LARVICULTURE OF SLIPPER LOBSTERS IN THE GENUS Ibacus AND Thenus: A REVIEW

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ABSTRACT

Slipper lobsters are commercially important crustaceans for the Indo-West Pacific countries. The populations of these lobsters at several locations are recently declined probably due to over-exploitation. Juvenile production and the subsequent farming are required for the food production and resource conservation; however, the techniques have not been established yet at practical level. To sort our current knowledge on the slipper lobster aquaculture, a history of larviculture is reviewed with a special attention to the dietary items of lobster larvae.

Keywords: Phyllosoma, Scyllaridae, Seed production, Lobster aquaculture, Gelatinous zooplankton

I. INTRODUCTION

Slipper lobsters are the crustaceans in the family Scyllaridae (Achelata, Decapoda). This family includes more than 80 species which are distributed in four subfamilies: Arctidinae (including the genera *Arctides, Scyllarides*), Ibacinae (*Ibacus, Parribacus, Evibacus*), Theninae (*Thenus*), and Scyllarinae (13 genera) (Holthuis, 1991; Webber and Booth, 2007; WoRMS, 2018). Except the species in Scyllarinae which are normally less than 10 cm in body length, the slipper lobsters are of commercial interest (Holthuis, 1991). Particularly in the Northwest and Western Central Pacific, the slipper lobsters are account for 15–50% of total lobster catch (Vijayakumaran and Radhakrishnan, 2011; FAO, 2018). Currently these lobsters are fully exploited from the natural environments. It has been reported that the lobster populations at several locations have been dramatically declined probably due to over-exploitation (Deshmukh, 2001; Radhakrishnan *et al*., 2005). Juvenile production and the subsequent farming are still in the research level and have desired from the viewpoints of both food production and resource conservation.

The early life cycle of slipper lobsters is similar to that of spiny lobsters in the family Palinuridae. The females of slipper lobsters brood the fertilized eggs on pleopods until the larvae hatch. The planktonic larva of slipper lobsters, so-called “phyllosoma”, is a zoeal phase which has an extremely flattened body (Phillips and Sastry, 1980; Sekiguchi *et al*., 2007; Palero *et al*., 2014). As it grows, the appendages develop at successive moults. At the final stage, phyllosoma has rudimental gills at the basal parts of pereiopods (Phillips and Sastry, 1980; Sekiguchi *et al*., 2007; Palero *et al*., 2014; Vijayakumaran and Radhakrishnan, 2011). The final-stage phyllosoma metamorphosed into the postlarval phase, named “nisto”, which corresponds to the puerulus of spiny lobsters and the megalopa of the brachyuran crabs (Martin, 2014; Palero *et al*., 2014). The nisto settles into a benthic habitat (Sekiguchi *et al*., 2007; Vijayakumaran and Radhakrishnan, 2011). It possesses the undeveloped mouthparts and is considered a non-feeding (Mikami and Kuballa, 2007). Finally it reaches the juvenile phase after a single moult and then starts eating.

Larvae of Ibacus and Thenus hatch in a more advanced condition compared with the larvae of the other species of scyllarids (Baisre, 1994; Booth *et al*., 2005). The newly hatched phyllosomas of *Ibacus* and *Thenus* lobsters possess four fully segmented pereiopods (1st to 4th pereiopods) and incompletely developed 5th pereiopods, whereas the phyllosomas of *Scyllarides, Arctides,* and *Parribacus* have three fully segmented pereiopods (1st to 3rd

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pereiopods). The larval size and the duration of the former groups are much larger and shorter than those in the latter groups. Lobsters in *Ibacus* and *Thenus* (Fig. 1) seem to be more ideal species in aquaculture.

Here, our knowledge on larviculture of these lobsters is reviewed with a special attention to the dietary items for phyllosomas.

