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Reproductive Biology of the Sergestid Shrimp *Acetes indicus* (Decapoda: Sergestidae) in Coastal Waters of Malacca, Peninsular Malaysia

Sarker Mohammad Nurul Amin[1,2,*], Aziz Arshad[1,3], Japar Sidik Bujang[4], Siti Shapor Siraj[4], and Stephen Goddard[5]

[1]*Laboratory of Marine Science and Aquaculture, Institute of Bioscience, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[2]*Institute of Marine Sciences and Fisheries, University of Chittagong, Chittagong-4331, Bangladesh*

[3]*Department of Aquaculture, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[4]*Department of Animal Science and Fishery, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia, Bintulu Campus, 89007 Bintulu Sarawak, Malaysia*

[5]*Department of Marine Science and Fisheries, Sultan Qaboos University, Oman*

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Sarker Mohammad Nurul Amin, Aziz Arshad, Japar Sidik Bujang, Siti Shapor Siraj, and Stephen Goddard (2009) Reproductive biology of the sergestid shrimp *Acetes indicus* (Decapoda: Sergestidae) in the coastal waters of Malacca, Peninsular Malaysia. *Zoological Studies* **48**(6): 753-760. The sex ratio, maturity, and spawning season of the sergestid shrimp *Acetes indicus* were determined by analyzing samples collected from coastal waters of Klebang Besar, Malacca between Apr. 2006 and Mar. 2007. The overall annual sex ratio of *A. indicus* was found to be 1: 2.10 (males: females). The annual variation in the gonadosomatic index (GSI) showed continuous breeding of *A. indicus* throughout the year. The size at sexual maturity of female *A. indicus* was 23 mm TL. No females with spent ovaries were found among the samples during the study period. The estimated mean fecundity of *A. indicus* was 1666.30 ± 262.10 (range, 1135-2235) eggs. The mean monthly GSI in females showed positive and significant ($p < 0.05$) correlations with conductivity ($r = 0.67$), salinity ($r = 0.65$), and total suspended solids ($r = 0.59$). However, no significant correlation ($p > 0.05$) was found for the mean monthly GSI with temperature or dissolved oxygen. This suggests that *A. indicus* may be adapted to a wide range of conditions in tropical and subtropical regions. http://zoolstud.sinica.edu.tw/Journals/48.6/753.pdf

Key words: Maturity, Spawning season, *Acetes indicus*.

The planktonic shrimp *Acetes indicus* is locally known as 'udang geragau' in Peninsular Malaysia and supports a considerable subsistence fishery. It occurs in the central part of the Indo-West Pacific, from the South China Sea through the Gulf of Thailand (Omori 1975) and the Bay of Bengal, Bangladesh (Mahmood et al. 1978), the Straits of Malacca (Pathansali 1966), and Andaman Sea to the entire east and west coasts of India (Ravindranath 1980). The species is most common along the Galle Harbour of Sri Lanka and Manora Channel near Karachi, Pakistan (Tirmizi and Ghani 1982). In Peninsular Malaysia, *A. indicus*, along with *A. japonicus*, is commercially exploited from Mar. to Dec., using estuarine push nets. The main uses of the shrimp are as fermented food and as a dried product. The commercial importance of *Acetes* is derived from consumption by humans and its potential as a food for aquaculture (Kungvankij et al. 1986, Ung and

*To whom correspondence and reprint requests should be addressed. E-mail:smnabd02@yahoo.com

Itoh 1989). These features make *Acetes* excellent candidates for the study of reproductive biology.

