

Larval Development of the Brackish Water Clam  
*Corbicula japonica* (Bivalvia: Corbiculidae),  
with Special Reference to Morphological  
Comparison with Concurrent Tidal Flat Bivalves

著者	Kimura Taeko, Soutome Yurina, Sekiguchi Hideo
journal or publication title	Venus : journal of the Malacological Society of Japan
volume	63
number	1-2
page range	33-48
year	2004-06-04
その他のタイトル	ヤマトシジミ幼生の成長および共存する二枚貝幼生との形態比較
URL	<a href="http://hdl.handle.net/10076/13304">http://hdl.handle.net/10076/13304</a>

## Larval Development of the Brackish Water Clam *Corbicula japonica* (Bivalvia: Corbiculidae), with Special Reference to Morphological Comparison with Concurrent Tidal Flat Bivalves

Taeko Kimura, Yurina Soutome and Hideo Sekiguchi

Faculty of Bioresources, Mie University, 1515 Kamihama-cho,  
Tsu, Mie 514-8507, Japan; k-taeko@bio.mie-u.ac.jp

**Abstract:** Based on fertilized eggs obtained from artificially induced spawning of the brackish water clam *Corbicula japonica*, the larvae and post-larvae were reared for 18 days in the laboratory. Planktonic larvae of *C. japonica* passed through the trochophore and D-shaped larval stages (the early stage of veliger larvae), but lacked umbo larvae (the latter stage of veliger larvae), with the result that the late-stage D-shaped larvae with a developed foot settled and metamorphosed on the bottom and walls of culture vessels. To aid in the identification of the larvae of *C. japonica* in plankton samples and their post-larvae in benthos samples, larval and post-larval shell morphology of the clam is described and compared with that of the other bivalves dominant in Japanese estuarine waters.

**Keywords:** *Corbicula*, morphology, larva, post-larva, development

### Introduction

Three *Corbicula* species have been recognized in Japan (e.g. Habe, 1977): *C. sandai* and *C. leana* are found in freshwater while *C. japonica* is in estuarine areas. The brackish water clam *C. japonica* is very common and abundant in Japanese estuarine waters, and is commercially important in Japan (see Nakamura, 2000). Despite several regulations imposed on *C. japonica* fisheries in Japan, the total annual catch of this clam has decreased drastically over the last 2 or 3 decades, probably through the progressive eutrophication of the estuarine and coastal waters. For example, occurrences of red tides and mass mortality of the clam due to the spread of oxygen-poor water has often been reported (Nakamura, 2000).

Information on the distribution, growth, physiological characteristics and fisheries of *C. japonica* has been reported (e.g. Tanaka, 1984a, b; Yamamuro & Koike, 1993; Nakamura, 2000; Takada *et al.*, 2001). However, we have not yet enough data on the larval recruitment processes of the clam, by which benthic populations are generated and maintained in estuarine waters as exemplified in several studies dealing with the clam *Ruditapes philippinarum*, which dominates Japanese tidal flats (Miyawaki & Sekiguchi, 1999, 2000; Ishii *et al.*, 2001). In order to clarify the larval recruitment processes of marine benthic populations, we have to be able to identify their planktonic larvae in plankton samples and their benthic post-larvae in benthos samples.

The larvae and post-larvae of *C. japonica* were described by Miyazaki (1936) and Tanaka (1984a). However, it is difficult to identify them in plankton/benthos samples based on these morphological descriptions, as they did not include descriptions of the hinge apparatus. Identification of larval bivalves is usually based on hinge morphology (Chanley & Andrews, 1971; Le Pennec, 1980). Recently, scanning electron microscopy (SEM) has made it possible to examine the detailed morphological features of the hinge. Based on the features of the hinge from veliger larval to post-larval stages, identification of several species of larval bivalves (particularly mytilids) has been possible (e.g. Lutz & Hidu, 1979; Fuller & Lutz, 1989; Sakai & Sekiguchi,

1992; Kimura & Sekiguchi, 1994; Hanyu *et al.*, 2001; Ozawa & Sekiguchi, 2002).

In the present study, based on fertilized eggs obtained from artificially induced spawning of *C. japonica*, the larvae and post-larvae of the clam were reared in the laboratory. Observations on larval development of the clam are reported. To aid in the identification of the larvae of *C. japonica* in plankton samples and the post-larvae of the clam in benthos samples, we describe shell morphology using an optical microscope and SEM.

## Materials and Methods

Mature specimens of *C. japonica* were collected in the tidal zone of the Toyogawa River, Aichi Prefecture, central Japan, in August 1997. Spawning of 30 mature specimens was artificially induced by immersing them in vessels of diluted natural seawater (salinity 8.0 PSU) based on field data (Asahina, 1941), and adding a drop of hormon-like cerotonin, with temperature stimulation.

The fertilized eggs and hatched larvae were kept at 25 °C in vessels (400 ml) containing filtered diluted natural seawater (salinity 8.0 PSU), following Tanaka (1984a). The larvae were divided into 3 groups 2 days after fertilization, and these were kept at 15 °C, at 20 °C and at 25 °C, respectively, with an initial concentration of 5 larvae/ml. All the water in the vessel was renewed every 2 days, and the microalga *Chaetoceros calcitorans* was supplied every 2 days ( $2.0 \times 10^6$  cells/ml). Fertilized eggs, larvae and post-larvae were sampled every 1-3 days, fixed in small vials with 70% alcohol and stored in a refrigerator at 5 °C until they were used for morphological observations. Morphological features of shells were examined with an optical microscope and SEM (JSM-T, Nippon Denshi Ltd) following the methods of Sakai & Sekiguchi (1990, 1992).