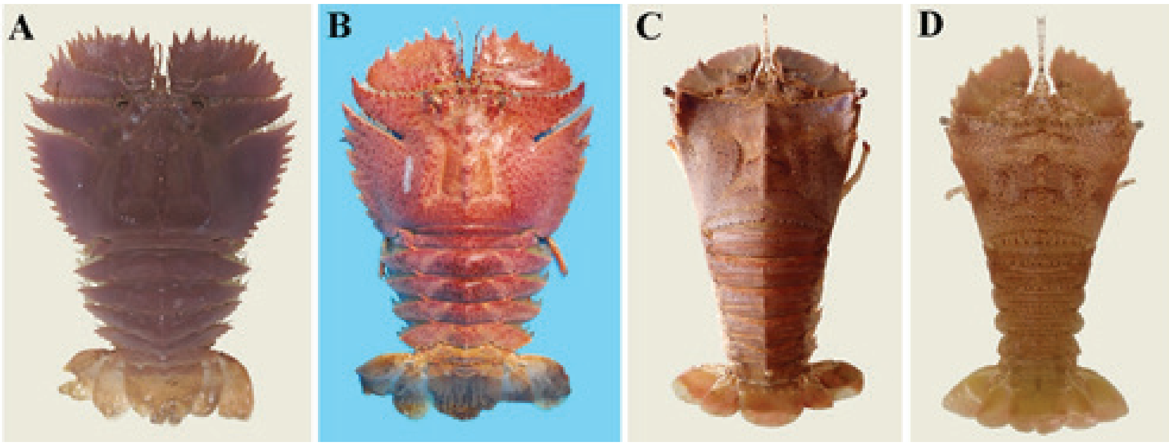

Figure 1. Selected species of the slipper lobsters in the genus *Ibacus* and *Thenus*.
(A) Ibacus ciliatus *(von Siebold, 1824), Karato fish market, Yamaguchi, Japan; (B)* Ibacus novemdentatus *Gibbes, 1850, off Ainan, Kochi, Japan; (C)* Thenus orientalis *(Lund, 1793), Binh Thuan, Vietnam; (D)* Thenus australiensis *Burton and Davie, 2007, Shark Bay, Western Australia*.

II. HISTORY OF LARVICULTURE TRIALS

1. *Ibacus* spp.

Saisho and Nakahara (1960) described the larval development of *Ibacus ciliatus* for the first time and achieved to observe the 1st to 4th stages of phyllosoma. Dotsu *et al*. (1966) also obtained the newly hatched phyllosomas of *I. ciliatus* as well as *Ibacus novemdentatus* and cultured them until the 3rd and 4th stages, respectively. These two trials were the pioneer works on the larval development of slipper lobsters in anticipation of seed production. *Artemia* nauplii and fish larvae which are commonly used for fish and crustacean larviculture were applied in these studies, but none of phyllosomas completed the planktonic phase.

Later, Takahashi and Saisho (1978) have achieved the complete larval development from hatching to metamorphosis of both *I. ciliatus* and *I. novemdentatus*. Phyllosomas of *I. novemdentatus* were demonstrated to take 7 instars and those of *I. ciliatus* to take 7 or 8 instars before metamorphosing into the nisto stage. Finely chopped clam flesh was mainly used as larval diet in their trials. Matsuda *et al*. (1988) and Mikami and Takashima (1993) also reported the completion of *I. ciliatus* larval development in which phyllosomas were fed with *Artemia* nauplii for the earlier stages and finely chopped mussel flesh for the later stages. Matsuda *et al*. (1988) tested diverse items including fish meat, clam, mussel, abalone, squid, krills, and moon jellyfish, and found out that bivalve flesh and moon jellyfish were the items on which phyllosomas preyed most actively. Most recently, Wakabayashi *et al*. (2012, 2016) reported the complete larval development of these lobsters with feeding jellyfish (Fig. 2). Jellyfish is known as one of the natural diets of phyllosomas (e.g. Booth *et al*., 2005; Sekiguchi *et al*., 2007; Wakabayashi *et al*., in press). Growth rates of phyllosomas fed on jellyfish were not inferior to those fed on clams reported by Takahashi and Saisho (Wakabayashi *et al*., 2012, 2016). Wakabayashi *et al*. (2012) demonstrated that different methods of rearing (static water *vs*. recirculating water) did not result in a significant difference of duration and size at each developmental stage throughout the phyllosomal phase of *I. novemdentatus*. However, survival rate in recirculating water was remarkably lower, which could be caused by multiple factors including interference between .

