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Abundance and Reproductive Biology of the Penaeid Prawns of Bagamoyo Coastal Waters, Tanzania

E.D. Teikwa[1] and Y.D. Mgaya[2]

[1]*Tanzania Fisheries Research Institute, P.O. Box 78850, Dar es Salaam, Tanzania;* [2]*University of Dar es Salaam, Faculty of Aquatic Sciences and Technology, P.O. Box 35064, Dar es Salaam, Tanzania*

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Abstract—The coastal waters of Bagamoyo in Tanzania constitute an important penaeid prawn trawling ground. Despite the high economic value attached to this resource, the biological information necessary for its sustainable exploitation is scanty and fragmented. The present study was therefore designed to investigate the species composition, population abundance and reproduction of the penaeid prawns in Bagamoyo coastal and nearshore waters. Samples were obtained monthly for a period of one year from inshore waters adjacent to the Ruvu Estuary while additional samples were bought at the beach from artisanal fishermen. In the laboratory, samples were identified to the species level. Four penaeid species, *Fenneropenaeus indicus* (formerly known as *Penaeus indicus* [Farfante and Kensley, 1997]), *Penaeus monodon*, *P. japonicus*, and *Metapenaeus monoceros* were found in the Ruvu Estuary and nearshore waters. *Fenneropenaeus indicus* was the most abundant, and more so during the rainy season than the dry season. The sex ratio in *F. indicus* was found to vary significantly from the theoretical 1:1 ratio while that of *P. monodon* did not vary significantly from 1:1. The average size at first maturity was different within sexes. For *F. indicus* males and females carapace length was 3.4 and 3.9 cm respectively. For *P. monodon* it was 3.58 and 4.3 cm for males and females respectively. Fecundity ranged from 40,000 to 222,000 eggs for *F. indicus* and 72,000 to 314,000 eggs for *P. monodon*. Fecundity increased with prawn size, suggesting that much of the available energy in larger prawns is devoted to egg production rather than growth.

INTRODUCTION

Penaeids include the widespread tropical and subtropical prawns of the genera *Fenneropenaeus*, *Penaeus* and *Metapenaeus* (Richmond, 2002). At least 19 species from seven genera occur in the western Indian Ocean region (Holthuis, 1980).

The majority of the species occur over mud or sand bottoms in shallow coastal areas, with juveniles entering mangrove forests (Subramaniam, 1980). Some portion of the life cycle is spent in the open ocean, resulting in the development of two fisheries: an artisanal fishery, which centres on the capture of penaeids within estuaries and during migrations from the estuaries to the sea, and a larger-scale commercial trawling fishery in the deeper waters offshore (King, 1995). Prawn fisheries have developed into a profitable industry in Tanzania and the main fishing grounds are located at Bagamoyo, Kisiju and Rufiji (Mgaya et al., 1999; Bwathondi et al., 2002).

Several workers have conducted studies on prawns in Tanzanian coastal waters. Subramaniam (1980) carried out studies which focused on juvenile prawns in their nursery environment in Chwaka Bay, Unguja (Zanzibar) Island, whereas Haule (1981) reported on growth and morphometric relationships of prawns of Kunduchi

Corresponding author: YDM.
E-mail: ymgaya@udsm.ac.tz

mangrove creek, Dar es Salaam. Mgaya et al. (1999) conducted crustacean resource evaluation in Bagamoyo District which included penaeid prawns, and more recently, Bwathondi et al. (2002) investigated the abundance and distribution of penaeid prawns of Bagamoyo and Rufiji delta.

There is substantial amount of information concerning species composition, abundance and reproduction of penaeid prawns elsewhere (e.g., Penn, 1980; Somers & Harris, 1987; Jackson & Rothlisberg, 1994; Somers, 1994). However, despite the great economic value of prawns in Tanzania, there is little information on the ecology and biology of penaeid species occurring there. With this in mind, the present study was conceived with the aim of determining the species composition, population abundance and some aspects of the growth (length–weight relationship) and reproductive biology of penaeid prawns. This type of information is essential in fisheries management, and will assist with the development of regulations for the small-scale seine fishery in Bagamoyo coastal waters, in order to ensure sustainable production.

