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The reproductive biology of the baby clam, *Marcia opima*, from two geographically separated areas of India

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Abstract

A study of the reproductive cycle of the baby clam, *Marcia opima* (Gmelin) was conducted at two sites along the southeast (Tuticorin Bay) and southwest (Ashtamudi estuary) coast of India from December 1998 to January 2000. Histological evidence showed that baby clam from both the sites showed two spawning seasons. First spawning season was recorded from May to July in the southeast coast. In the southwest coast, the first spawning season was observed through March to May. A second spawning season from September to December was recorded in both the coasts. In the southeast coast, minimum and maximum condition indices were obtained in January 2000 and April 1999 respectively and decreased from May to June and November to January, signifying the two spawning periods. Most of the animals were either in spent or indeterminate gonadal stage from May to August and November to January indicating the active spawning during that months in the southeast coast.

Keywords: *Marcia opima*; Baby clam; Histology; Reproduction; Condition index

1. Introduction

Among the molluscan shellfish, clams are regularly fished for meat and shell from most of the brackish waters, creeks, coastal lagoons and estuaries in India. The venerid clams are the most sought after among the clam species of India. There is a good export market for frozen clam meat of *Marcia opima*. Currently, the predominant areas for baby clam population are in the southeast and southwest coast of the country, concentrated in the Tuticorin Bay and Ashtamudi estuary.

Studies have shown that gametogenic cycles in marine invertebrates are influenced by exogenous factors (Giese, 1959; Fretter and Graham, 1964; Wilson, 1969; Sastry, 1970, 1979; Adiyodi and Adiyodi, 1983), of which temperature is believed to be one of the most significant (Orton, 1920; Mann, 1979). Temperature is influential on the onset of both gametogenesis and spawning in many clam species (Calabrese, 1970; Keck et al., 1975; Hesselman et al., 1989; Kanti et al., 1993; Lubet, 1994). Temperature is closely associated with geographic location and thus many studies have assessed the importance of geographical locations in defining and controlling gametogenesis (Prosser, 1955; Ansell et al., 1964; Broom, 1983; Hadfield and Anderson, 1988; Narasimham, 1988). In addition to geographic variations in the reproductive cycle of clams, many investigations have reported annual variations in factors such as timing of the cycle, timing and duration

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of spawning and number of spawning per year (Chipperfield, 1953; Mac Donald and Thompson, 1998; Laruelle et al., 1994). Varadarajan and Subramoniam (1982) studied the breeding habits of hermit crab and recorded their observations in relation to the continuous breeding habits observed in tropical crustaceans and molluscs.

The baby clam, *Marcia opima*, has so far been indicated as *Katelysia opima* in Indian waters (John Taylor, personal communication). The effect of environmental factors on the growth and breeding pattern of baby clam from Adayar estuary on the east coast of India was studied by Rao (1951). Nagabhushanam and Mane's (1975) study of the baby clam from Kalbadevi estuary, India described the importance of environmental parameters such as temperature and salinity on the reproduction. A study on the reproductive biology of the same species from Vellar estuary, on the east coast of India was described by Jayabal and Kalyani (1986). However, no detailed works on such aspects have been carried out on the baby clam in the southeast and southwest coast of India. Larval rearing and large scale spat production of this species has been successfully achieved for the fist time in India by Muthiah et al. (2002).

The aims of the current paper are to establish and compare the reproductive cycle of the baby clam in the southeast and southwest coast of India, histological examination of gametogenic cycle, and to correlate the reproductive cycle of the species with variations in ambient temperature and salinity.

2. Materials and methods

2.1. Study sites

The study site of Tuticorin Bay is in the state Tamil Nadu on the southeast coast of peninsular India (8° 45' N and 78° 12'E) and is perennially supplied with freshwater by a small rivulet. The second study site, Ashtamudi estuary is in the state Kerala on the south west coast (9° 28' and 76° 28E') and is supplied with fresh water throughout the year by River Pamba that originates in the Sahya mountain range (Fig. 1). Both the habitats have natural bed of the species and muddy substrata. These stations are about 250 km apart along the seacoast.

2.2. Sampling

Samples ($n=85$) of *Marcia opima* were collected at monthly intervals from Tuticorin Bay between December 1998 and January 2000. Fifty-five clams were collected from Ashtamudi estuary for the months of March 1999, May 1999, July 1999, September 1999, November 1999 and January 2000. To collect the clams, a wooden frame of 50 sq. m. was placed in the exposed area of the intertidal zones of the sampling sites during low tide and the clams were hand picked. All clams ranged in size from 26.2 mm to 57.6 mm length. The mean length of sampled clam population from Tuticorin Bay varied between 27.59 mm to 36.77 mm. The clam population from Ashtamudi estuary showed a mean length range of 32.12 mm and 37.11 mm.

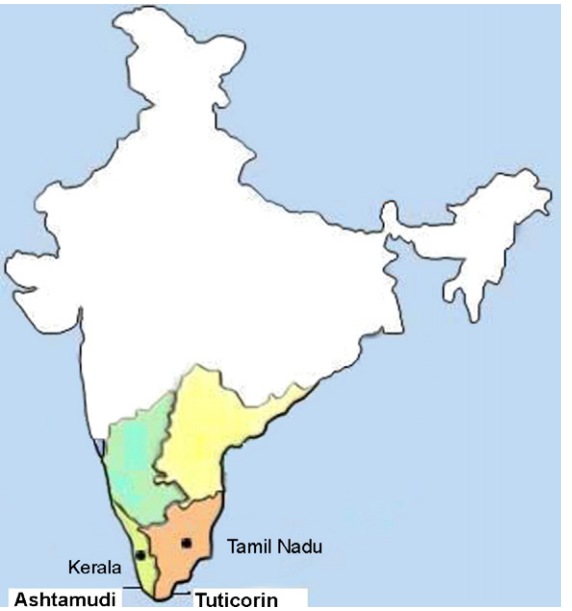

Fig. 1. Location of study sites.