The reproductive biology of the genus *Acetes* such as the sex ratio, maturity, breeding patterns, and fecundity is essential information for developing the aquaculture industry and forming management policies for the *Acetes* fishery. The ecological and economic importance of sergestids has stimulated various investigations about the reproduction and ecology of *Acetes* shrimp (Xiao and Greenwood 1993). The monthly mean gonadosomatic index (GSI) is most frequently used to detect shrimp and fish spawning seasons (Jayawardane et al. 2002, Oh and Jeong 2003, Kim and Hong 2004, Oh and Hartnoll 2004, Wu et al. 2008). Spawning of pelagic shrimp usually occurs in open water in > 50 m of depth, and often much shallower (Dall et al. 1990). Few data are available on the time interval between copulation and spawning of *Acetes*; however (Omori 1974) asserted that *A. japonicus* spawns 10-15 d after copulation. Females spawn their eggs directly into the water (Xiao and Greenwood 1993). Fecundity is defined as the number of maturing eggs in the ovaries before spawning (Towhid 1994). The study of fecundity of any species is important to have a full understanding of its biology. The evaluation of fecundity is necessary because it is considered a measure of the reproductive fitness of crustaceans (Nazari et al. 2003) and is directly influenced by natural selection. Furthermore, fecundity and breeding frequency are characteristics directly related to a species life strategy (Oh and Hartnoll 2004).

A study of the reproduction biology of *A. indicus* was reported by Deshmukh (2002) in Bombay waters. A few studies were recently carried out on the population structure, age, growth, and mortality of *Acetes* in coastal waters of Peninsular Malaysia (Arshad et al. 2007, Amin et al. 2008, 2009). However, until now there has been no study of the reproductive biology of this species in Peninsular Malaysia. In the present study, therefore, our goal was to provide information on the reproductive biology including the breeding season, fecundity, size at sexual maturity, and sex ratio of *A. indicus* in coastal waters of Malacca, Peninsular Malaysia. The results obtained in this study can serve as an important reference for management and conservation decision making.

MATERIALS AND METHODS

Samples were taken every 2 wk between Apr. 2006 and Mar. 2007 from Klebang Besar (102°13.009'N, 102°11.921'E), coastal waters of Malacca, Peninsular Malaysia. *Acetes* spp. were caught using an estuarine push net (with a triangular shape) known locally as ‘sungkor’, as described by Omori (1975) in coastal waters of Klebang Besar, Malacca. Dimensions of the net were 5.0-6.0 m long, 4.0-4.5 m wide, and 3.0-3.5 m high. The mean mesh sizes were 3.2 (± 0.27) cm in the anterior section, 0.75 (± 0.05) cm in the middle, and 0.5 (± 0.08) cm at the cod end (when stretched). The estuarine push nets were operated along the coast of Klebang Besar at depths of 0.5-1.5 m. The fishing effort was 1 person per hour and the towing length was approximately 1000 m. After being collected, samples were immediately preserved in 10% formalin and transported to the laboratory for further analyses.

Sex ratio

Twenty grams subsample of *Acetes* was randomly taken from the total catch after separation of fish larvae and other shrimp. *Acetes indicus* was identified from the subsample using a Nikon dissecting microscope (Nikon-122764, Japan) and Omori (1975). Sexes were determined by the presence or absence of a clasping spine or petasma. The monthly sex ratio (females/total) was calculated, and the result was tested by Chi-squared analysis (χ^2 tests) for differences from the hypothetical ratio of 1: 1.

Ovary examination

In total, the ovarian condition and gonadosomatic index (GSI) of 30-32 females of *A. indicus* were determined every 2 wk. Body wet weight was measured to the nearest 0.1 mg using an electronic balance. Females were dissected under a microscope to investigate the ovaries. Dissection was carried out with fine forceps to remove the ovaries which were immediately preserved in 5% formalin for examination. The ovary weight was recorded to the nearest 0.01 mg. Ovarian maturity was classified based on the color, shape, size, diameter, and transparency of the developing ova. The maturity of the ovaries was differentiated into 4 categories based on morphological characteristics, according to Wu and Cheng (1957).

Stage I (immature ovaries): Eggs are small (23.0-82.8 μm in diameter). The ovary is ribbon-like in small *Acetes*, with anterior lobes developing in larger ones. No spermatophores are implanted in the thelycum.

Stage II (mature ovaries): Egg sizes considerably vary, with most being 64-161 μm in diameter, but some small eggs as above are still present. The size of the ovary has clearly increased, and the lobes have developed wavy margins. The ovary is expanded laterally on the dorsal side of the 1st and 2nd abdominal somites. Most individuals have spermatophores implanted in this stage.

