada. The stations used were the oceanographical research sites of Kagawa Prefectural Fisheries Experimental Station (Fig. 1).

Planktonic *O. oratoria* larvae were collected every two weeks from July to October 1994, (8 times), co-incident with the period when the developed larvae are observed in the present waters and more generally in western Japan, including the present waters (Hamano et al., 1987; Hamano & Morrissy, 1992). A plankton net (78 cm in diameter, mesh number GG40) with two floats, a sinker, and jellyfish removal cover-net (mesh size 19.5 × 19.5 mm) over the net mouth was employed (Fig. 2a). The net was completely submerged beneath the surface and towed at about 1.7 m/s, speeds at which the flow meter becomes efficient, for 5 minutes per station. Volume of water sampled was recorded with a flow meter. Sampling was carried out at night when *O. oratoria* larvae distribute near the surface (Senta, 1967). Collected individuals were preserved in 5% seawater formalin (vv). The number of individuals and carapace length (CL) were measured following the method of Hamano & Matsuura (1987). When a sample contained more than 100 individuals, we measured only one hundred

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**Fig. 1.** Map showing the eastern part of the Sea of Hiuchi-Nada, Japan. Twenty sampling stations, A–T, were located around Ibuki-jima Island.
individuals extracted at random from the sample. The mean carapace length, which is useful to define the degree of development, was calculated for each haul according to Hamano et al. (1995). Individual densities of larvae were calculated by the following formula: number of larvae collected / volume of water filtered (m³).

Sampling of newly settled juveniles of *O. oratoria* was conducted in August and October 1995 when we expected many metamorphosed juveniles to appear following both the results of a previous study in an adjacent sea region (Hamano & Morrissy, 1992) and that of the present larval investigation described below. Juveniles were captured by using a sledge net (net mouth 30 cm high and 200 cm wide, mesh size 1.46 × 1.46 mm) (Fig. 2b). A flow meter was attached onto the outside of the upper part of the net mouth. The net was towed during the daytime for 3 minutes at approximately 1.0 m/s. Shooting and hauling of each net was conducted slowly and carefully to minimize disturbance to the flow meter. Samples were preserved in 5% seawater formalin (v/v), and carapace length (CL) was measured following Hamano & Morrissy (1992). According to population research of the present species in adjacent waters, we regarded individuals of CL ≤ 10 mm in August and CL ≤ 16 mm in October as juveniles newly settled in that year (Hamano & Morrissy, 1992). Individual densities of juveniles were calculated as follows: number of individuals / swept area (m²). Here, swept area is described by the following formula: width of the net mouth × tow distance calculated from the flow meter.

We measured the surface water temperature (WT) during larval sampling in 1994 and the bottom WT and dissolved oxygen concentration (DO) using the YSI model 58 DO Meter of Yellow Springs Instrument Co., Inc. during sampling of juveniles in 1995.

Results and Discussion

We collected 151,219 planktonic larvae in 1994 and 104 benthic juveniles of *O. oratoria* in 1995.

For each larval sample, specimens were divided into five groups corresponding to III, IV, V, VI, VII+ larval stages described by Hamano & Matsuura (1987) using the mean carapace length of *O. oratoria* larval stages as determined by Hamano et al. (1995). On 13 July, large sized larvae (≥ 3.5 mm CL) at densities of < 10 inds./m³ of *O. oratoria*, which would soon metamorphose and become the early settling group defined by Hamano & Morrissy (1992), were concentrated in the northwest of Ibuki-jima Island (Stns. A, B, D–F, I–K of Fig. 3). On 27 July, larvae decreased in densities at all sampling stations. On 9 August, small sized larvae (< 1.5 mm CL), which would belong to the late settling group of Hamano & Morrissy (1992), appeared in high densities (≥ 25 inds./m³) in the northwest of Ibuki-jima Island (Stns. A, D–F, I–K of Fig. 3). On 23 August, larvae of < 2.5 mm CL were found at high densities (≥ 25 inds./m³) in the west to the southwest of Ibuki-jima Island (Stns. N–P of Fig. 3). Further on 6 September, there were many larvae (≥ 25
Fig. 3. Distribution of planktonic larvae of *O. oratoria* from July to August (left page) and from September to October (right page) 1994. The size and color of the circles indicate the mean carapace length and individual density, respectively, at each sampling station.
inds./m³) from the northeast to the northwest of Ibuki-jima Island (Stns. A, C, D, E, G, H, M of Fig. 3). Although on 20 September, planktonic *O. oratoria* larvae were observed at high densities (≥ 25 inds./m³) in the northwest of Ibuki-jima Island (Stns. A, D–F, I of Fig. 3), their density had decreased by 5 October. On 18 October, few larvae (< 5 inds./m³) were captured and large sized larvae (≥ 3.5 mm CL) appeared to the west and south of Ibuki-jima Island (Stns. I, J, N–Q of Fig. 3). Many larvae were collected to the northwest of Ibuki-jima Island throughout this sampling period.

The waters of the present study, the eastern part of the Sea of Hiuchi-Nada, are the most stratified in the Seto Inland Sea. A residual current circulates counterclockwise around Ibuki-jima Island at a constant velocity of 10–20 cm/s (Iuchi & Takeoka, 1985). It is known that residual currents have a large transport capacity even though current speed may be slow. From the shifts of larval densities over time, it seems that many *O. oratoria* larvae had started a planktonic life to the northwest of Ibuki-jima Island and were
transported counterclockwise around Ibuki-jima Island by the residual current.

In the samples of *O. oratoria* juveniles on 2 and 3 August in 1995, newly settled individuals (estimated from their body size), were captured at most of the sampling stations (Fig. 4). Size of collected juveniles on 11 and 12 October in 1995 widely varied for each sampling station and the density of individuals was low. Furthermore, juveniles were not sampled from areas south of Ibuki-jima Island in October (Stns. N–R of Fig. 4). In this area, dissolved oxygen of the bottom layer is low due to the summer stratification in August, however, stratification had disappeared by October (Fig. 5). Although juveniles were even present at stations with low levels of dissolved oxygen in August, they were absent at 11 stations in October when the oxygen deficient waters no longer existed. Manabe (1978) reported that the annual occurrence of oxygen deficient waters in the study area causes mortalities in fishes and shellfish from July to October. Given this, we propose that oxygen deficient waters of the bottom layer during August to October partially contributed to the distribution of *O. oratoria* juveniles in October.

As a result, we believe that the early life history of *O. oratoria* in the Sea of Hiuchi-Nada as follows: their spawning season starts in the middle of May (Sentag. et al., 1969) and the larvae are distributed and grow in the residual current. In the middle of July they settle widely on the bottom, and then metamorphose to benthic juveniles of the early settling group. The late settling group of larvae begin planktonic life in early August in waters to the northwest of Ibuki-jima Island. They are then transported at about 1 km/day around Ibuki-jima Island by the counterclockwise residual current, judging from the temporal and spatial change of high larval density in Fig. 3. Finally, these larvae settle widely on the sea bed and metamorphose to benthic juveniles. Most of the newly recruited juveniles die between August and October due to low dissolved oxygen concentrations in the southern waters of Ibuki-jima Island. Hence, the occurrence of oxygen-deficient waters...
during recruitment may cause fluctuations in the population size of *O. oratoria*.

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Literature Cited


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