MATERIALS AND METHODS

Field work

Specimens for the study were obtained twice in a month for 12 months (January to December 1998) from inshore waters adjacent to the Ruvu Estuary in Bagamoyo District (Fig. 1). Sampling was done for two consecutive days chosen randomly during

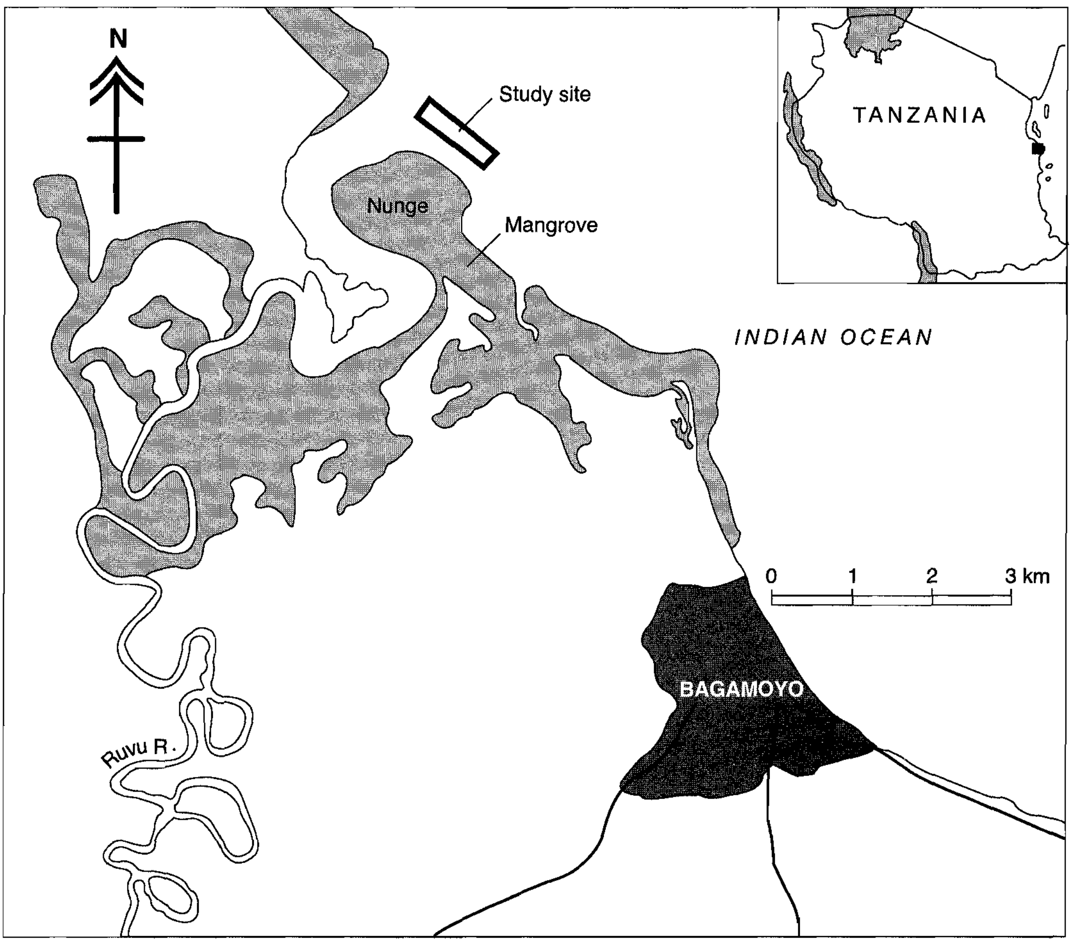

Figure 1. Map of Bagamoyo coastal area showing the study site

spring tides. Fishing was undertaken during low tide using a beach seine net measuring 100 metres long and with a stretched mesh size of 3.81 cm (1.5 inch). Two people who waded through shoulder- or neck-deep waters and set the net in a semi-circle operated the seine net. The net was then dragged to the beach using a stick attached to the end of the net. A total of seven or eight hauls were made on each sampling day. After collection, the prawns were frozen and transferred to the University of Dar es Salaam for further examination.