Stage III (near-spawning ovaries): The eggs are all 82.8-207 μm in diameter, and are regularly arranged. The general color of the ovary is green or brown at or near spawning.

Stage IV (spent ovaries): There are no mature eggs in the protruding parts of the margins of the ovary, but there are massive numbers of small eggs near the blood vessels in the center of the ovary. In some cases, the ovary may be completely empty, or containing only a very few eggs.

The gonadosomatic index (GSI) was determined as follows:

$$\mathrm{GSI} = \frac{\text{Ovary wet weight}}{\text{Female body wet weight}} \times 100$$

Fecundity

In total, 32 female shrimp with ovaries in mature or near-spawning stages were used to estimate fecundity. A preserved ovary was dissected from each individual at 3 positions (fore, middle, and rear) of the ovary. Each of the samples (matured oocytes) was weighed to the nearest 0.01 mg and counted under a Keyence Digital Microscope (VHX-500, Japan) by manipulating the ovary with forceps and a needle. The following equation was used to estimate the fecundity of each individual (Kodama et al. 2004):

$$F = F_s \times \frac{GW}{GW_s}$$

where F is the estimated fecundity of an individual, F_s is the number of oocytes in a sample, GW is the total weight of the ovary, and GW_s is the weight of the sample of the ovary. The mean of the estimated fecundity of the ovary samples within each individual was regarded as that individual's fecundity.

Environmental variables

Physicochemical variables such as water temperature, salinity, dissolved oxygen (DO), and conductivity were recorded every 2 wk using a YSI meter (556 MPS, USA) during the sampling time. Total suspended solids (TSS) were calculated as follows:

$$\mathrm{TSS\ (mg/L)} = \frac{(A - B)}{V} \times 100;$$

where A is the weight of the filter + dried residue (mg), B is the weight of the filter (mg), and V is the volume of the sample (ml).

Statistical analysis

To determine the relative fecundity, relationships between the absolute fecundity and total length (TL), body weight (BW) and gonad weight (GW) were established by a leastsquare linear regression with log transformed values. The Pearson correlation coefficient, *r* (Sokal and Rohlf, 1981), was used between environmental variables (temperature, DO, salinity, conductivity, and TSS) and the reproductive indicator (GSI) in *A. indicus*.

RESULTS

Sex ratio

In total, 5255 *A. indicus* individuals were examined including 3570 females and 1685 males. The result indicated that the overall sex ratio of males to females was 1: 2.10. The proportions of males and females *A. indicus* in the samples were taken monthly as shown in figure 1. There was a predominance of females in the samples. The total number of females was higher than that of males in samples throughout the sampling period. The Chi-squared test revealed that the number of females was significantly (χ^2 = 85.61, *d.f.* = 22, $p < 0.001$) greater than that of males in samples throughout the year, although the sex ratio varied from month to month. The sex ratio by size class (TL) showed a clear predominance of the male's number in the lower sizes (< 20 mm). On the other hand, the number of females gradually increased in the larger size classes (> 20 mm) (Fig. 2). No male was observed with a total length of > 30 mm.

Ovarian maturity stage

In the immature phase (stage I), the ovary was very thin and translucent. The ova were spherical and small with a diameter ranging 22.00-38.00 μm (Table 1). The ovary was ribbon-like with anterior lobes developing into larger ones. In the mature phase (stage II), the ovary had clearly increased in size, and the lobes had developed wavy margins. The ova had increased in diameter to 31-97 μm (Table 1). In the near-spawning phase (stage III), the ovary was deep yellow, which became orange after preservation. It was enlarged and had extended anteriorly in the cephalothoracic region and posteriorly in the abdomen to the 6th segment. The mature ova were packed with yolk, and their diameters ranged 106.00-140.00 μm (Table 1). The mean egg lengths (horizontal × vertical) were 28.20 × 32.60 μm in stage I, 55.79 × 71.71 μm in stage II, and 122.36 × 129.71 μm in stage III (Table 1). On the contrary, no females with spent ovaries were observed during the study period.