2.3. Environmental parameters

The water temperature of the sampling site was noted using a thermometer on the date of sampling. The temperature measurements were taken at 0.5 to 1.0 m depth in the water column. Salinity of water samples collected from the sampling sites were estimated by Mohr–Kundson titration method as given by Strickland and Parsons (1972).

2.4. Histological Techniques

Sixty clams from Tuticorin and 30 clams from Ashtamudi were segregated for histological examination during the sampled months. The soft tissues of clams were removed from the shell using a scalpel. One longitudinal cut through the body of the animal was made, providing a transverse section, which contained gonad, digestive gland and muscular foot tissue. The gonad tissue was fixed in Davidson's fluid for 48 h and stored at 4 °C. Following the method of Howard and Smith (1983), the tissues were subsequently dehydrated by immersion in a graded series of ethanol, dealcoholized in butanol and embedded in wax. Wax blocks were sectioned at 7 μm by using a rotary microtome. Sections were stained in Harri's haematoxylin and counter-stained in eosin (Humanson, 1979). The prepared microscope slides were examined using ×5, ×20 and ×40 magnification to determine sex and stage of

reproductive development. The photographs of identified reproductive stages were taken at a magnitude of ×40.

From the histological examination of the gonad, clam reproductive maturity was categorized in to 5 stages using a version of the maturity scale described by Nagabhushanam and Mane (1975). When more than one developmental stage was evident within a single individual, the clam was assigned to the reproductive stage that was observed in the majority of the follicles. A stage in which sex is not distinguishable was named as indeterminate. Many animals could not be defined definitively by one reproductive stage. In any individual, many follicles were undergoing different reproductive stages, so that two and some times three stages were evident. The stage, which was the most abundant amongst follicles, was noted as the reproductive stage for that animal.

2.5. Condition index

The shell of 25 clams was opened and soft tissues were shucked out. The tissues and shells were dried at 60 °C for 48 h and weighed to obtain the dry shell weight and dry flesh weight. The condition index was calculated according to Walne (1976) as:

$$\text{Condition index} = \frac{\text{Dry flesh weight (g)} \times 100}{\text{Dry shell weight (g)}}$$

2.6. Statistics

Data sets were checked for goodness-of-fit to a normal distribution. The Pearson product–moment correlation was used to examine correlation between the male and female reproductive cycles, temperature, salinity and condition index. A Chi square test (χ^2) was used to analyse the sex ratios. An unpaired *t*-test was used to ascertain differences between salinities and condition indices at the two study sites, and the Mann–Whitney *U* test to ascertain differences in temperatures.

3. Results

3.1. Environmental parameters

During the study period, the water temperature in Tuticorin Bay ranged between 26 °C and 32. 5 °C. The minimum temperature was recorded in January 2000 and the maximum temperature was recorded in November 1999. The pattern of oscillation seen in the water temperature was bimodal with two peaks and two depressions in a year. Salinity was generally higher during the summer months and lower in the monsoon months due to influx of fresh water run off. Salinity of the Tuticorin Bay fluctuated through 32 to 37 ppt. Maximum salinity was reported in May 1999 and minimum in January 2000. Salinity was positively correlated with temperature (Pearson product–moment correlation, $r=0.621$, $p<0.01$) in Tuticorin Bay.

The water temperature of Ashtamudi estuary ranged between 24 °C and 34 °C. The minimum temperature was recorded in July 1999 and the maximum temperature was observed in March 1999. A maximum salinity of 30 ppt was observed in March 1999 and a minimum salinity of 26 ppt was recorded in November 1999 and January 2000 as well. There was a significant positive correlation between salinity and temperature in Ashtamudi estuary also (Pearson product–moment correlation, $r=0.821$, $p<0.01$). The seasonal variations in water temperature and salinity at both the sites are given in Fig. 2(a) and (b).

There was no significant difference between temperatures at the two sites (Mann- Whitney U test, $p=0.724$), whilst Tuticorin Bay experienced significantly higher salinities than Ashtamudi estuary (Unpaired *t*-test, $p<0.01$).

3.2. Reproductive biology

3.2.1. Gonad position and histology

The gonad of *M. opima* was located near to the muscular foot and expands in to the visceral mass with the progression of gametogenesis. Based on the histological observation, the description and criteria for each gonadal maturity stage for both males and females are summarized in Table 1 and also illustrated in Fig. 3(a) to (i).