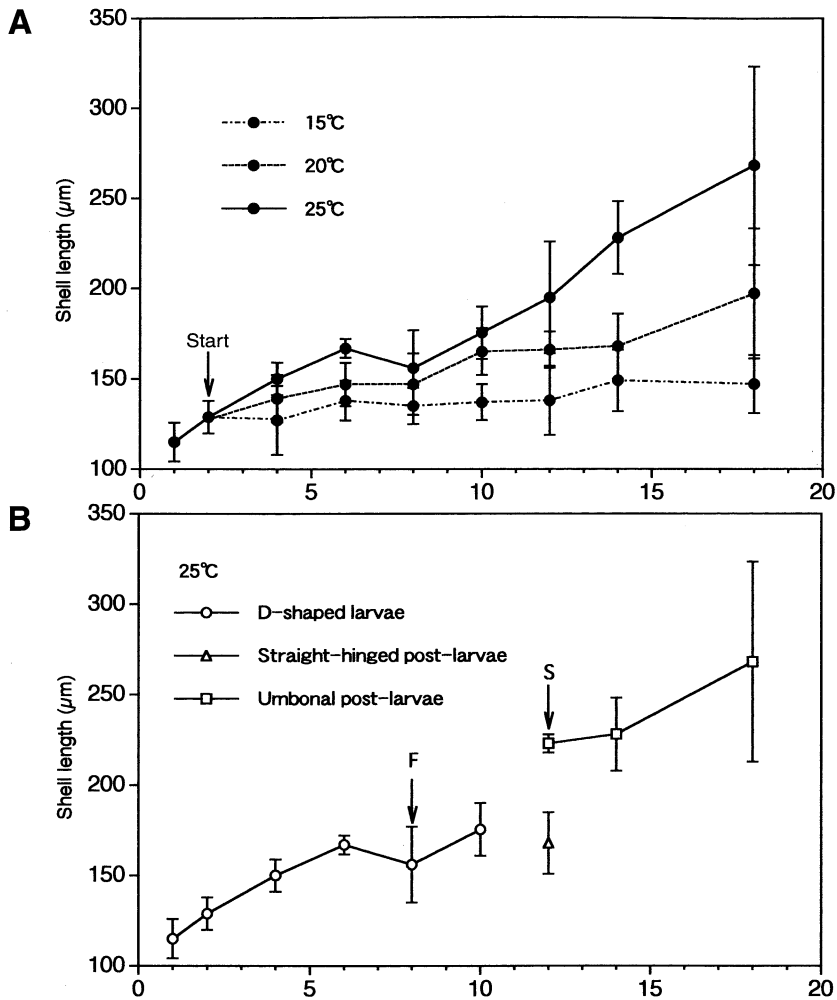
Because *Corbicula japonica* lack umbo larvae, and settle on the substrate as competent D-shaped larvae with the velum bearing a spike-like tuft and with a developed, ciliated foot (functionally referred to as pediveliger larvae), this species is very different in its larval development from brackish and marine bivalves (Sastry, 1979; Mackie, 1984). Thus, we limited the definition of larvae to D-shaped larvae, and define the post-larvae without the velum as early juveniles. Terminology for hinge and teeth on the larval and post-larval shells follows Cox (1969) and Sakai & Sekiguchi (1992). Shell length is the greatest dimension along any axis of the shell.

## Results

### *Larval development of Corbicula japonica*

Eggs were spherical with a diameter of 103 µm on average (98-123 µm, n = 11). The larvae pass through the trochophore stage at 25 °C within 24 hrs after the eggs hatch. Shell lengths of D-shaped and post-larvae were greatest, middle and shortest at 25 °C, 20 °C and 15 °C, respectively (Fig. 1). The larvae and post-larvae kept at 25 °C showed higher survival rates and longer shells than those at the other temperatures. The larvae settled on the bottom and walls of the vessel at 20 °C and 25 °C, while those at 15 °C had still not settled 18 days after fertilization, when the experiments stopped. Below we describe in detail the development of the larvae and post-larvae reared at 25 °C (Fig. 1).

It took 29 hours from fertilization for D-shaped larvae to develop, with shell lengths of 115 µm on average (100-125 µm, n = 4). D-shaped larvae were found from 1 to 10 days after fertilization, with shell lengths of 100-200 µm, though the larvae 10 days after fertilization had shell lengths of 176 µm on average (150-200 µm, n = 10). Early D-shaped larvae were planktonic, while late ones were planktonic/benthic. Late D-shaped larvae, with shell lengths of 156 µm on average (123-181 µm, n = 8), were found 8 days after fertilization, bearing a spike-like tuft on the velum and a developed, ciliated foot. Most of the larvae settled on the bottom and walls of

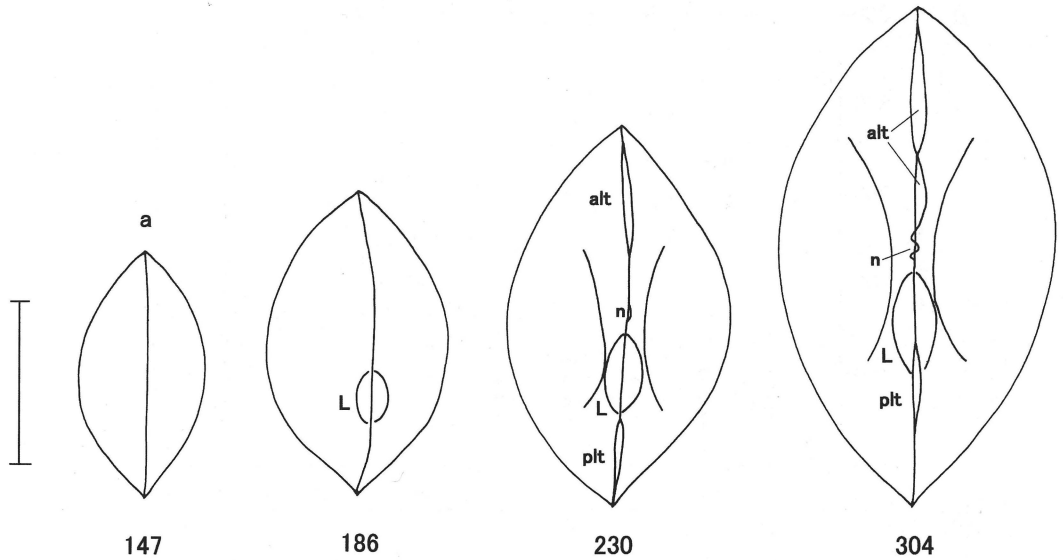


**Fig. 1.** Larval development of *Corbicula japonica* reared in the laboratory at three different temperatures. **A.** solid circles, average shell lengths; vertical lines, standard deviation of shell lengths. Start - starting experiments under 3 different temperature conditions. **B.** open circles, triangles and square, average shell lengths of D-shaped larvae, straight-hinged post-larvae and umbonal post-larvae respectively. F - foot formation; S - settlement.

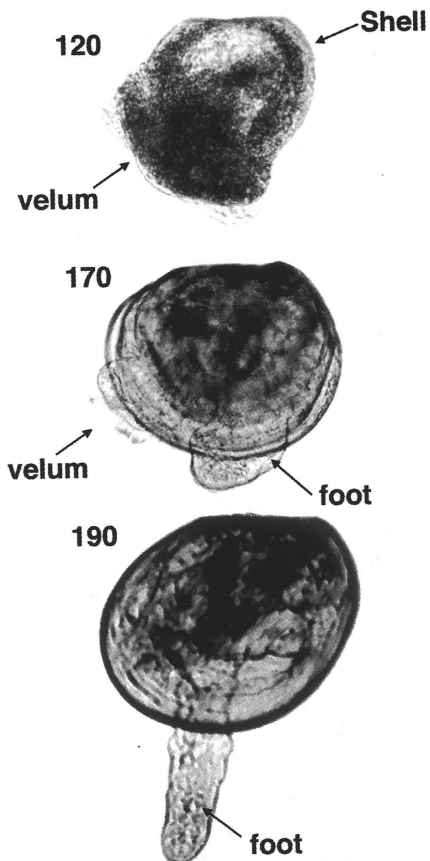
vessels 12 days after fertilization, with shell lengths of 195  $\mu\text{m}$  on average (147-230  $\mu\text{m}$ ,  $n = 8$ ). We distinguished post-larvae with 2 types of shell shape, straight-hinged and umbonal. Straight-hinged post-larvae with shell lengths of 168  $\mu\text{m}$  on average (147-186  $\mu\text{m}$ ,  $n = 4$ ) were found 12 days after fertilization, while umbonal ones with shell lengths of 223  $\mu\text{m}$  on average (221-230  $\mu\text{m}$ ,  $n = 4$ ) were found 12 days after fertilization (Figs. 2, 3). Eyespots were not observed in either the larvae or the post-larvae.