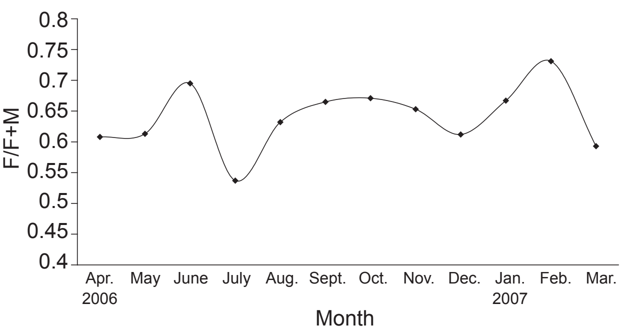

Fig. 1. Temporal variations in the sex ratio of *Acetes indicus* in coastal waters of Malacca, Peninsular Malaysia. The dotted line indicates a ratio of 1: 1 (females: males)

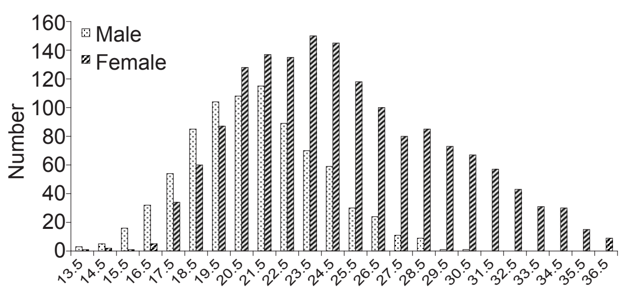

Fig. 2. Variations in the sex ratio of *Acetes indicus* in relation to size (total length; TL) in coastal waters of Malacca, Peninsular Malaysia.

Spawning season

Changes in the mean GSI for females every 2 wk are presented in figure 3. The mean GSI of females increased from Apr. and reached a peak in June, Aug., Oct., and Dec. 2006 and Jan. to Mar. 2007. The GSI values remained at a low level between late Aug. and Sept. 2006. Proportions

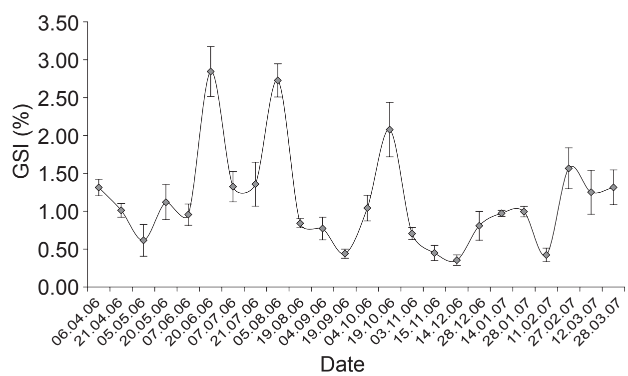

Fig. 3. Variations in the gonadosomatic index (GSI) of female *Acetes indicus* measured every 2 wk during Apr. 2006 to Mar. 2007. Solid squares indicate the mean GSI, and vertical bars indicate the standard deviation.

Table 1. Egg length (μm) of different stages of *Acetes indicus* from coastal waters of Malacca, Peninsular Malaysia

	Stage I (n = 135)		Stage II (n = 135)		Stage III (n = 135)	
	SA (μm)	LA (μm)	SA (μm)	LA (μm)	SA (μm)	LA (μm)
Mean	28.20	32.60	55.79	71.71	122.36	129.71
SD	5.32	4.84	8.50	10.50	9.76	6.85
Minimum	22.00	20.00	31.00	34.00	106.00	89.00
Maximum	38.00	39.00	97.00	143.00	140.00	153.00

SA, short axis; LA, long axis.

of the 3 different ovarian maturity stages showed seasonal variations (Fig. 4). The immature ovary phase (stage I) occurred during Apr., July-Dec., and Feb.-Mar. with < 50%. The mature and near-spawning ovary phases (stages II and III) occurred in > 50% of females each month throughout the year and reached 100% during the months of May, June, and Jan. This therefore indicates that *A. indicus* likely breeds continuously throughout the year. This is in agreement with variations in GSI values and the occurrence of mature ovaries, which showed the same trends (Figs. 3, 4). The mean monthly GSI in females showed positive and significant correlations with conductivity ($r = 0.67$; $p < 0.05$), salinity ($r = 0.65$; $p < 0.05$), and TSS ($r = 0.59$; $p < 0.05$). No significant correlation ($p < 0.05$) was found between the mean monthly GSI and the remaining variables tested (mean annual temperature and DO).