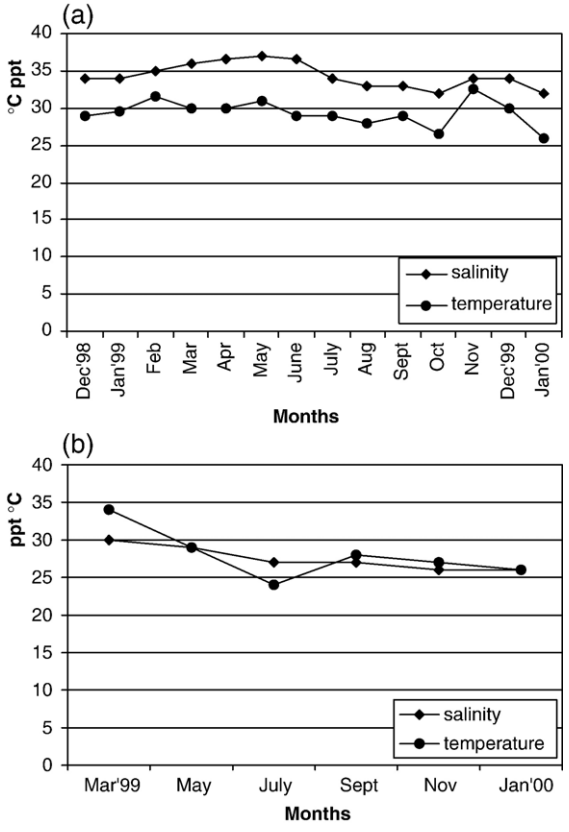

Fig. 2. (a). Seasonal variation in sea temperature and salinity at Tuticorin Bay sampling site from December 1998 to January 2000. (b). Seasonal variation in sea temperature and salinity at Ashtamudi Estuary sampling site from March 1999 to January 2000.

Table 1
Description of reproductive stages for male and female *Marcia opima*

Maturity stages		Male	Female
Stage 1	Maturing	Gonad is small, inconspicuous and colourless. Secondary spermatocytes appear in large numbers along with the primary spermatocytes	Gonad is small, inconspicuous and colourless. The oogonia with indistinct nucleus, small and spherical in shape and the size ranges from 22–33 μm diameters
Stage 2	Mature	Gonad attains maximum size, cream coloured; entire lumen is filled with bunches of spermatozoa	Gonad attains maximum size, cream coloured; Nucleated oocytes of size range 33–66 μm fill up the lumen and get detached from the stalks
Stage 3	Partially spent	Gonad becomes flabby and loose in consistency. Colour of the gonad slightly changes to grey. Few unreleased sperms are seen in the lumen	Gonad becomes flabby and loose in consistency. Colour of the gonad slightly changes to grey. Lumen shows the presence of unreleased oocytes
Stage 4	Spent	Follicular walls collapse and shrink further; unreleased sperms undergo degeneration. The vesicular connective tissue increases	Follicular walls collapse and shrink further. Phagocytes appear. The vesicular connective tissue increases
Stage 5	Indeterminate	Gonad is small and translucent, with much connective tissue. No traces of gametes are seen, so the sex is indistinguishable	

3.2.2. Sex ratio

Of the 840 clams examined from Tuticorin Bay, 326 were male and 390 were female and 124 were indeterminate. Table 2 outlines the numbers of males, females and sexually undifferentiated specimens observed from each site. The sex ratio at Tuticorin Bay was 1:1.3, which differed significantly from a 1:1 ratio ($\chi^2=10.72$, $df=1$, $p=0.05$), in favour of females. The male: female sex ratio for Ashtamudi estuary clams also showed a significant deviation from the 1:1 ratio ($\chi^2=13.55$,$df=1$, $p=0.05$), in favour of males. Hermaphrodite specimens were not observed. Indeterminate specimens occurred from December through to March and July to August in Tuticorin Bay and in March, May, July, November and January in Ashtamudi estuary.

3.2.3. Sexual cycle

3.2.3.1. Tuticorin Bay

3.2.3.1.1. Male. Fig. 4(a) illustrates the percentage of male clams in various reproductive stages at Tuticorin Bay. At the start of the study in December 1998, all males were in the partially spent or spent stage. Gametogenesis began in January 1999. In February, majority of the males were in the maturing stage as indicated by 22 out of 33 individuals. The first mature males appeared in March 1999 when 19 out of 31 were ripe. Mature individuals were present in samples from March 1999 through to June 1999. Major spawning started in May 1999, when 27 out of 35 males were either in the partially spent or spent stages having released their gametes. Majority of the specimens were in the spent phase in June 1999. Spawning continued till July, as evidenced by the presence of spent individuals in the sample. In July and August, a number of specimens were in the indeterminate stage. Gametogenesis resumed in July 1999, when 6 out of 26 males were in the maturing phase. Mature males again occurred in August 1999. From September to October 1999, majority of the specimens were in the mature stage. A minor release of spermatozoa occurred in September 1999, when 6 out of 33 were either in partially spent or spent stages having released their gametes. Small scale spawning continued during the post monsoon period. Spawning continued from October to December, which was evident by the dominance of partially spent and spent individuals in the samples. In the following year, gametogenesis recommenced in December with the appearance of 3 out of 39 males in the maturing condition.

The male gametogenic cycle was not significantly correlated with temperature (Pearson product–moment correlation, $r=0.251$, $p>0.05$) or salinity (Pearson product–moment correlation, $r=0.316$, $p>0.05$), but was significantly correlated with the condition index (Pearson product–moment correlation, $r=0.737$, $p>0.05$).