### Observations on larval and post-larval shell morphology of *Corbicula japonica*

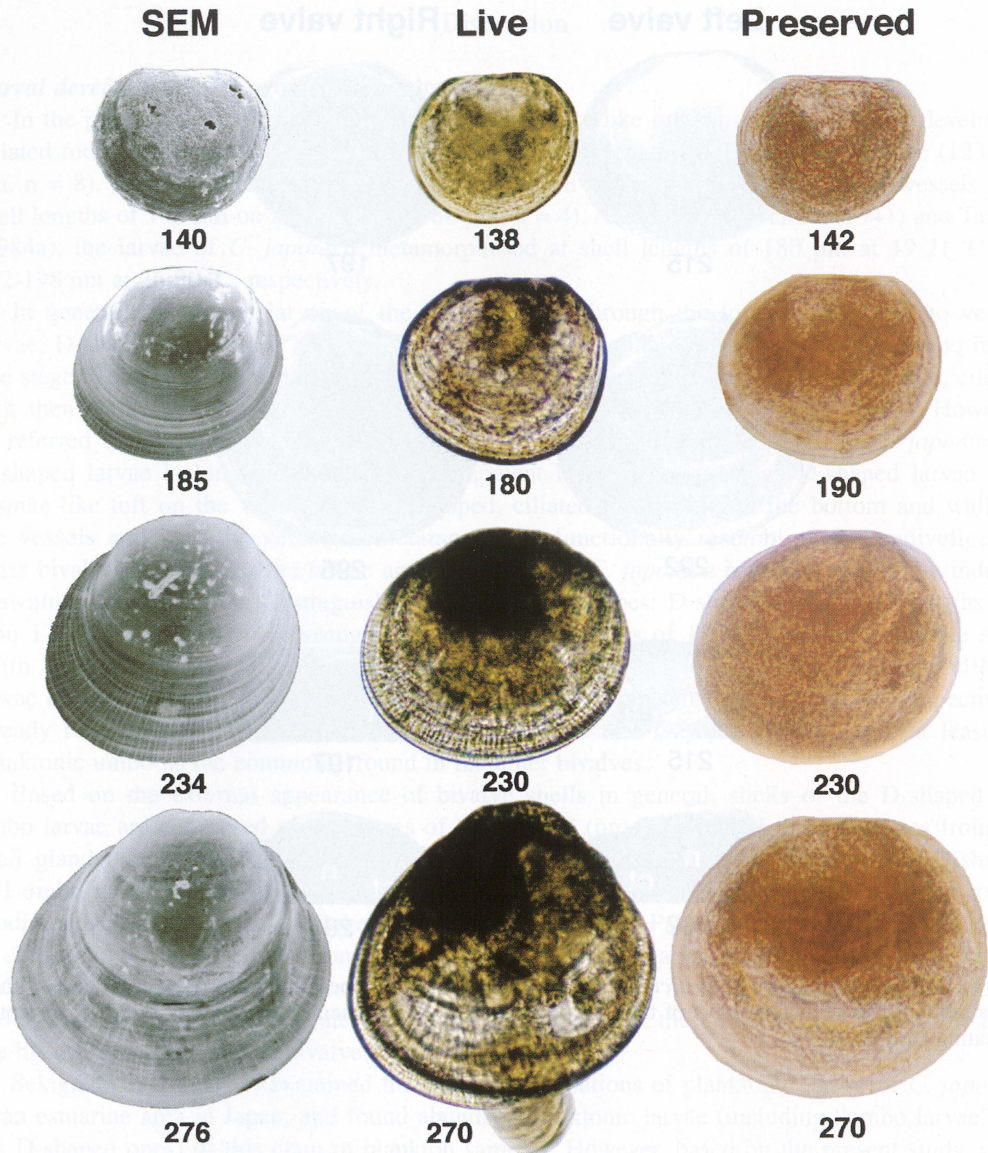
**Shell shape (Fig. 4):** In the D-shaped larvae with shell lengths of 100-200  $\mu\text{m}$ , the shells became oval with growth. Shells of post-larvae with lengths of 220  $\mu\text{m}$  or more were ellipsoid with round postero-ventral margins, while those with shell lengths of 170  $\mu\text{m}$  or more bore ribs in



**Fig. 2.** Dorsal views of larval and post-larval shells of *Corbicula japonica* using an optical microscope. a - anterior, alt - anterior lateral teeth, L - ligament, n - minute notch, plt - posterior lateral teeth. Numerals indicate shell lengths ( $\mu\text{m}$ ). Vertical line = 100  $\mu\text{m}$ .



**Fig. 3.** Non-competent D-shaped larvae, competent D-shaped larvae (pediveliger) and straight-hinged post-larvae of *Corbicula japonica* reared in the laboratory. The competent larvae bear a spike-like tuft on the velum and a developed, ciliated foot, while post-larvae lose the velum. Numerals indicate shell lengths ( $\mu\text{m}$ ).

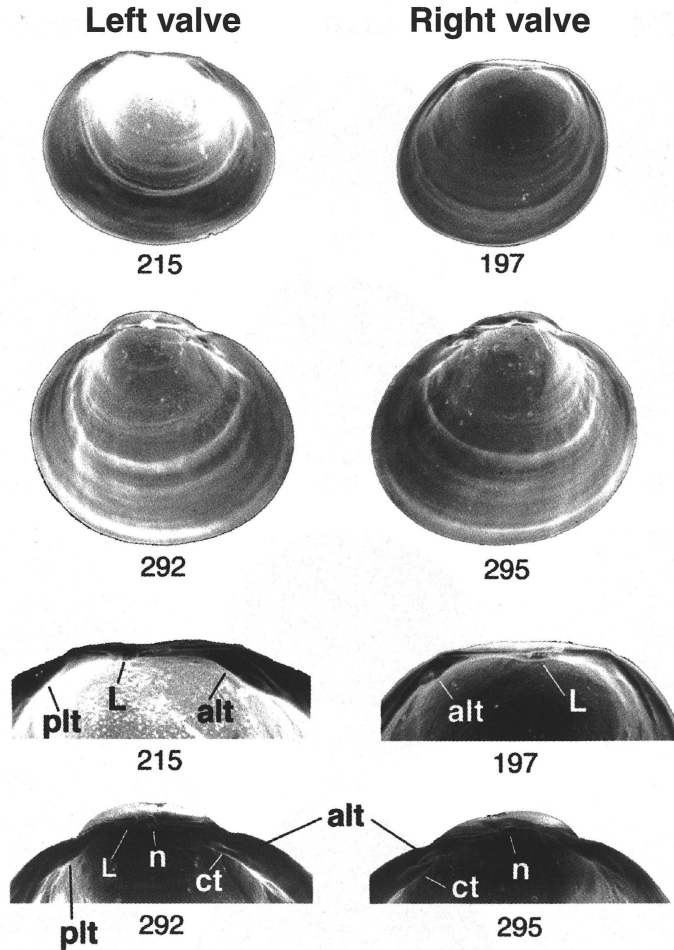


**Fig. 4.** Lateral views of left valves of larvae and post-larvae of *Corbicula japonica* reared in laboratory. Left row (SEM): specimens deposited in 80% alcohol vials for over half a year. Middle row (optical microscope): live specimens. Right row (optical microscope): specimens deposited for 4 years. Post-larvae in live specimens bear ribs in a radial pattern on the ventral margin of their shells. Numerals indicate shell lengths ( $\mu\text{m}$ ). See text for further explanation.

a radial pattern on the ventral margin of the shell, although it was difficult to observe the ribs in those stored in 80% alcohol for a long time. The shells grew antero-ventrally, bearing a low umbo located at the posterior portion along the dorsal margin. Eyespots were not found in either the larvae or the post-larvae.