Size at sexual maturity

To estimate the length at sexual maturity, the percentage composition of females at each ovarian maturity stage according to the total length classes was examined (Fig. 5). Stages II and III first appeared at > 50% with a total length of 23 mm. This reveals that that the size at sexual maturity of female *A. indicus* was 23 mm of total length. The percentage of mature females gradually increased at a size of > 23 mm (Fig. 5). The maturity of females increased with an increase in total length.

Fecundity

The mean fecundity of *A. indicus* was 1666.30 (± 262.10) eggs. Individual fecundity ranged 1135-2235 eggs at sizes ranging 25-37 mm in total length (Table 2). Models of the least square regression were used to analyze the relationship between absolute fecundity (F) and total length (TL). A slightly curvilinear regression provided the best-fit curve (Fig. 6), and a log-transformed regression equation was positive with a significant result:

$$\text{LogF} = 1.230985\ (\pm 0.36) + 1.3323\ (\pm 0.24)\ \text{LogTL}$$
$$(R^2 = 0.509,\ n = 32,\ p < 0.01).$$

Analysis of the relationship between the absolute fecundity (F) and body weight (BW) also revealed a linear relationship with log-transformed

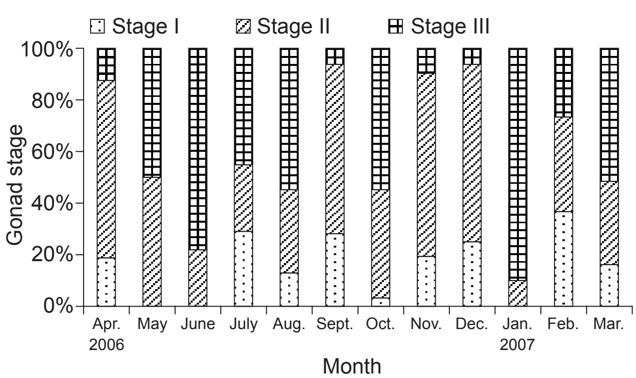

Fig. 4. Monthly changes in the percentage occurrence of each ovarian maturity stage of female *Acetes indicus* during Apr. 2006 to Mar. 2007 in coastal waters of Malacca, Peninsular Malaysia.

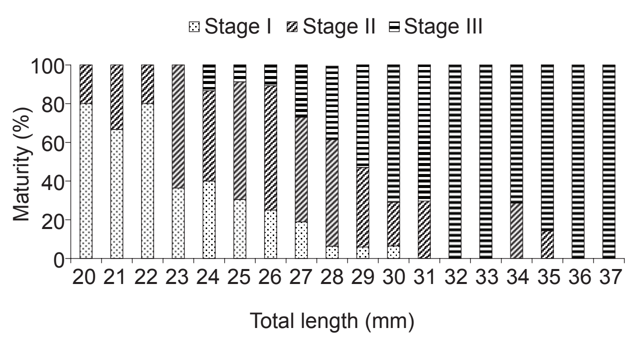

Fig. 5. Percentage occurrence of each ovarian maturity stage against size class (total length; TL) for female *Acetes indicus* in coastal waters of Malacca, Peninsular Malaysia.