3.2.3.1.2. Female. As in the case of males, at the start of the study in December 1998, most females were either in the spent stage or in the partially spent stage [Fig. 4(b)]. The spawning continued throughout January and February 1999. Maturing female specimens were first observed in January 1999 when 4 out of 34 were in the maturing stage. The gonad development activity continued during February and March 1999. The number of matured specimens was maximum in April as evidenced by 22 out of 29 females with fully-grown gonads. Spawning begun in May and continued through June and July 1999 as indicated by the presence of partially spent and spent animals in the samples. From August until October, few young oocytes were present in the follicles. In these months, most oocytes were mature and as released to the lumens of follicles, acquired a polygonal shape. From May to August 1999, most of the females were either spent or indeterminate (83 out of 111). Minor onset of gametogenesis had begun as early as August 1999, when 7 specimens were observed in maturing stage. By September, due to active gametogenesis 11 out of 28 females were in matured phase. By October, majority of the specimens were mature. A second spell of spawning was observed from September to January 2000. In November, majority of the samples were either partially spent or spent. In December, most of the females were in spent stage. Gametogenesis recommenced in December 1999 with the appearance of maturing specimens among the samples. This shows that the progression of gametogenesis was earlier in 2000 than the previous year.

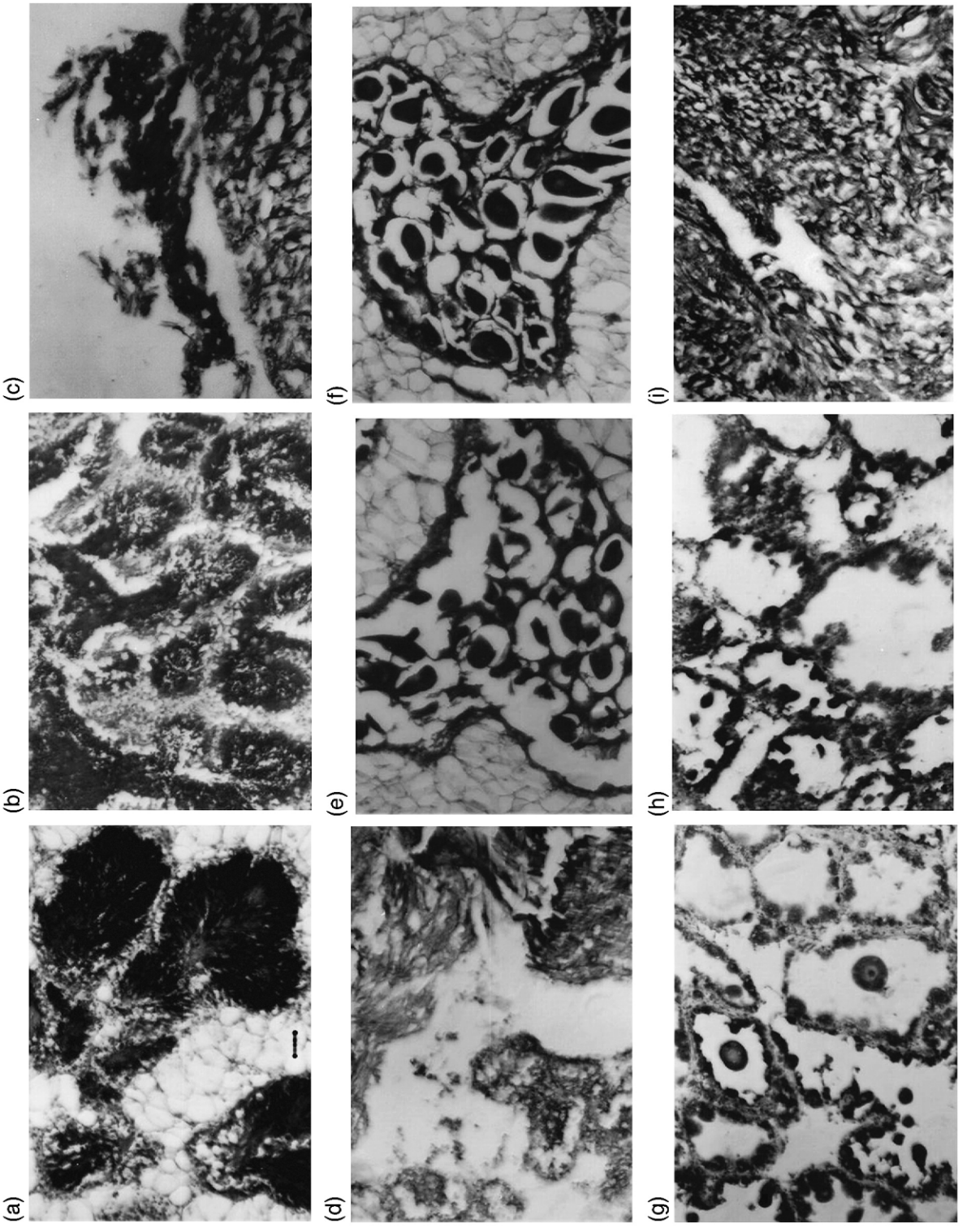
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)

Table 2
Numbers and percentages of males, females and sexually undifferentiated clams from each site

	Male	Female	Indeterminate	Total
Tuticorin Bay	326 (31.9%)	390 (38.2%)	124 (121%)	840 (82.4%)
Ashtamudi Lake	80 (7.8%)	63 (6.2%)	37 (3.6%)	180 (17.6%)
Total	406 (39.8%)	453 (44.4%)	161 (15.7%)	1020 (100%)

During December to January, most female clams were either spent or indeterminate. The females described as having begun gametogenesis in these months invariably contained spent follicles as well.