The complete larval development of the Australia species *Ibacus peronii* was also achieved by Marinovic *et al*. (1994). Phyllosomas were fed with *Artemia* nauplii and then mussel ovaries as they grew. This species passes through 6 instars before metamorphosing.

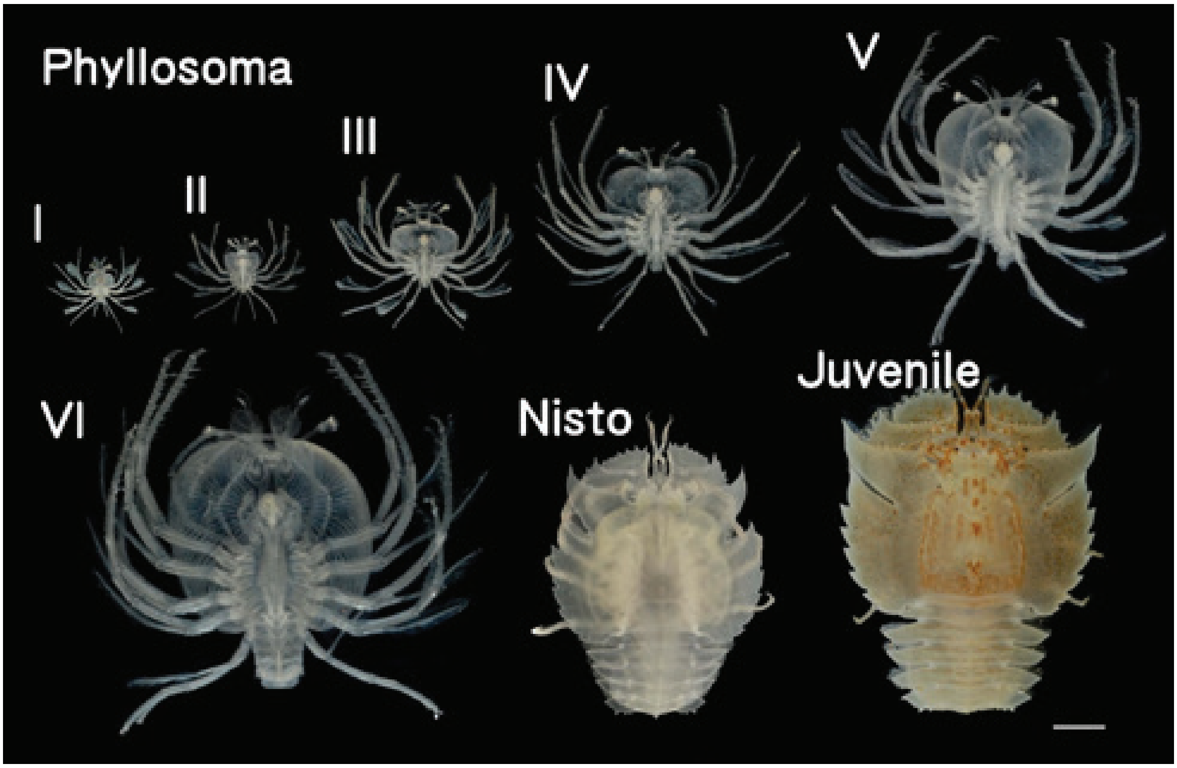

Figure 2. Complete larval development from newly hatched phyllosoma to the first juvenile stage of *Ibacus novemdentatus* Gibbes, 1850. *Scale bar: 5 cm. This figure is reproduced after Wakabayashi and Tanaka (2012) with a permission from the Japanese Society of Systematic Zoology.*

2. *Thenus* spp.