Table 2. Fecundity of *Acetes indicus* from coastal waters of Malacca, Peninsular Malaysia

	Total length (mm)	Total weight (mg)	Gonad weight (mg)	Fecundity (no. of eggs)
Mean	31.03	210.71	6.1875	1666.28
SD	2.69	79.71	2.68	262.06
Range	25.00-37.00	144.00-435.20	1.80-13.60	1135-2235

values. Retransformed values of fecundity and body weight provided a conventional allometric equation (Fig. 7):

$$\text{LogF} = 2.295927\ (\pm\ 0.17) + 0.3993\ (\pm\ 0.07)\ \text{LogBW}$$
$$(R^2 = 0.501,\ n = 32,\ p < 0.01).$$

A linear regression between fecundity (F) and gonad weight (GW) was positive and significant with log-transformed values. However, the arithmatic scale provided the allometric curve (Fig. 8):

$$\text{LogF} = 2.95799\ (\pm\ 0.02) + 0.3417\ (\pm\ 0.02)\ \text{LogGW}$$
$$(R^2 = 0.906,\ n = 32,\ p < 0.01).$$

DISCUSSION

The sex ratio was calculated to obtain the ratio of the numbers of male and female shrimp in nature, so that appropriate numbers of male and female shrimp can be mated during artificial spawning. The annual sex ratio in the *A. indicus* population in coastal waters of Malacca was 1: 2.10 (males: females). In general, the sex ratio is known to be close to 1: 1 (males: female) in nature (Fisher 1958), although the population of *A. indicus* in coastal waters of Malacca was skewed in favor of females for most of the year. Similar results were observed in other *Acetes* species (Henry 1977, Oh and Jeong 2003). Female dominancy was observed in *A. japonicus* in the Ariake Sea of Japan (Yasuda et al. 1953) and eastern Guangdong Province, China (Lei 1988). A skewed sex ratio can be caused by different mortality rates between sexes and different behavioral characteristics such as migration (Kim 2005). Chiou et al. (2003) reported that *Acetes* exhibits strong vertical and horizontal migration patterns. In summer, when the southwesterly monsoon prevails and river discharge is great, adult sergestid shrimp (*A. intermedius*) migrate from estuaries to coastal waters and perform a diel vertical migration off southwestern Taiwan. They aggregate near the surface during the night and migrate to lower water layers deeper than 30 m during the day. In this study, samples were collected from 1 location and a small range of depths (0.5-1.5 m). It was assumed that the skewed sex ratio could be a result of different habitat preferences by sex.

The sex ratio varied seasonally, and the causes of such seasonal variations are unknown. It can be influenced by the growth, mortality, and behavior of populations. The faster growth of females leads to biased proportions toward

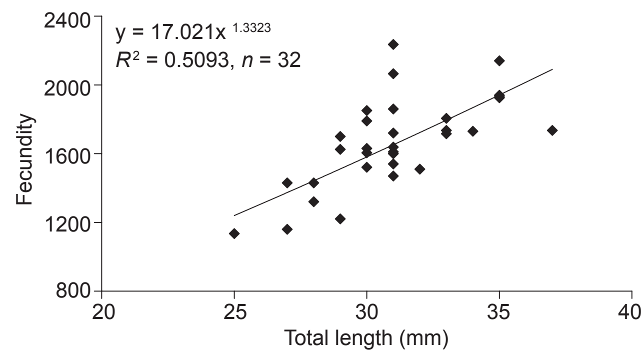

Fig. 6. Curvilinear relationship between fecundity (the number of eggs) and total length (TL) of *Acetes indicus* collected from coastal waters of Malacca, Peninsular Malaysia. *n*, number of shrimp investigated.

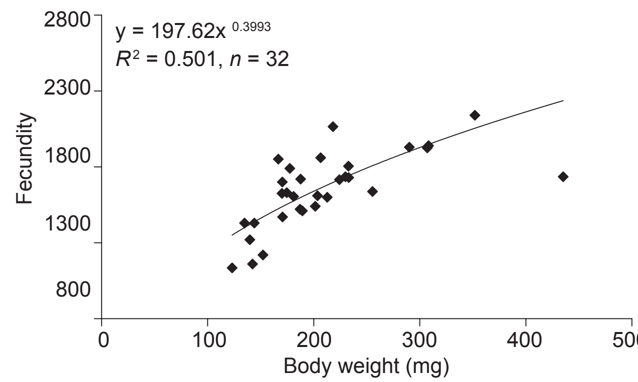

Fig. 7. Allometric relationship between the fecundity (the number of eggs) and body weight (BW) of *Acetes indicus* collected from coastal waters of Malacca, Peninsular Malaysia. *n*, number of shrimp investigated.

