

Ecology and behaviour of puerulus of spiny lobsters*

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Abstract: Because of the difficulty to culture phyllosoma/puerulus in laboratory and to collect puerulus just after metamorphosis, little has been known about ecology and behaviour of puerulus. Recently complete development of phyllosomas has been shown for several species of spiny lobsters: *Panulirus japonicus*, *Palinurus elephas*, *Jasus lalandii*, *J. edwardsii*, *J. verreauxi* and a hybrid between *J. novaeollandiae* and *J. edwardsii*.

The newly moulted puerulus was transparent at the early stage. It was carried by current and swam rotating with occasional beating of the pleopods. Slight differences were observed in the swimming posture between species. The clinging behaviour was observed one or few days after metamorphosis. A puerulus of *P. japonicus* settled 4 days after metamorphosis. *J. edwardsii* and *J. verreauxi* were observed to occupy the shelter on the following day of metamorphosis. *J. edwardsii* burrowed into the fine silt substratum while *J. verreauxi* showed clinging behaviour on artificial fibre.

No feeding behaviour was observed during the entire period of the puerulus. Without feeding the dark pigmentation developed on the carapace at the advanced stage. The puerulus moulted into the postpuerulus stage about two weeks after metamorphosis for *P. japonicus* and about three weeks for *P. elephas* and *Jasus* spp. Transparent pueruli of *J. edwardsii* were tolerable to high water temperature of 26°C and low salinity of 26‰.

1. Introduction

Spiny lobsters hatch phyllosoma larvae which disperse by currents into the open ocean. The larval life is estimated as up to about a year. The final stage phyllosomas metamorphose into the puerulus stage, which is the only transitional stage from the phyllosoma to the juvenile. Because of the difficulty to culture phyllosoma/puerulus in the laboratory and to collect puerulus in the ocean, little has been known about ecology and behaviour of the puerulus.

The advanced stage puerulus is trapped by various type collectors. The pueruli of the Western Australia spiny lobster *Panulirus cygnus* were captured by the grass type collector by PHILLIPS (1972). Those of the New Zealand spiny lobster *Jasus edwardsii* were investigated using the crevice type collector by BOOTH (1979). Recently, requirements of the settlement substratum and factors induced molting into the postpuerulus have been investigated on the California spiny lobster *P. interruptus* by

SERFLING and FORD (1975), and on the Caribbean spiny lobster *P. argus* by MARX and HERRNKIND (1985a, 1985b).

The stage of the puerulus is identified with the development of hepatopancreas and pigmentation of exoskeleton. However, the early stage pueruli captured by the collectors are lacking the information after metamorphosis until settlement. The information at the early stage could be available through complete development of phyllosoma and puerulus cultured in the laboratory. Recently culture of phyllosoma and puerulus from egg has been shown for several species of spiny lobsters: the Japanese species *P. japonicus* (KITTAKA and KIMURA, 1989), the European species *Palinurus elephas* (KITTAKA and Ikegami 1988), the South African species *J. lalandii* (KITTAKA, 1988), the New Zealand species *J. edwardsii*, and *J. verreauxi*, (unpublished), and a hybrid between *J. edwardsii*, and the Australian species *J. novaeollandiae* (KITTAKA, et al., 1988). Although the number of pueruli produced was very few, ecology and behaviour of puerulus just after metamorphosis have been revealed in the laboratory.

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2. Materials and methods

Puerulus cultured in the laboratory

Matured spiny lobsters: Matured *P. japonicus* were caught in Japan and *P. elephas* and 4 species of the genus *Jasus* were transported to Japan from their origin countries. Several females and males were reared in a FRP tank (dimensions: 2.5m×1.2m×height 0.7m) with slowly running seawater and aeration. Water temperature maintained between 12°C and 22°C for *P. japonicus* and 10°C and 20°C for *P. elephas* and *Jasus* spp. Mussels *Mytilus edulis* were given as food daily. Mating, spawning and hatching occurred once every year. Females carried eggs for 2–3 months after mating.

Phyllosomas: Hatching occurred in February for *P. elephas*, in July and August for *P. japonicus* and *J. verreauxi* and almost all year round for other *Jasus* spp.. Several thousand first stage phyllosomas were cultured in a 100 l circular tank. Seawater treated with a 5 µm ceramic filter and ultra-violet sterilizer was supplied at the bottom through a recirculating system. Cultured microalgae *Nannochloropsis* sp. was added at several million cells/ml to the culture water. Water temperature was maintained at approximately 25–26°C for *P. japonicus* and at 18–20°C for other species. The larvae were fed with *Artemia* nauplius at the initial stage and small pieces of mussels at advanced stage. The culture water was exchanged for about 2–4 weeks.

Puerulus: After metamorphosis, the pueruli were kept in the phyllosomas tank for several days. After the pueruli showed settling

behaviour, they were transferred into a plastic cage (dimensions: 13 cm×9 cm×height 11 cm) placed in another FRP tank. A piece of mussel shell was placed in the cage as shelter. Ambient sea water was supplied through a 5 µm cartridge filter. Water temperature was maintained at about the same range for phyllosomas. The pueruli cultured from phyllosomas are shown in Table 1.