Taxonomy of this genus was recently revised (Burton and Davie, 2007). As the only species *Thenus orientalis* was recognized before the revision, the earlier studies on the larviculture were also represented by a single species.

Ito (1988) for the first time cultured the newly hatched larvae of *Thenus* lobsters in Australian (described as *T. orientalis* Form A and B, currently identified as either one of *Thenus parindicus* and *Thenus australiensis*). He used *Artemia* nauplii and clam flesh; however, the larvae did not survive until the metamorphosis. Mikami and Greenwood (1997) achieved the complete larval development of the both *Thenus* species and confirmed that these species take four instars before metamorphosing into the nisto stage. Phyllosomas preyed on fresh clam flesh could develop into the juvenile stage, while those fed on defrosted clam flesh did not survive. They used *Artemia* nauplii enriched with a commercial product of Selco as supplemental diet together with clam flesh although the presence of supplemental diet did not affect the results. Hải *et al*. (2012) worked on larval development of *T. orientalis* (no detailed information of species identification was given) in Vietnam. They mainly used

Artemia nauplii and fresh oyster flesh as larval diet and blood cockle flesh was also used as a supplemental diet. Metamorphosis was not observed, but it was noticed that the larvae preyed on the supplemental diet for longer period grew and survived better than those had lesser opportunity of preying on blood cockle flesh.

In India, the completion of larval development of *Thenus unimaculatus* (former *T. orientalis* in India) was described by Kizhakudan *et al*. (2004) and Kizhakudan and Krishnamoorthi (2014). Phyllosomas were fed with fresh chopped clam flesh and live ctenophores. The phyllosomas at the earlier stages likely prefer the clam flesh to ctenophores, whereas those at the later stages are opposite. Recently, phyllosomas of *T. australiensis* with a confirmation of species identification were reared in tanks and the complete larval development was described by Wakabayashi and Phillips (2016). Moon jellyfish was used as the sole diet for phyllosomas which successfully metamorphosed into the nisto stage, though the juveniles showed an abnormal form.

III. IMPORTANCE OF SIZE AND MOTILE CHARACTERS IN DIET FOR PHYLLOSOMAS

Each trial in the previous papers had different rearing conditions, and those differences probably influenced the results of phyllosomal growth and survival more or less. Even considering this, the previous observations clearly show that the choice of food items makes a critical difference of results in growth of phyllosomas.

A known information can tell us that the major natural diet of slipper lobster phyllosomas are likely gelatinous zooplankton. They have been often found in association with gelatinous zooplankton in the wild (Shojima, 1963; 1973; Thomas, 1963; Herrnkind *et al*., 1976; Barnett *et al*., 1986; Ates *et al*., 2007; Wakabayashi *et al*., 2017 a, b). Anatomical and molecular approaches demonstrated that digestive organs of wild-caught scyllarid phyllosomas contained gelatinous zooplankton tissues including cnidarian jellyfish and larvaceans (Sims and Brown, 1968; Suzuki *et al*., 2006, 2007). In the laboratory, a variety of food items including gelatinous zooplankton were tested as the diet materials for slipper lobster phyllosomas as mentioned above (see also table 5.1 in Mikami and Kuballa, 2007). The phyllosomas do accept a diverse type of food, it may be because they are opportunistic feeders as suggested in spiny lobsters (Jeffs, 2007).