There was a significant positive correlation (Pearson product–moment correlation, $r=0.756$, $p<0.01$) between the male and female gametogenic cycles. The female gametogenic cycle was not significantly correlated with temperature (Pearson product–moment correlation, $r=322$, $p>0.05$) or salinity (Pearson product–moment correlation, $r=247$, $p<0.01$), but was significantly correlated with the condition index (Pearson product–moment correlation, $r=0.786$, $p>0.05$).

3.2.3.1.3. Condition index. Fig. 5 compares the seasonal changes in Condition index of sampled population from Tuticorin Bay and Ashtamudi Estuary. The individual values of average condition index during the sampled period varied from 6.50 in November 2000 to 9.36 in April 1999 with an average of 7.93. A steady increase was observed from January 1999 to April 1999 and also from June 1999 to October 1999, indicating the active gametogenesis, which leads to the maturity of gonads. Indices reached their highest values in April 1999 and October 1999 attaining maximum of 9.3 and 9.0 respectively. From May to June and from November to December there was a significant decrease in the condition index, signifying the spawning period. The lowest indices occurred in June 1999 and December 1999, indicating periods of spent and resting gonads. The index was not significantly correlated with temperature (Pearson product–moment correlation, $r=0.227$, $p>0.05$) or size of clams (Pearson product–moment correlation, $r=0.163$, $p>0.05$) in Tuticorin Bay.

3.2.3.2. Ashtamudi Estuary

3.2.3.2.1. Male. Fig. 6(a) represents the proportions of clams in various reproductive stages at Ashtamudi estuary. Though the sampling for this station was done during alternate months, a clear trend on the gametogenic activity was evident. The Ashtamudi estuarine population showed an early spawning when compared to that at Tuticorin Bay. Mature and partially spent animals represented majority of the sample in March 1999 and 3 out of 30 were in spent phase. In May 1999, most of the clams were either partially spent or spent. Some of the clams entered into the indeterminate stage (6 out of 37). By July 1999, the number of spent specimens reduced and gametogenesis had begun with the appearance of maturing individuals in the sample. The presence of partially spent and spent clams in the population indicated a second spawning cycle occurred in September 1999. The majority of the specimens were in the spent stage or resting stage during November 1999. Spawning continued until January 2000. Gametogenic activity recommenced in January 2000 as observed by the presence of maturing and mature specimens (11 out of 32).

No significant correlation was observed between male gametogenic cycle with respect to temperature (Pearson product–moment correlation $r=-0.365$, $p>0.05$) or salinity (Pearson product- moment correlation $r=0.125$, $p>0.05$). The correlation between the male gametogenic cycle and the condition index was significant (Pearson product–moment correlation $r=0.899$, $p>0.05$).

3.2.3.2.2. Female. As was the case for the male specimens in this sample, the majority of specimens in March 1999 were represented by mature and partially spent animals and the remainder was spent animals [Fig. 6 (b)]. There was a dominance of partially spent and spent specimens (30 out of 33) in May 1999 and hence it appeared that spawning continued. Gametogenesis appears to have begun in July, as evidenced by the presence of 5 out of 28 females in the maturing stage. Interestingly, 2 females from the July sample had entered into the mature stage and the remaining formed spent and resting specimens. In September 1999, 12 out of 35 females were mature and the number of maturing animals increased than that of July. The presence of partially spent and spent individuals in September implied the onset of spawning. By November 1999, most females were in the spent stage. Gametogenesis was recommenced in January 2000 as observed by the presence of 6 out of 30 females in maturing stage.

The male and female gametogenic cycles in Ashtamudi estuary were significantly correlated (Pearson product–moment correlation $r=0.734$, $p>0.05$). There were no significant correlations between female gametogenic cycle with temperature (Pearson product–moment correlation $r=0.214$, $p>0.05$) and salinity (Pearson product–moment correlation $r=0.365$, $p>0.05$). A significant correlation was observed between the female gametogenic cycle and the condition index (Pearson product–moment correlation $r=0.758$, $p>0.05$).

Fig. 3. (a) to (d). Gonad developmental stages for male *Marcia opima*. The scale bar in Fig. 3 (a) is equivalent to 137.5 μm and is applicable to Fig. 3 (a) to (i) (a). Stage 1: Maturing. (b). Stage 2: Mature. (c). Stage 3: Partially spent. (d). Stage 4: Spent. Fig. 3 (e) to 3 (h). Gonad developmental stages for female *Marcia opima.* (e). Stage 1: Maturing. (f). Stage 2: Mature. (g). Stage 3: Partially spent. (h). Stage 4: Spent. Fig. 3 (i). Stage 5: Indeterminate.