**Hinge morphology (Figs. 2, 5):** D-shaped larvae at the early stage, with shell lengths less than





**Fig. 5.** Post-larval shells of *Corbicula japonica* using SEM. Upper figures are inner views of their shells while lower ones are views of their hinges. Symbols and numerals are same as in Fig. 2 except ct indicating cardinal teeth.

147  $\mu\text{m}$ , lacked any tooth on the hinge, while those in the latter stage with shell lengths less than 210  $\mu\text{m}$  bore weak dentition in the middle portion. Post-larvae with shell lengths of 220  $\mu\text{m}$  or more had a minute notch (n) in the middle portion.

**Lateral teeth (Figs. 2, 5):** D-shaped larvae with shell lengths less than 147  $\mu\text{m}$  lacked any lateral tooth. Post-larvae with shell lengths of 215  $\mu\text{m}$  or more had both anterior (alt) and posterior lateral teeth (plt), and those with shell lengths of 290  $\mu\text{m}$  or more had cardinal teeth (ct) beneath anterior lateral teeth (alt).

**Ligament (Figs. 2, 5):** D-shaped larvae with shell lengths less than 147  $\mu\text{m}$  lacked any ligament. A ligament (L) was observed at the posterior portion of the hinge in D-shaped larvae that had a developed foot (and so were competent for settling) with shell lengths of 186  $\mu\text{m}$ , while a well-developed ligament was observed in post-larvae with shell lengths of 220  $\mu\text{m}$  or more. The ligament moves posteriorly with growth.

## Discussion

### *Larval development of Corbicula japonica*

In the present study, D-shaped larvae bearing a spike-like tuft on the velum and a developed, ciliated foot were found 8 days after fertilization, at shell lengths of 156  $\mu\text{m}$  on average (123-181  $\mu\text{m}$ ,  $n = 8$ ). 12 days after fertilization, these settled on the bottom and walls of the vessels with shell lengths of 168  $\mu\text{m}$  on average (147-186  $\mu\text{m}$ ,  $n = 4$ ). According to Asahina (1941) and Tanaka (1984a), the larvae of *C. japonica* metamorphosed at shell lengths of 180  $\mu\text{m}$  at 19-21 °C and 172-198  $\mu\text{m}$  at 26-30 °C, respectively.

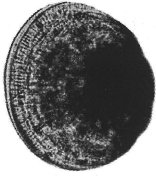














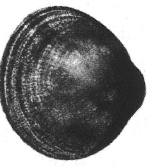


In general, planktonic larvae of the Bivalvia pass through the trochophore stage to veliger larvae; D-shaped larvae lack an umbo in the early stage, while umbo larvae bear an umbo in the late stage. Competent umbo larvae bearing a spike-like tuft on the velum and a developed, ciliated foot then settle and lose the velum to metamorphose (Sastry, 1979; Mackie, 1984). However, as referred to earlier, we define planktonic larvae following the trochophore in *C. japonica* as D-shaped larvae lacking an umbo while competent larvae (the late-stage D-shaped larvae with a spike-like tuft on the velum and a developed, ciliated foot) settle on the bottom and walls of the vessels and lose the velum to metamorphose, functionally resembling the pediveliger of other bivalves. By rearing the larvae and post-larvae of *C. japonica* based on artificially induced spawning, Tanaka (1984a) distinguished larvae of three types: D-shaped (with shell lengths less than 172  $\mu\text{m}$ ), the metamorphosing stage (with shell lengths of 172-198  $\mu\text{m}$ ) and the late stage (with shell lengths of 210-220  $\mu\text{m}$ ). However, based on shell morphology, Tanaka's (1984a) larvae clearly are equivalent to the early and late stage (competent) and post-larvae, respectively, already referred to in the present study. This indicates that *C. japonica* may lack at least the planktonic umbo larvae commonly found in the other bivalves.

Based on the external appearance of bivalve shells in general, shells of the D-shaped and umbo larvae are composed of two types of larval shell (prodissoconch I that originates from the shell gland of the trochophore larvae, and prodissoconch II that is generated during D-shaped and umbo larval periods), while those of their post-larvae bear a dissoconch in addition to the prodissoconch I and II shells (Ockelmann, 1965; Carriker & Palmer, 1979; Martel *et al.*, 1995). According to our SEM observations of *C. japonica*, D-shaped larvae display both prodissoconch I and II shells while benthic post-larvae have a dissoconch shell in addition to the prodissoconch I and II shells (Fig. 4). This indicates that *C. japonica* may lack the umbo larvae found in the early life histories of most marine bivalves.

Sekiguchi *et al.* (1991) examined the vertical distributions of planktonic larvae of *C. japonica* in an estuarine area in Japan, and found abundant planktonic larvae (including "umbo larvae" but not D-shaped ones) of this clam in plankton samples. However, based on the present study, these "umbo larvae" may have been post-larvae. This is also true of Soutome *et al.* (in preparation) who at first had regarded planktonic larvae (excluding D-shaped ones) of this clam as umbo larvae. These observations indicate that the post-larvae of the clam may be both planktonic and benthic in natural estuarine environments, but that in the laboratory the flotation/dispersal of the post-larvae does not occur. Post-larval transport/dispersal in water using drifting threads (byssus threads) has been reported for a variety of bivalves (Sigurdsson *et al.*, 1976; Lane *et al.*, 1985). Transport/dispersal using drifting threads has been observed in adults of the freshwater clam *Corbicula fluminea* (Prezant & Chalermwat, 1984), but not so far in the post-larvae of any freshwater/estuarine *Corbicula*.