Puerulus collected in the wild

Collection of pueruli of *J. edwardsii* was made at Castlepoint on the east coast of the North Island of New Zealand during the period from January 17 to February 22 in 1989 (HAYAKAWA *et al.*, 1990) and from January 28 to February 15 in 1991. Collectors were composed of eight plywood sheets (38 cm×38 cm×1 cm) to make crevices of 2.5 cm in height at the edge part (BOOTH 1979) and were placed with concrete weights. The collectors were checked daily and settled pueruli were removed for observation in the laboratory. Effects of water temperature and salinity were tested with 10 l plastic containers.

3. Results

Metamorphosis and swimming behaviour of puerulus

Cessation of feeding and retraction of hepatopancreas are signs of approaching moult for phyllosomas of all species observed. Final stage phyllosomas became moveless about 2 days before molting. On the day of metamorphosis the body colour of the phyllosomas became white-turbid, and several hours before moulting eyestalks and pereopods

Table 1. List of puerulus cultured in the laboratory

Species	Date of hatching	Date of metamorphosis	Final stage of phyllosoma (instar)	Duration of phyllosoma (days)	Duration of puerulus (days)
<i>Jasus lalandii</i>	1 Aug. 1986	3 Jun. 1987	15 (estimated)	306	31
<i>Jasus</i> hybrid	8–13 Sep. 1986	31 Jul. 1987	15 (estimated)	319	
<i>Palinurus elephas</i>	19 Mar. 1987	29 Jul. 1987	9 (estimated)	132	15
	18 Feb. 1988	16 Jul. 1988	9 (estimated)	148	11
<i>Panurilus japonicus</i>	18 Jul. 1987	22 Jun. 1988	29 (estimated)	340	15
				391	12
<i>J. edwardsii</i> *	20 Dec. 1989	18 Oct. 1990	17	303	19
<i>J. verreauxi</i> *	17 Jul. 1990	7 Feb. 1991	17	205	20

*un published.

became flaccid for the majority species except *J. verreauxi*. The latter species occasionally bent abdomen and beated pleopods vigorously like newly moulted puerulus of other species. The puerulus took two or three minutes to emerge dorsally through the thoracoabdominal membrane. The newly moulted puerulus was transparent except in the eyes. It was carried by current and swam rotating with vigorous beating of the pleopods. They jumped backwards occasionally with bending abdomen. Slight differences were observed in the swimming posture between species: the second antennae and five pairs of pereopods were extended forward for *J. lalandii*, the pereopods were slightly out-stretched for *P. japonicus*, both the second antennae and pereopods were slightly out stretched for *J. edwardsii* and *J. verreauxi* and both were stretched wide for *P. elephas*.

Settlement behaviour

The clinging behaviour was observed in the following day about 12 hours after metamorphosis for a puerulus of *P. japonicus*. However, the individual left the substratum and began to swim again. Three days after metamorphosis, this individual was observed to extend appendages wide and cling to the screen net on the recirculating system placed in the center of culture container. The individual was observed again to swim in the following morning and to cling in the afternoon 4 days after metamorphosis. The latter case is considered as the settlement because no swimming behaviour was observed after that time.

Another individual of *P. japonicus* showed clinging behaviour 5 days after metamorphosis. For the individual, molting was not done complete at metamorphosis and malformation was formed at one of the second antennae. This may be a possible factor to delay settlement behaviour for the individual.

Clinging behaviour was observed three days after metamorphosis for *P. elephas*. The puerulus clung on the substratum with its wide stretched 5 pairs of pereopods. The clinging posture of this species was remarkably different from others: the puerulus lifted

the cephalothorax part and supported its abdomen with beating vigorously 5 pairs of pleopods. Sheltering behaviour was not observed for this species. To determine settlement behaviour for precisely *P. elephas*, further observation will be required.

J. edwardsii was observed to occupy the shelter one day after metamorphosis or to burrow into the fine silt substratum. They showed preference on fine silt such as sedimented at Castlepoint rather than fine sand sampled at Sanriku coast. *J. verreauxi* showed clinging behaviour on stones or artificial fibre on the day of metamorphosis, while no burrowing behaviour was observed for this species.

Feeding behaviour

The phyllosomas preyed food particles with the third, fourth and fifth pereopods, and transferred to the mouthparts with maxillipeds to graze. They have large hepatopancreas which is usually filled with food materials. After metamorphosis, the pueruli showed no appetite on any kind of animal or vegetable foods, and no food materials were found in hepatopancreas. If they took food, the food materials could be visible because the puerulus is transparent at its early stage.

The light-coloured hepatopancreas became visible several days after metamorphosis and well developed at the advanced stage of puerulus. No feeding behaviour was observed during the entire period of the puerulus. Rearing condition for the pueruli of *P. japonicus* was summarized in Table 2.

Without feeding the dark pigmentation developed on the carapace at the advanced stage, and the pueruli molted into the post-uerulus 15 and 12 days after metamorphosis, respectively. The first moult post-uerulus begun to feed mussels on the day after moulting.