Among the five previous trials with *I. ciliatus*, phyllsomas fed on fresh bivalves or jellyfish successfully metamorphosed into the nisto stage, whereas those fed on *Artemia* and fish larvae did not (Table 1). Dotsu et al. (1966) observed that newly hatched phyllosoma of *I. ciliatus* likely had a difficulty of catching *Artemia* nauplii. They used fish larvae (> 3.0 mm in total length) instead of *Artemia* nauplii (< 1.0 mm in total length) and found out that phyllosomas preferred large sized fish larvae (*Sebastes achycephalus nigricans*, 7.0 mm in total length) followed by middle (*Sebastes innermis*, 5.0 mm in total length) and small (*Sebastiscus marmoratus*, 3.0 mm in total length) items. However, the survival of phyllosomas fed on those fish larvae was not improved from the trials with *Artemia* nauplii (Table 1), which causes were not discussed by the authors. Hải et al. (2012) mentioned in their paper that their colleagues found out that both rotifer and *Artemia* nauplii were not adequate food items for *Thenus* lobster phyllosomas because those animals were too small and swimming too fast, respectively. Mikami and Kuballa (2004) also pointed out that size and nutritional quality of *Artemia* nauplii is not ideal for *Thenus* lobster phyllosomas. Bivalve flesh and jellyfish are more ideal items rather than rotifer, *Artemia* and fish larvae for a success of long-term larval rearing of *Ibacus* and *Thenus* phyllosomas, in size and motile points of view.

Growth increment of *I. ciliatus* phyllosomas normally ranges between 5.6% and 8.2% of total length per day at any developmental

Table 1. Comparison of larval rearing trials with the Japanese fan lobster, *Ibacus ciliatus* von Siebold, 1824.

References		Saisho & Nakahara (1960)				Dotsu et al. (1966)				Takahashi & Saisho (1978)				Mikami & Takashima (1993)				Wakabayashi et al. (2016)			
Water		23.5-28.4 °C				18-22 °C				23-26 °C				24 °C				23 °C			
Metamorphosis		-				-				58-67 days				59.6 days*				65-70 days			
Major Diet		*Artemia* nauplii				Fish larvae				Clam flesh				*Artemia* nauplii, mussel flesh				Jellyfish			
Parameters		Duration (days)	TL (mm)	Increment		Duration (days)	TL (mm)	Increment		Duration (days)	TL (mm)	Increment		Duration (days)	TL (mm)	Increment		Duration (days)	TL (mm)	Increment	
				mm/d	%/d			mm/d	%/d			mm/d	%/d			mm/d	%/d			mm/d	%/d
Stage	I	-	3.06	-	-	-	2.73	-	-	-	3.36	-	-	-	3.05	-	-	-	2.90	-	-
	II	10	3.70	0.06	2.1	15	3.88	0.08	2.8	11	4.61	0.11	3.4	7.5	4.32	0.17	5.6	6.4	4.00	0.17	5.9
	III	10	4.54	0.08	2.3	17	4.57	0.04	1.0	6	6.37	0.29	6.4	5.8	6.14	0.31	7.3	6.6	5.98	0.30	7.5
	IV	8	6.00	0.18	4.0	-	-	-	-	6	9.36	0.50	7.8	6.2	8.86	0.44	7.1	8.0	8.66	0.34	5.6
	V	-	-	-	-	-	-	-	-	6	13.73	0.73	7.8	6.8	12.32	0.51	5.7	8.9	13.64	0.56	6.5
	VI	-	-	-	-	-	-	-	-	7	20.46	0.96	7.0	7.5	18.45	0.82	6.6	7.3	21.79	1.12	8.2
	VII	-	-	-	-	-	-	-	-	8	32.00	1.44	7.1	8.8	29.86	1.30	7.0	8.8	34.64	1.46	6.7

**the average duration from hatching to metamorphosis was calculated by the author from the figure 2 in Mikami and Takashima (1993). TL: total length*

stages in the three previous successful trials regardless of rearing environment (Table 1). The average value of daily growth increment is 6.6–6.7%. At least for *I. ciliatus*, this may be useful as an indicator to maintain a quality of rearing environment for a successful larval development. A high survival rate of phyllosomas from hatching to settlement (ca. 60%) can be expected when using an individual rearing system to avoid the mortality due to cannibalism (Wakabayashi et al. 2016).

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