Although Morton (1986) recognized two *Corbicula* species (*C. fluminea*, *C. fluminalis*) in Japan, more recent studies have recognized three (Okamoto & Arimoto, 1986 for chromosomes; Takayasu *et al.*, 1986 for shell morphology; Sakai *et al.*, 1994 for isozymes; Harada & Nishino, 1995 for siphon morphology): the two freshwater species *C. leana* and *C. sandai*, and the

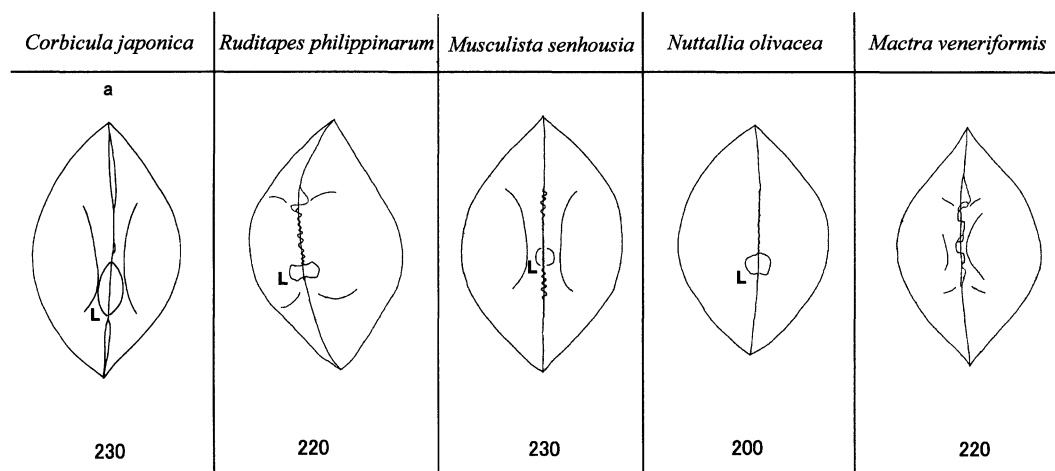


Post-larvae		Planktonic larvae	
 230	 190	 138	<i>Corbicula japonica</i>
 380	 310	 210	<i>Ruditapes philippinarum</i>
 410	 250	 170	<i>Musculista senhousia</i>
 380	 270	 200	<i>Nuttallia olivacea</i>
 410	 320	 230	<i>Mactra veneriformis</i>
 390	 310	 175	<i>Meretrix lusoria</i>

**Fig. 6.** Differences in lateral shell profiles of planktonic larvae and post-larvae of several bivalve species dominant in Japanese estuarine waters. Figures of *Corbicula japonica* are after the present study, *Ruditapes philippinarum*, *Nuttallia olivacea*, *Mactra veneriformis* and *Musculista senhousia* after Sakai & Sekiguchi (1992) and *Meretrix lusoria* after SEM figures of our specimens reared in the Akasuka Fishermen union. Planktonic larvae of *C. japonica* are D-shaped ones while the other larvae are Umbo ones. See text for further explanation. Symbols and numerals are same as in Fig. 2.

brackish water *C. japonica*. Interestingly, these *Corbicula* species show life histories very different from most marine clams on tidal flats and in neighbouring shallows. In addition to the difference in habitat, these *Corbicula* species show different reproductive strategies. Both *C. sandai* and *C. japonica* are dioecious and shed their eggs, while *C. leana* is monoecious with self-fertilization, sometimes with gyrogenesis (Komaru *et al.*, 1997), and is ovoviviparous (Ikematsu & Yamane, 1977). Furthermore, *C. sandai* lacks planktonic larvae: the species sheds eggs and sperm in the water, fertilized eggs sink onto the bottom substrate and the larvae pass through the D-shaped stage within their eggs, the umbo larvae (umbonal juveniles ?) being benthic (Furukawa & Mizuki, 1953; Ikematsu & Yamane, 1977). *C. leana* also lacks planktonic larvae: fertilized eggs are retained in a brood pouch among the gills, and then benthic D-shaped larvae move out from the parent to metamorphose to post-larvae, with no umbo-larvae stage (Miyazaki, 1936; Ikematsu & Yamane, 1977). This is also true of the fresh/brackish water clam *C. fluminea* that was introduced from Asian waters to the U.S. waters where it is now common (King *et al.*, 1986; Kraemer & Galloway, 1986).

Based on the present study, the brackish water clam *C. japonica* has planktonic D-shaped larvae but lacks umbo larvae, taking 8 days and more (at water temperature of 25 °C) after fertilization to form pediveligers, and 12 days and more after fertilization to settle. On the other hand, the fresh/brackish water *C. fluminea* lacks planktonic larvae, takes 100 hrs (at water temperature of 19-25 °C) after fertilization to form pediveligers (benthic, competent D-shaped larvae), and 112 hrs after fertilization to metamorphose to post-larvae (early juveniles) (Kraemer & Galloway, 1986). Unfortunately, we have little information on the larval period of the other *Corbicula* species, including *C. sandai* and *C. leana* (Miyazaki, 1936; Furukawa & Mizuki, 1953; Ikematsu & Yamane, 1977). The above facts indicate that the larval period may be much longer for *C. japonica*, that has planktonic larvae than for fresh/brackish water *Corbicula* species that lack planktonic larvae. This may be related closely to larval recruitment of *C. japonica*: according to Sekiguchi *et al.* (1991), planktonic larvae of *C. japonica* inhabiting upper estuarine waters disperse and are transported to coastal waters, and then planktonic but competent larvae get back to the juvenile/adult habitat within the upper estuarine waters through the intrusion of saline bottom waters during flood tides.



**Fig. 7.** Differences in dorsal profiles of post-larval shells of several bivalve species dominant in Japanese estuarine waters. Figures of *Corbicula japonica* are after the present study, *Ruditapes philippinarum*, *Nuttallia olivacea*, *Macrta veneriformis* and *Musculista senhousia* after Sakai & Sekiguchi (1992). Symbols and numerals are same as in Fig. 2.

**Table 1.** Characteristics of shell shape and hinge apparatus of bivalves dominated on tidal flats in Japan.

				<i>Corbicula japonica</i>	<i>Ruditapes philippinarum</i>
		D-shaped shell	Shell length	100-200 $\mu\text{m}^*$ (25 °C)	95-110 $\mu\text{m}$ (23 °C) (1)
	Veliger larvae	Umbo larvae	Shell shape	umbo larvae lacked	rounded triangle (210 $\mu\text{m}$ shell length) (1, 2)
External appearance	Shell length at settlement			147-186 $\mu\text{m}$ (25 °C)	240-255 $\mu\text{m}$ (23 °C) (1)
	Post-larvae	Shell shape	from D-shaped to oval. ellipsoid with swollen anterior part of ventral shell margin, shell anteriorly stretching with growth	rounded triangle with swollen anterior part of dorsal shell margin (2)	
		Umbo	umbo located rather posteriorly, lower than that of <i>Nuttallia</i>	high, located in the middle (2)	
		Eyespots	absent	absent	
		Radial ribs	present (170 $\mu\text{m}$ shell length)	absent	
		Ligament	posterior	posterior (2)	
Hinge	Teeth	teeth absent (147 $\mu\text{m}$ shell length), anterior and posterior lateral teeth present (> 215 $\mu\text{m}$ shell length)	12 teeth on each valves (260 $\mu\text{m}$ shell length) (**, 2), anterior lateral tooth present (> 260 $\mu\text{m}$ shell length) (2)		
	Adults	Teeth	3 cardinal teeth, anterior and posterior lateral teeth present (5)	3 cardinal teeth, lateral teeth absent (5)	

\*including straight-hinged post-larvae, \*\*personal observations, (1): Tanaka (1981a,b, 1982a,b), (2): Sakai & Sekiguchi (1992), (3): Kimura & Sekiguchi (1994), (4): Kimura & Sekiguchi (1996), (5): Cox *et al.* (1969), (6): Kamijo (1982).

**Table 1 (continued).** Characteristics of shell shape and hinge apparatus of bivalves dominated on tidal flats in Japan.