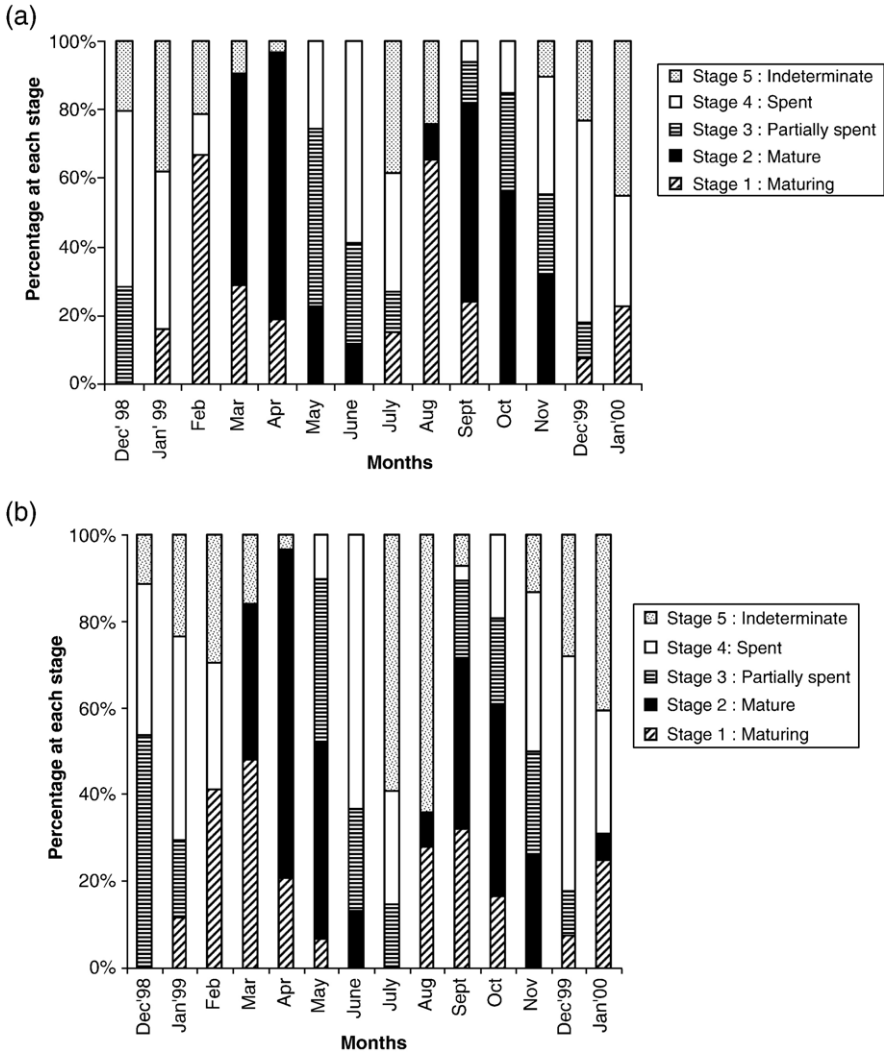

Fig. 4. (a). The percentage of male baby clams in various reproductive stages at Tuticorin Bay from December 1998 to January 2000. (b). The percentage of female baby clams in various reproductive stages at Tuticorin Bay from December 1998 to January 2000.

3.2.3.2.3. Condition index. Condition index was negatively correlated with temperature (Pearson product–moment correlation $r=-0.429$, $p>0.05$) and it was not significantly related to size of clams (Pearson product–moment correlation $r=0.406$, $p>0.05$). Although the index appears to be higher for clams in Tuticorin Bay in comparison to Ashtamudi estuary there was no significant differences between condition indices for corresponding months at both sites (Unpaired *t*-test, $p=0.0018$).

4. Discussion

The four stages of reproductive maturity for both males and females and the sexually indeterminate used in this study, have been followed by most authors on baby clam reproductive biology (Rao, 1951; Nagabhushanam and Mane, 1975; Jayabal and Kalyani, 1986). *M. opima* is primarily marine and is found burrowing in sand and mud in quite shallow waters but secondarily it invades backwaters and estuaries in which its distribution is confined to regions, in the closest vicinity of the sea. It is never found far up to the river mouth where salinity is low (Rao, 1951).

Successive events in the annual reproductive cycle of clams can be correlated with differences in the environment that develop during the year. Temperature has been cited as the major environmental factor regulating reproduction in marine bivalves (Sastry,

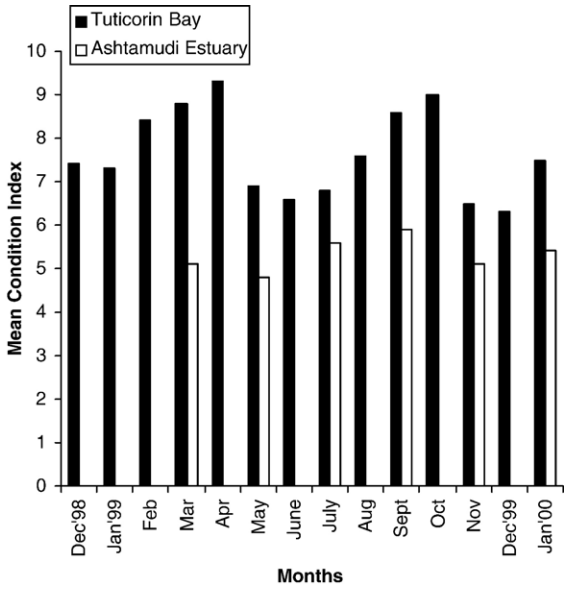

Fig. 5. Seasonal changes in condition index of baby clams in Tuticorin Bay from December 1998 to January 2000 and in Ashtamudi Estuary during the sampled months from March 1999 to January 2000.

1979). It has been suggested that the breeding period of a species occurs at characteristic temperatures, which remain a constant throughout the geographical range (Orton, 1920). Gametogenesis is initiated and spawning occurs only within fairly narrow, species-specific temperature ranges. Thus, differences in the timing of gametogenesis and spawning within a species over a latitudinal range occur because critical temperatures are attained at different times. In tropical regions, where the variations in water temperature are minimal, even a slight increase in temperature is known to correspond with the period of breeding.