Laboratory work

In the laboratory, prawns were sorted into species and identified according to Bianchi (1985). Carapace length and total length were measured to the nearest 1 mm, and body weight of each individual was measured to the nearest 0.1 g after blot-drying the specimen. Carapace length was measured as the distance from the inside of the eye socket to the centre of the dorsal margin of the carapace, whereas total length was measured as the distance from the inside of the eye socket to the end of the telson.

Length–weight relationship was calculated for *Fenneropenaeus indicus* and *Penaeus monodon* using the formula: $W = aL^b$ and was logarithmically transformed into $\log W = \log a + b \log L$, where W = body weight (g), L = total length (cm), a = proportionality constant, and b = regression coefficient. The parameters a and b were calculated by using a non-linear iterative least-squares regression with Marquardt's algorithm (Saila et al., 1988).

Population abundance

Total weights (g) of the sample for each species were recorded and relative abundance was estimated as catch per unit effort (Gammelsrød, 1992) for both dry (July, August, September) and wet (March, April, May) seasons. Catch per unit effort was recorded as weight (g) of the prawns caught per haul.

Size at first maturity and fecundity

Sex was determined and a maturity classification was made (Farfante, 1969) where stages III and IV were considered to be mature for males and females respectively. For both males and females, the size at first maturity was determined by calculating the proportion of mature individuals in each size class (carapace length). The size at which 50% of individuals were mature was taken as the size at which prawns reach maturity for the first time (King, 1995).

Fecundity

Assessment of fecundity of ripe ovaries was carried out as described by Bagenal & Braum (1978). A total of 6 and 17 ovaries from ripe female *F. indicus* and *P. monodon,* respectively, were assessed for fecundity. Since we were not able to obtain a large number of ripe females no criteria were used for the selection of ovaries. The volumetric sub-sample method was used to estimate the number of ripe eggs in the ovaries using the formula: $F = nV/v$, where n = number of ripe eggs in the sub-sample; V = volume to which the total number of eggs is made up; v = volume of sub-sample.

Statistical analysis

The differences in sex ratio were analysed and tested for significant divergence from the expected 1:1 ratio by using a Chi-square (χ^2) goodness of fit test (Zar, 1999). For length–weight relationship, a modified t-test was used to compare two regression lines of males and females while a t-test was applied to test whether the slope was equal to three (in isometric growth). Correlation analysis was carried out to test whether there was a significant relationship between fecundity and carapace length as well as between fecundity and body weight. An unpaired t-test was used to test whether there was a significant difference in relative abundance of prawns between dry and wet seasons. All statistical inferences were based on a significant level of $\alpha = 0.05$.

Table 1. Length-weight relationship and related statistics of *Fenneropenaeus indicus* and *Penaeus monodon* collected from Ruvu estuary, Bagamoyo

		Total length (cm)		Weight (g)		Regression parameters		
Species/Sex	n	min	max	min	max	a	b	r^2
F. indicus								
Male	245	5.0	15.9	2.9	48.4	1.102	3.032	0.937
Female	392	2.9	14.7	1.5	39.2	1.092	3.035	0.929
Pooled	637					1.264	2.973	0.889
P. monodon								
Male	302	7.5	16.8	4.3	59.8	0.915	3.106	0.943
Female	327	6.5	17.7	3.0	71.0	0.751	2.299	0.901

RESULTS

Length–weight relationship

The results of the length–weight relationship analysis of two species are summarised in Table 1. Regression coefficients of male and female *F. indicus* were not significantly different ($t = 0.2$, $P > 0.50$, $df = 633$); consequently a common regression coefficient was calculated (Table 1). For *P. monodon,* the regression coefficients for males and females were different ($t = 36.68$, $P < 0.001$, $df = 625$) hence data were not pooled for a common regression equation. For both species the value of b was not significantly different from 3 (t-test, $P > 0.10$).

Species composition and population abundance

The composition of penaeid species caught from January to December 1998 is summarised in Table 2. Monthly percentage species composition of the four penaeid species is shown in Fig. 2. Despite having a higher overall percentage composition than the other species, *Fenneropenaeus indicus* was more common in the catches for four months only (February, March, May, and August), whereas *Penaeus monodon* was more common in the catches for eight months (January, April, June, July, September, October, November, and December). *Penaus japonicus* and *Metapenaeus monoceros* were caught only occasionally, with the former species only appearing in the catch in June and the latter species in July and September.