Effects of water temperature and salinity

Surface water temperature and salinity fluctuated between 16 and 21°C and between 33.6 and 35.5‰ at Castlepoint during the survey period in January and February in 1989. Collected transparent pueruli were tested in number of 5 each at water temperature

Table 2. Culture condition for the pueruli of *Panulirus japonicus*

Puerulus	1		2	
Date of metamorphosis	22 June 1988		12 August 1988	
Days of phyllosoma stage	340		391	
Period of puerulus (days)	15		12	
Water condition	<i>Nannochloropsis</i>	Filtered	<i>Nannochloropsis</i>	Filtered
Days	7 (initial)	8 (final)	5 (initial)	7 (final)
Water temperature(°C)	26.4	25.3	25.3	25.1
Salinity (‰)	35.43	35.24	35.37	35.20
pH	8.30	8.30	8.26	8.25
<i>Nannochloropsis</i> ($\times 10^3$ cells/ml)	63	0	70	0
Water exchange (daily %)	0.3	22.5	0.8	2.6

24, 26 and 28°C, respectively. All individuals survived for about 96 h at 24 (range:23.1–25.9) and 26 (24.9–27.1)°C. All individuals died at 27.9°C within 2.5 h. Lethal water temperature for the early stage puerulus is considered at 27–28°C.

Transparent pueruli were also tested in number of 5 each at salinity 35.0, 31.5, 28.0, 26.3, 24.5, and 21.0 ‰, respectively. All individuals survived at salinity higher than 26.3 ‰. All individuals died at 24.5 ‰ within 7 hours and at 21.0 ‰ within 5 hours. Lethal salinity for the early stage puerulus is considered at 25–26 ‰.

4. Discussion

Pelagic phase of spiny lobsters is composed of the planktonic phyllosoma stage and the nectic puerulus stage. Duration of the pelagic phase is roughly estimated by time difference between hatching season and settlement season. Thus, it is estimated at about one year. To estimate the puerulus period is rather difficult due to lack of sampling of the late stage phyllosomas and the early both stage puerulus. Pueruli at various developmental stages are collected at seashores at Castlepoint (BOOTH, 1979; HAYAKAWA *et al.*, 1990). However, duration after metamorphosis for them is unclear. Accurate information will be available by complete development in the laboratory.

The puerulus of *P. elephas* (KITAKA and IKEGAMI, 1988) *P. japonicus* (KITAKA and KIMURA, 1989) and *Jasus* spp. showed clinging behaviour relatively short period (1–3 days) after

metamorphosis. Clinging behaviour is considered to be the site searching behaviour for settlement. An active puerulus of *P. japonicus* was observed to settle 4 days after metamorphosis (KITAKA and KIMURA, 1989). The hepatopancreas became visible several hours after settlement, a V-shaped structure one day after settlement, and bifidness at the anterior parts 2 days after settlement (KITAKA and KIMURA 1989). This may suggest that puerulus consumes energy for swimming purpose only during pelagic phase, perhaps including site searching phase. Development of hepatopancreas will commence just after settlement.

The duration of puerulus was 11 days for *P. elephas* (KITAKA and IKEGAMI, 1988), 12–15 days for *P. japonicus* (KITAKA and KIMURA, 1989), 19 days for *J. edwardsii*, and 21 days for *J. verreauxi* under laboratory conditions, respectively. While in the wild the puerulus of *J. edwardsii* is estimated to swim inshore after metamorphosis up to 20–40 days according to the local oceanographic conditions and the width of the continental shelf (BOOTH, 1989). Assuming that the wild puerulus of *J. edwardsii* takes similar site searching behaviour and developmental stage, the duration of *Jasus* puerulus is estimated at about 40–60 days. This estimated duration of puerulus in the wild will be corrected if metamorphosis occurred rather inshore on puerulus transport mechanism was more efficiently provided in the ocean.

Once culture method was established, ecological and behavioural data obtained in the

laboratory would provide more accurate information. Although feeding by puerulus was reported for *J. lalandii* (SILBERBAUER, 1971) and *P. elephas* (ORTON and FORD, 1933) feeding was not observed for both species by our culture experiments. Without feeding the pueruli of *P. japonicus* molted into the postpuerulus (KITAKA and KIMURA, 1989). The pueruli were kept in the phyllosoma culture tank for initial several days after metamorphosis, which contained microalgae *Nannochloropsis* sp. to control water quality. Morphological observation of the puerulus of *J. edwardsii* showed distinct regression of the mouthparts compared to both late phyllosoma and postpuerulus stage (NISHIDA *et al.* 1990). If the puerulus depended on nutritionally microalgae in the water, the digestive glands would be filled with microalgae intake. No such evidence was realized.

Transparent puerulus just after settlement showed tolerance to higher water temperature and lower salinity which seldom occur in the wild. Thus, the puerulus is very tough animal. However, they require good water quality and sufficient water exchange. An improved device to culture pueruli is required for further behavioural studies.

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