The same species of clams of one locality are known to differ in their reproductive cycles from those of a different locality. Baby clam displayed a single reproductive cycle at Adayar estuary (Rao, 1951) and Vellar estuary (Jayabal and Kalyani, 1986), east coast of India. It is in contrast for the same species from Kalbadevi estuary along the west coast (Nagabhushanam and Mane, 1975), which had two reproductive cycles in a year. The single spawning activity of baby clam in the east coast is reported to be in March (Rao, 1951; Jayabal and Kalyani, 1986) whilst the major spawning season in the west coast is October and the minor one is in March (Nagabhushanam and Mane, 1975). In this study, it was observed that the baby clam in the southeast and southwest coast of India also shows two spawning periods in a year. The trend towards bimodal spawning peaks may be an adaptation to optimal temperature ranges for reproduction, which occur twice a year in the sampled sites. The study confirms the observations of previous authors on the gametogenic cycle of baby clam in the west coast. However, unlike the previous study on the east coast, the species showed bimodal spawning cycle in the present study. Even the first spawning season was delayed at Tuticorin when compared to that reported for Adayar and Vellar estuaries. It coincided with that reported for Ashtamudi and is in conformity with the results obtained by earlier researchers (Nagabhushanam and Mane, 1975) for Kalbadevi estuary. It is reported that, on the Indian coast, intensities of breeding of crustaceans and molluscs differ in accordance with the southwest and northeast monsoon, thus showing distinctive peaks in the reproductive cycle (Varadarajan and Subramoniam, 1982).

The basis of reproductive variation in geographically separated populations is not clear for most marine invertebrates. Sastry (1970) reported that the changes in the reproductive physiology of the bay scallop from two geographically separated populations might be associated with differences in temperature or abundance of food. Hesselman et al. (1989) opined that differences in the gonad development of bivalves might be the result of local differences in temperature, food availability, salinity or other factors regulating gametogenesis. Physiological variation in population of a species exposed to different environments could be either phenotypic response of a single genotype or could be truly genotypic (Prosser, 1955). The present study reported that in 1998, the baby clams from Tuticorin Bay showed onset of gametogenesis in January. This is followed by a period of continuous spawning from May to July, and subsequently the commencement of a second cycle of gametogenic activity from July, followed by a second spawning season from September to December. An increase in the temperature from the previous month was observed in both May and September. The salinity was maximum in May when compared to other months during the study period.

In Ashtamudi estuary, the first spawning period was from March to May and the second spawning season was from November to January. A comparison of water temperatures at both the stations has indicated that the same was higher in Ashtamudi estuary than that of Tuticorin Bay during March. This might have triggered earlier spawning period of the baby clams in the former station. A maximum salinity of 30 ppt was also reported in March. It can be envisaged that the first and second spawning periods in both the sites are associated with an increase in temperature and salinity during the summer

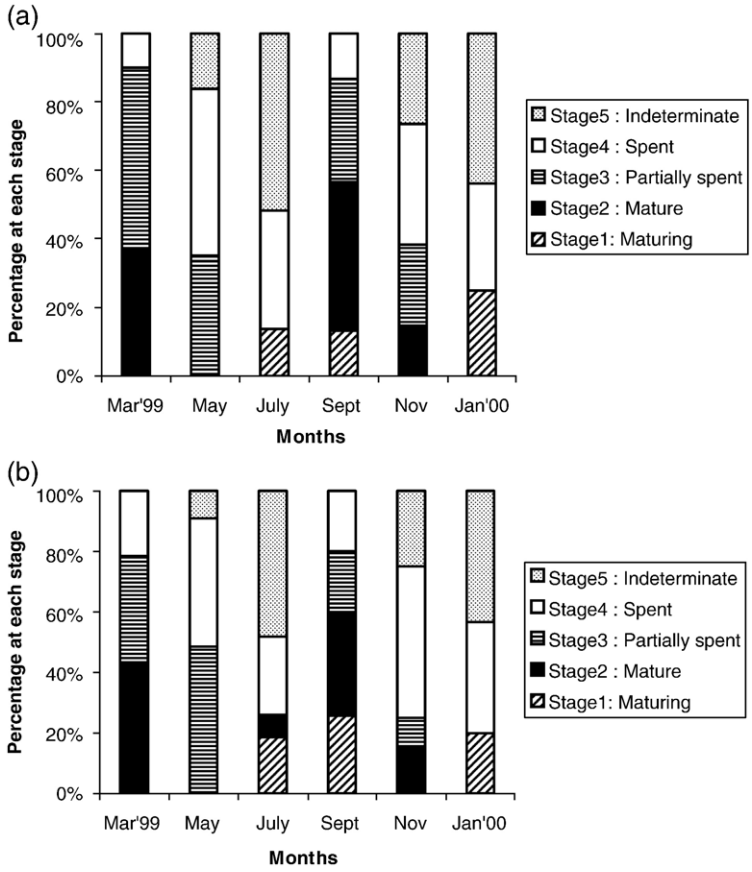

Fig. 6. (a). The percentage of male baby clams in various reproductive stages at Ashtamudi Estuary from March 1999 to January 2000. (b). The percentage of female baby clams in various reproductive stages at Ashtamudi Estuary from March 1999 to January 2000.