<i>Musculista senhousia</i>	<i>Nuttallia olivacea</i>	<i>Macra veneriformis</i>	<i>Meretrix lusoria</i>
70-120 µm (25 °C) (3)	< 200 µm (field sample) (2)	81-110 µm (? °C) (1)	100-130 µm (23-25 °C) (6)
egg shaped with a pointed anterior margin (120-300 µm shell length) (3)	rounded with longer anterior-posterior axis (200 µm shell length) (2)	oval with posterior part of shell being rather angular (230 µm shell length) (2)	ellipsoid with anterior part of dorsal shell margin longer than posterior one, anterior part of shell narrow (175 µm shell length) **
240 µm (30 °C) (4) 300 µm (25 °C) (4)	200-300 µm (field sample) (2)	220-260 µm (? °C) (1)	200 µm (23-25 °C) (6)
dorsal shell margin being swollen, but posterior part of dorsal shell margin being rather angular with growth (3)	rounded with anterior part of ventral shell margin being swollen little, shell stretching anteriorly with growth (2)	oval with anterior and posterior shell margins being rather rounded (320µm shell length) (2)	rather triangle, anterior part of dorsal shell margin being longer than posterior one as compared with <i>Ruditapes</i> (2)
high, located anteriorly (2)	medium, located posteriorly (2)	medium, located nearly in the middle (2)	medium, located nearly in the middle (2)
present (3)	absent	absent	absent
absent	absent	absent	absent
middle to posterior (3)	posterior (2)	absent (2)	posterior (2)
9-13 teeth, encroached median teeth (550 µm shell length) (3) posterior lateral teeth present (> 500 µm shell length) (3)	one tooth each on both valves (310 µm shell length) (2) lateral teeth absent (2)	broad protuberance on hinge in addition to 2 teeth each on both valves (220 µm shell length) (2) anterior and posterior lateral teeth present (> 470 µm shell length) (2)	teeth absent, anterior lateral teeth present (> 260 µm shell length) **
cardinal teeth absent, posterior lateral teeth and dysodont teeth present (5)	3 small cardinal teeth, lateral teeth absent (5)	inverted V-shaped cardinal tooth of left valve, two cardinal teeth of right valve, posterior of which interior side of ligament bound, strong anterior and posterior lateral teeth present (5)	3 cardinal teeth, anterior lateral teeth present, minute notches on the dorsal surface of posterior cardinal teeth (5)

### ***Distinguishing the larvae and post-larvae of Corbicula japonica from others***

The present study of larval and post-larval shell morphology in *C. japonica* aims to aid in the identification of its larvae and post-larvae, contributing to the clarification of the larval recruitment processes by which benthic populations are generated and maintained in estuarine waters (e.g. Miyawaki & Sekiguchi, 1999, 2000; Ishii *et al.*, 2001). Unfortunately, there is little information on larval shell morphology of bivalves, particularly the larval hinge, in Japan and elsewhere (see Sakai & Sekiguchi, 1992). In Japanese estuarine waters where the brackish water clam *C. japonica* is found commonly and abundantly (Nakamura, 2000), five bivalves (*Ruditapes philippinarum*, *Musculista senhousia*, *Nuttallia olivacea*, *Macraa veneriformis* and *Meretrix lusoria*) are also commercially important to local fisheries (Sekiguchi *et al.*, 1991; Sakai & Sekiguchi, 1992; Miyawaki & Sekiguchi, 1999, 2000). We have tried to distinguish the larvae and post-larvae of *C. japonica* from these bivalves as follows.

**Planktonic larvae (Figs. 6, 7 and Table 1):** Based on the present study, planktonic larvae of *C. japonica* are so-called D-shaped larvae. In general, it is difficult to identify D-shaped larvae to species based on shell morphology. However, shell lengths of D-shaped larvae for the above bivalves (except for *N. olivacea*) are clearly shorter than those of *C. japonica* (Yoshida, 1953, Tanaka, 1981a, b, 1984a; Sakai & Sekiguchi, 1992, Kimura & Sekiguchi, 1994). Information on larval shell morphology is not sufficient to distinguish *N. olivacea*, though shell lengths of its D-shaped larvae may be less than 200  $\mu\text{m}$  because umbo larvae with shell lengths of 200  $\mu\text{m}$  were found according to Sakai & Sekiguchi (1992). In summary, if D-shaped larvae in plankton samples have larger shell lengths (more than 130  $\mu\text{m}$ ), it is safe to identify these larvae as those of *C. japonica*.

**Post-larvae (Figs. 6, 7 and Table 1):** Post-larvae (straight-hinged and umbonal) of *C. japonica* are 147  $\mu\text{m}$  and more in shell length, those at 170  $\mu\text{m}$  and more having ribs in a radial pattern on their ventral margin of their shells (Fig. 4). Accordingly, post-larvae with shell lengths of 147  $\mu\text{m}$  and more of *C. japonica* are distinguishable from umbo and post-larvae with the same range of shell lengths of other species. However, these ribs disappear in specimens of post-larvae stored in 80% alcohol or formalin seawater for longer. Accordingly, we have tried to distinguish post-larvae of *C. japonica* from the umbo and post-larvae of these five bivalves, based on hinge morphology as follows.

***Corbicula* vs *Ruditapes*.** Based on the dorsal view of their shells (Tanaka, 1981b; Sakai & Sekiguchi, 1992), post-larvae of *C. japonica* lack teeth and bear a larger and ellipsoid ligament while those of *R. philippinarum* clearly display teeth in addition to a ligament. Those of *C. japonica* with shell lengths of 215  $\mu\text{m}$  or more bear lateral teeth, while those of *R. philippinarum* with shell lengths of 260  $\mu\text{m}$  or more bear an anterior lateral tooth.

***Corbicula* vs *Musculista*.** Based on the dorsal view of their shells (Sakai & Sekiguchi, 1992; Kimura & Sekiguchi, 1994), post-larvae of *C. japonica* are distinguishable from those of *M. senhousia* by lacking teeth and eyespots and also by the presence of a larger and ellipsoid ligament. These post-larvae are distinguishable based on the lateral view of their shells: those of *M. senhousia* indicate a unique form of the shell specific to mytilids (see Lutz & Kennish, 1982; Fuller & Lutz, 1989).

***Corbicula* vs *Nuttallia*.** Based on the dorsal view of their shells (Sakai & Sekiguchi, 1992), post-larvae of *C. japonica* lack teeth and bear a larger ligament, while those of *N. olivacea* display teeth in addition to a ligament. Those of *C. japonica* with shell lengths of 215  $\mu\text{m}$  or more bear lateral teeth, while those of *N. olivacea* do not bear any lateral tooth. These post-larvae are distinguishable by the form of their ligaments.

***Corbicula* vs *Macraa*.** Based on the dorsal view of their shells (Tanaka, 1981a; Sakai & Sekiguchi, 1992), post-larvae of *C. japonica* bear a larger ligament but lack teeth while the reverse is true of *M. veneriformis*, though post-larvae of both bivalves bear lateral teeth.