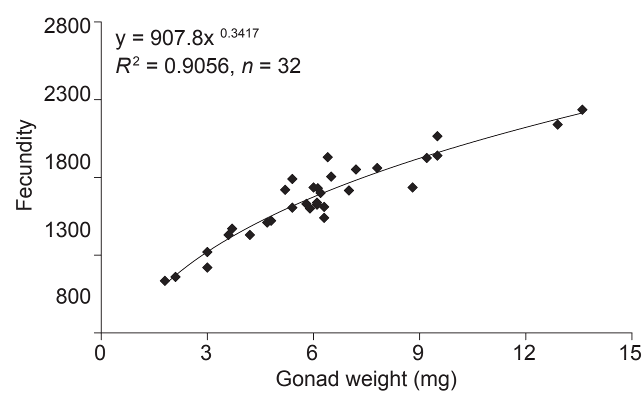

Fig. 8. Allometric relationship between fecundity (the number of eggs) and gonad weight of *Acetes indicus* collected from coastal waters of Malacca, Peninsular Malaysia. *n*, number of shrimp investigated.

females because of their greater sizes, and hence dominance especially in commercial catches (Xiao and Greenwood 1993). According to Ikematsu (1953), after copulation in the Ariake Sea, *A. japonicus* died. However, this interpretation cannot be applied to populations in the Seto Inland Sea, also of Japan (Yasuda et al. 1953). According to Luo and Zhang (1957), spawning migration and vertical migration of *Acetes* showed strong annual and seasonal spatial variations and possibly lead to the biased sex ratio. They concluded that migration of *A. chinensis* in Liaotung Bay, China may be associated with changes in water temperature and food availability.

The *A. indicus* population in western Malaysia showed a continuous breeding cycle throughout the year with peaks in June, Aug., Oct., Feb., and Apr. This was reflected by both monthly changes in the percentage occurrence of each ovarian maturity stage and the GSI of females. This result is generally consistent with observations in coastal waters of Bombay (Deshmukh 2002) in which *A. indicus* breeds continuously throughout the year with a peak during Sept.-Jan. In this study, no female with spent ovaries was found. Similar observations were made for *A. chinensis* in coastal areas of Korea (Oh and Jeong 2003) and *A. japonicus* in the Ariake Sea (Ikematsu 1953). This suggests that females die immediately after spawning. Further detailed studies need to be done regarding the lack of any spent ovaries of this species to justify the present results.

The size at sexual maturity of female *A. indicus* was observed to be 23 mm in TL. There is no published report on the sexual maturity of *A. indicus* to compare the present result. However, a reproductive study of other species of *Acetes* showed that the size at maturity fell into the range of a total length of 18-43 mm in Pohai Bay, China (Zhang 1992) and 21.2-40.9 mm on the west-central western coast of Korea (Kim 1974). There is no report available so far on the size at sexual maturity of the same species to compare the present result.

The mean fecundity of *A. indicus* was 1666.30 eggs. The estimated maximum and minimum values of fecundity of *A. indicus* in this study were 2235 and 1135 eggs, respectively, at TLs ranging 25-37 mm. Deshmukh (2002) reported that the fecundity of *A. indicus* in Indian waters was in the range of 4333-10,275 eggs, which is much higher than that of the present study. A larger egg size at higher latitudes is usually associated with more advanced larval stages at hatching and increased development time (Hines 1982). Egg size is an important diverse life history characteristic of species. In particular, reproductive patterns and life history traits can be determined by the mode of energy allocation to either single embryos or brood output (Clarke 1993). *Acetes indicus* appears to adopt a maximum reproductive output compared to other related sergestids from higher latitudes. The difference in the maximum reproductive output among crustacean species seems to primarily be the result of differences in female body size; however, other biotic or abiotic factors, such as egg size, and latitudinal and seasonal variations, may also be important (Boddeke 1982).

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