months and in the post monsoon months respectively. The inconsistency in the onset and duration of the rainy season, which controls salinity of the water probably accounts for the changes in post monsoon reproductive behaviour of both the sites. It has been already reported that an increase in salinity favours the spawning of baby clams in the west coast (Nagabhushanam and Mane, 1975) and also in the east coast (Rao, 1951). Although the ranges in the monthly temperature and salinity values are not markedly high, there appear to be distinct seasonal trends on their bearing on the breeding behaviour of *M. opima*. Outside the range of suitable environmental conditions for gametogenesis and spawning, reproductive success, which ultimately determines the geographic range of a species, is minimized. It can be summarized as in monsoon (June to September) gradual fall in temperature and salinity affects the activity of clams. By the end of September, majority of clams undergo gametogenesis and this leads to spawning in the post monsoon season. In the next cycle, increase in temperature and salinity after the winter accelerates metabolism, makes the gonad to undergo active gametogenesis and reach full maturation by March to April. An optimum temperature and salinity during summer favour another spawning season. It is possible that the variation in the populations of baby clams could have been induced by their coordination of reproductive events with the environment at the whole organism level.

Both male and female clams followed almost the same pattern of gonadal development at a time. During the second onset of gametogenesis in Tuticorin Bay, the male gametogenic activity started in July, while the first maturing female appeared in August. By December most of the male and female clams were either spent or partially spent and entering in to a period of gonadal inactivity. The occurrence of sexually indeterminate specimens continued up to March. The resting period

was more defined in the west coast as there was very little gonadal activity occurring at this time, where as this study observed individuals in various other reproductive stages. The male and female samples from Ashtamudi estuary showed similar pattern of reproductive changes, except that of early maturation of females in the second reproductive cycle with 7% of specimens entering in to the mature stage in July samples, whilst in the male population mature specimens were not represented in July.

Due to the similarity that exists in the latitudinal positioning of the Tuticorin Bay and Ashtamudi estuary, the clams from both the stations exhibited similar reproductive pattern. The slight difference in the reproductive activity may have been favoured through selection as an adaptive response to the geographical differences in temperature, salinity or food availability. The gonadal development of baby clams in Ashtamudi estuary mirrored that of Tuticorin Bay. Though about 250 km apart along the seacoast, the sites experienced almost similar water temperature regimes. Though higher salinities were recorded in Tuticorin Bay throughout the study period than Ashtamudi estuary, but this alone had limited effect on the reproductive activity of the baby clam there. However, it is possible that a combination of favourable saline and temperature conditions trigger the onset of gametogenic activity for the species in both the stations. The findings are broadly similar to those from the previous studies on baby clam reproduction in India (Rao, 1951; Nagabhushanam and Mane, 1975; Jayabal and Kalyani, 1986) albeit with some divergences.

The Tuticorin Bay data demonstrates the contrast in the early stages of gametogenesis between the years 1998 and 1999. In December 1998, all specimens were in the partially spent, spent and indeterminate stage and gametogenesis was started in January 1999 whilst in December 1999, gametogenesis has been initiated and active gametogenesis was observed by January 2000. It would appear that prevailing environmental conditions were more favourable in 1999 than 1998, as suggested by the earlier commencement of gonadal activity in 1999. Visual observations at the sampled sites revealed that both the spawning events contribute to the recruitment of the *M. opima* population at the studied locations.

The baby clam is a dioecious organism. Hermaphrodites were not encountered in this study. In India, the sex change in clams has not been reported so far. Nagabhushanam and Mane (1975) did not observe any hermaphrodite from a sample of 1131 baby clams, confirming the view that occurrence of hermaphrodites is a rare event for this species. The baby clam population from Tuticorin showed a female dominance, which is similar to the result of sex ratio from the west coast for the same species.

Evidence gathered in this study from histological slides of gonad of baby clam indicate that the first onset of gametogenesis occurred in December to January and a second cycle of gametogenic activity started in July. The histological slides also supported the occurrence of two spawning cycles.

The condition factor of bivalves can act as an indicator of reproductive activity and the condition of clam meat is dependent on the gametogenic activity. Significant increases in the condition index are seen at times the gonad was ripening and gonad growth was favoured over somatic growth, e.g. March to April and August to September in Tuticorin Bay clams. The condition was high just before spawning and it was low immediately after the completion of spawning. On the basis of this, it could be inferred that this period may be ideal for fishing of baby clam for consumption due to the presence of meat of high quantity. This was evident in histological sections when ripe gonad occupied a large area of the visceral mass as well as the foot in the pre monsoon and post monsoon months. The maximum conditions observed in April and October appear to be the result of peak ripeness following an accumulation of resources in preparation for spawning. The decline in index from May to June and from November to December, from which a spawning event could be inferred, was consistent with the histological results. Narasimham (1988) and Hesselman et al. (1989) observed a similar result and reported that condition index was low in the resting and spent hard clams and wedge clams respectively.

The commercially exploited clam generates female employment and supplements the protein requirement of rural inhabitants in coastal areas of states like Kerala, Tamil Nadu, and Karnataka of peninsular India. It is also gaining popularity in urban and export markets. As seed production and larval rearing has been achieved under controlled conditions, it is assumed that the knowledge on the spawning periodicity of the species at two geographically separated areas where it shows abundance, would be helpful in collection of brood stock as well as induced maturation and rearing of juveniles in hatcheries. Large-scale seed production in hatcheries could facilitate aquaculture or sea ranching of the species, easing the exploitation pressure on the natural resources. The information on spawning periodicity could also help conservation.

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