*Corbicula* vs *Meretrix*. Based on several studies (Yoshida, 1953; Tanaka, 1981b; Kamijo, 1982; Sakai & Sekiguchi, 1992), post-larvae of both *C. japonica* and *M. lusoria* bear a ligament but lack teeth and eyespots. Those of *C. japonica* with shell lengths of 215  $\mu\text{m}$  or more bear lateral teeth, while those of *M. lusoria* with shell lengths of 260  $\mu\text{m}$  or more bear an anterior lateral tooth. However, those of the former species are distinguishable from those of the latter by the form of the ligament in the dorsal view of their shells.

### Acknowledgements

We would like to express our sincere thanks to Dr. K. Okamoto and his colleagues of the Fisheries laboratory of the University of Tokyo, to Dr. K. Matsuoka and his colleagues of Toyohashi Natural History Museum for using their facilities, to Mr. S. Ogawa of Mie University for aiding in SEM observation, and to Mr. S. Kimura and his colleagues of Miya Fishery High School of Aichi Prefecture for their encouragement throughout the present study. Thanks are also due to people of the Akasuka fishermen union for rearing the larvae and post-larvae of the clam *Meretrix lusoria* in their laboratory, and to Dr. J. D. Booth, MAF of New Zealand, for polishing the English. We are grateful to two anonymous referees for their comments and criticism that improved the manuscript. This study was partially supported by a JSPS Research Fellowship for Young Scientists (5940) awarded to T. Kimura.

### References

- Asahina, E. 1941. An ecological study of *Corbicula japonica* group, the brackish water bivalve, with special reference to the environmental factors of its habitat in Hokkaido. *Bulletin of the Japanese Society of Scientific Fisheries* 10: 143-152. (in Japanese)
- Carriker, M. R. & Palmer, R. E. 1979. Ultrastructural morphogenesis of prodissoconch and early dissoconch valves of the oyster *Crassostrea virginica*. *Proceedings of the National Shellfish Association* 69: 103-128.
- Chanley, P. & Andrews, J. D. 1971. Aids for identification of bivalve larvae of Virginia. *Malacologia* 11: 45-119.
- Cox, L. R. 1969. General features of bivalves. In: Moore, R. C. (ed.), *Treatise on Invertebrate Paleontology (N) Mollusca* 6, pp. 2-129. The Geological Society of America, Inc. and University of Kansas, Colorado.
- Cox, L. R., Newell, N. D., Branson, C. C., Casey, R., Chavan, A., Coogan, A. H., Dechaseaux, C., Fleming, C. A., Haas, F., Hertlein, L. G., Keen, A. M., LaRocque, A., McAlester, A. L., Perkins, B. F., Puri, H. S., Smith, L. A., Soot-Ryen, T., Stenzel, H. B., Turner, R. D. & Weir, J. 1969. Systematic descriptions. In: Moore, R. C. (ed.), *Treatise on Invertebrate Paleontology (N) Mollusca* 6, pp. 225-913. The Geological Society of America, Inc. and University of Kansas, Colorado.
- Fuller, S. C. & Lutz, R. A. 1989. Shell morphology of larval and post-larval mytilids from the northwestern Atlantic. *Journal of the Marine Biological Association of the United Kingdom* 69: 181-218.
- Furukawa, M. & Mizuki, S. 1953. An ecological studies on the bivalve "seta-shijimi", *Corbicula sandai* Reinhardt of the Lake Biwa- 2. On the development. *Bulletin of the Japanese Society of Scientific Fisheries* 19: 91-94. (in Japanese)
- Habe, T. 1977. *Systematics of Mollusca in Japan, Bivalvia and Scaphopoda*, 372 pp. Zukan-no-Hokuryukan, Tokyo. (in Japanese)
- Harada, E. & Nishino, M. 1995. Differences in inhalant siphonal papillae among the Japanese species of *Corbicula* (Mollusca: Bivalvia). *Publications of the Seto Marine Biological Laboratory* 36: 389-408.
- Hanyu, K., Toyama, K., Kimura, T. & Sekiguchi, H. 2001. Larval and post-larval shell morphology of the green mussel *Perna viridis* (Linnaeus, 1758) (Bivalvia, Mytilidae). *American Malacological Bulletin* 16: 171-177.
- Ikematsu, W. & Yamane, S. 1977. Ecological studies of *Corbicula leana* Prime-III On spawning throughout the year and self-fertilization in the gonad. *Bulletin of the Japanese Society of Scientific Fisheries* 43: 1139-1146. (in Japanese)
- Ishii, R., Sekiguchi, H., Nakahara, Y. & Jinnai, Y. 2001. Larval recruitment of the manila clam *Ruditapes philippinarum* in Ariake Sound, southern Japan. *Fisheries Science* 67: 579-591.
- Kamijo, Y. 1982. Report of rearing technology of *Meretrix lusoria*. Oita Prefectural shallow water

- fisheries experimental station, 36 pp. Oita Prefecture. (in Japanese)
- Kimura, T. & Sekiguchi, H. 1994. Larval and post-larval shell morphology of two mytilid species *Musculista senhousia* (Benson) and *Limnoperna fortunei kikuchii* Habe. *Venus (Japanese Journal of Malacology)* 53: 307-318.
- Kimura, T. & Sekiguchi, H. 1996. Effects of temperature on larval development of two mytilid species and their implication. *Venus (Japanese Journal of Malacology)* 55: 215-222.
- King, C. A., Langdon, C. J. & Counts, C. L. 1986. Spawning and early development of *Corbicula fluminea* (Bivalvia: Corbiculidae) in laboratory culture. *American Malacological Bulletin* 4: 81-88.
- Komaru, A., Konishi, K., Nakayama, I., Kobayashi, T., Sakai, H. & Kawamura, K. 1997. Hermaphroditic freshwater clams in the genus *Corbicula* produce non-reductional spermatozoa with somatic DNA content. *The Biological Bulletin* 193: 320-323.
- Kraemer, L. R. & Galloway, M. L. 1986. Larval development of *Corbicula fluminea* (Muller) (Bivalvia: Corbiculidae): an appraisal of its heterochrony. *American Malacological Bulletin* 4: 61-79.
- Lane, D. J., Beamont, A. R. & Hunter, J. R. 1985. Byssus drifting and the drifting threads of the young post-larval mussel *Mytilus edulis*. *Marine Biology* 84: 301-308.
- Le Penneec, M. 1980. The larval and post-larval hinge of some families of bivalve mollusks. *Journal of the Marine Biological Association of the United Kingdom* 60: 601-617.
- Lutz, R. A. & Hidu, H. 1979. Hinge morphogenesis in the shells of larval and early post-larval mussels (*Mytilus edulis* L. and *Modiolus modiolus* (L.)). *Journal of the Marine Biological Association of the United Kingdom* 59: 111-121.
- Lutz, R. A. & Kennish, M. J. 1982. Ecology and morphology of larval and early post-larval mussels. In: Gosling, E. (ed.), *The Mussel Mytilus: Ecology, Physiology and Culture*, pp. 53-86. Elsevier Science Publishers B. V., Amsterdam.
- Mackie, G. L. 1984. Bivalves. In: Tompa, A. S., Verdonk, N. H. & Biggelaar, J. A. M. (eds.), *The Mollusca*, Vol. 7, pp. 351-418. Academic press, London.
- Martel, A., Hynes, T. M. & Buckland-Nicks, J. 1995. Prodissoconch morphology, planktonic shell growth, and size at metamorphosis in *Dreissena polymorpha*. *Canadian Journal of Zoology* 73: 1835-1844.
- Miyawaki, D. & Sekiguchi, H. 1999. Interannual variation of bivalve populations on temperate tidal flats. *Fisheries Science* 65: 817-829.
- Miyawaki, D. & Sekiguchi, H. 2000. Long-term observations on larval recruitment processes of bivalve assemblages on temperate tidal flats. *Benthos Research* 55: 1-16.
- Miyazaki, I. 1936. On the development of bivalves belonging to the genus *Corbicula*. *Bulletin of the Japanese Society of Scientific Fisheries* 5: 249-256. (in Japanese)
- Morton, B. 1986. *Corbicula* in Asia – an updated synthesis. *American Malacological Bulletin, Special edition* 2: 113-124.
- Nakamura, M. 2000. *Corbicula Fisheries in Japan – The Present Situation and Problems –*, 266 pp. Tatarashobo, Shimane. (in Japanese)
- Ockelmann, K. W. 1965. Developmental types in marine bivalves and their distribution along the Atlantic coast of Europe. In: Cox, L. R. & Peake, J. F. (eds.), *Proceedings of the First European Malacological congress*, pp. 25-53. Conchological Society of the Great Britain and Ireland and the Malacological Society of London.
- Okamoto, A. & Arimoto, B. 1986. Chromosomes of *Corbicula japonica*, *C. sandai* and *C. (Corbiculina) leana* (Bivalvia: Corbiculidae). *Venus (Japanese Journal of Malacology)* 45: 194-202.
- Ozawa, H. & Sekiguchi, H. 2002. Shell morphology of larvae and post-larvae of the two tropical *Modiolus* species, *Modiolus auriculatus* and *Modiolus philippinarum* (Bivalvia: Mytilidae). *Venus (Japanese Journal of Malacology)* 61: 25-39.
- Prezant, R. S. & Chalermwat, K. 1984. Floatation of the bivalve *Corbicula fluminea* as a means of dispersal. *Science* 225: 1491-1493.
- Sakai, A. & Sekiguchi, H. 1990. A simple method of examination on hinge apparatus in settled bivalves. *Benthos Research* 39: 21-22. (in Japanese)
- Sakai, A. & Sekiguchi, H. 1992. Identification of planktonic late-stage larval and settled bivalves in a tidal flat. *Bulletin of the Japanese Society of Fisheries Oceanography* 56: 410-425. (in Japanese)
- Sakai, H., Kamiyama, J., Jeon, S. R. & Amio, M. 1994. Genetic relationships among three species of freshwater bivalves genus *Corbicula* (Corbiculidae) in Japan. *Nippon Suisan Gakkaishi* 60: 605-610. (in Japanese)
- Sastry, A. N. 1979. Pelecypoda (excluding Ostreidae). In: Geise, A. C. & Pearse, J. S. (eds.), *Reproduction of Marine Invertebrates: Molluscs: Pelecypoda and Lesser Classes*, Vol. 5, pp. 113-292. Academic Press, New York.



- Sekiguchi, H., Saito, H. & Nakao, H. 1991. Spatial and temporal distributions of planktonic and benthic phases of bivalves in a tidal estuary. *Benthos Research* 40: 11-21.
- Sigurdsson, J. B., Titman, C. W. & Davis, P. A. 1976. The dispersal of young post-larval bivalve molluscs by byssus threads. *Nature* 262: 386-387.
- Soutome, Y., Kimura, T. & Sekiguchi, H. Larval recruitment and habitat shift of the brackish water clam *Corbicula japonica* in tidal estuaries (in preparation).
- Takada, Y., Sonoda, T., Nakamura, M. & Nakao, S. 2001. Growth and settlement of the bivalve, *Corbicula japonica* population in Lake Shinji. *Nippon Suisan Gakkaishi* 67: 678-686. (in Japanese)
- Takayasu, K., Urushido, J. & Okude, F. 1986. Comparative shell morphology of the three species of Japanese Corbiculinae. *Geological reports of Shimane University* 5: 35-42. (in Japanese)
- Tanaka, Y. 1981a. Identification of bivalve larvae-13. *Kaiyo-To-Seibutsu (Aquabiology)* 14: 200-201. (in Japanese)
- Tanaka, Y. 1981b. Identification of bivalve larvae-14. *Kaiyo-To-Seibutsu (Aquabiology)* 15: 310-313. (in Japanese)
- Tanaka, Y. 1982a. Identification of bivalve larvae-16. *Kaiyo-To-Seibutsu (Aquabiology)* 18: 23-26. (in Japanese)
- Tanaka, Y. 1982b. Identification of bivalve larvae-17. *Kaiyo-To-Seibutsu (Aquabiology)* 19: 137-139. (in Japanese)
- Tanaka, Y. 1984a. Morphological and physiological characteristics of the post larval stages in *Corbicula japonica* Prime, reared in the laboratory. *Bulletin of National Research Institute of Aquaculture* 6: 23-27. (in Japanese)
- Tanaka, Y. 1984b. Salinity tolerance of the brackish-water clam, *Corbicula japonica* Prime. *Bulletin of National Research Institute of Aquaculture* 6: 29-32. (in Japanese)
- Yamamura, M. & Koike, I. 1993. Nitrogen metabolism of the filter-feeding bivalve *Corbicula japonica* and its significance in primary production of a brackish lake in Japan. *Limnology and Oceanography* 38: 997-1007.
- Yoshida, H. 1953. Studies on larvae and young shells of industrial bivalves in Japan. *Journal of the Shimonoseki College of Fisheries* 3: 1-106. (in Japanese)

(Received July 3, 2003 / Accepted April 16, 2004)

## ヤマトシジミ幼生の成長および共存する二枚貝幼生との形態比較

木村妙子・五月女祐里奈・関口秀夫

## 要 約

汽水性二枚貝ヤマトシジミは本邦における水産重要種である。本研究では、ヤマトシジミの人工産卵誘発によって得られた受精卵を 15℃、20℃、25℃の温度条件で18日間飼育し、浮遊幼生、変態期幼生、着底稚貝の成長と形態を観察した。ヤマトシジミの受精卵はトロコフォア幼生を経てD型幼生に成長するが、この幼生は後期ベリジャー幼生期にあたる殻頂期幼生にはならず、D型幼生の後期に足を発達させ、変態期幼生となって着底する。着底直後の稚貝の殻はD型であり、これはやがて殻頂をもつ殻に変わる。最も成長のよかった25℃の温度条件下では、受精後12日に平均殻長195µmに達し、ほとんどの個体が着底した。一方、15℃の温度条件下では実験終了まで着底個体は観察されなかった。本研究では野外の浮遊幼生や稚貝の試料の同定のために、ヤマトシジミの浮遊幼生と着底稚貝の形態を記載し、これらと本州河口干潟に優占する二枚貝類幼生（アサリ、ホトトギスガイ、イソシジミ、シオフキガイ、ハマグリ）の形態との比較をおこなった。浮遊幼生はD型幼生では大きさ以外の識別点は乏しい。それに対して着底稚貝では、ヤマトシジミの殻の周縁に形成される放射肋により、他の種とは明確に識別できる。