Table 2. Percentage composition of penaeid prawn species in Bagamoyo, Tanzania for the period January–December 1998

Species	Percentage composition (%)
Fenneropenaeus indicus	50.08
Penaeus monodon	49.53
Metapenaeus monoceros	0.31
Penaeus japonicus	0.08

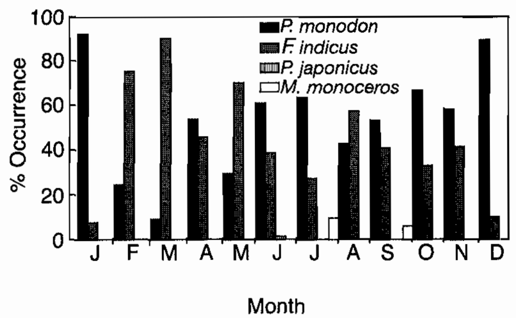

Fig. 2. Monthly percent composition of four penaeid species in Bagamoyo, January–December 1998

The monthly pattern of abundance in relation to rainfall showed variations whereby peaks were recorded during the period February to June, and the lowest abundance was observed from July to December (Fig. 3). It can also be seen in Fig. 3 that the last six months of the year (July to December) showed less variation in abundance compared to the first six months of the year (January to June). There was a significant difference in relative abundance between dry and wet seasons ($t = 4.712$, $p = 0.0092$, $df = 4$).

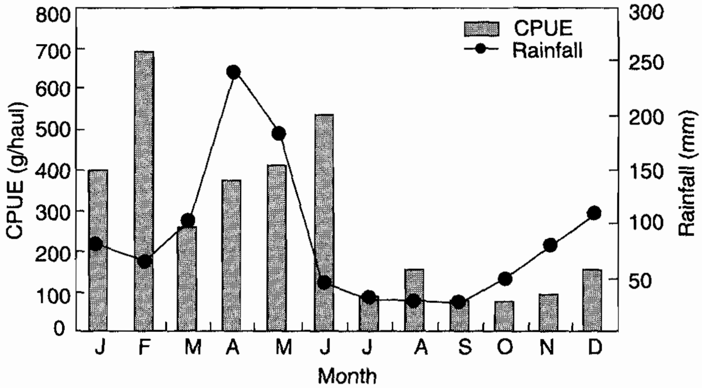

Fig. 3. Monthly variation in prawns abundance expressed as catch per unit effort (CPUE) in relation to rainfall in 1998

Sex ratio

A total of 637 specimens of *F. indicus* was sexed, of which 392 were female and 245 were male, giving a sex ratio of 0.625:1 in favour of females. A chi-square goodness of fit test was performed and the results showed that the ratio was significantly different from a 1:1 ratio ($\chi^2 = 33.9$, $P < 0.001$). The monthly chi-square values for *F. indicus* showed that there were significant differences from a 1:1 ratio except in February, March, October, November and December (Table 3).

Penaus monodon had a total of 630 specimens that was sexed, of which 328 were female and 302 were male, giving a sex ratio of 0.92:1 in favour of females. A chi-square goodness of fit test was performed and the ratio was not significantly different from 1:1 ($\chi^2 = 1.073$, $0.25 < P < 0.50$).

The monthly chi-square values in *P. monodon* were not significantly different from a 1:1 ratio except in August where the ratio was in favour of females (Table 4).

Table 3. Chi-square values for monthly sex ratio of *Fenneropenaeus indicus*

Month	Numbers		M : F ratio	χ^2	Significance level
	Male	Female			
January	1	13	0.08 : 1	7.429	***
February	112	104	1.08 : 1	0.296	–
March	41	55	0.75 : 1	2.042	–
April	19	39	0.49 : 1	6.896	***
May	39	69	0.57 : 1	8.334	***
June	19	67	0.28 : 1	26.79	***
July	1	7	0.14 : 1	4.5	*
August	1	19	0.05 : 1	16.2	*
September	1	6	0.17 : 1	5.286	**
October	1	5	0.2 : 1	2.667	–
November	6	6	1.0 : 1	0	–
December	4	2	2.0 : 1	0.667	–

– = not significant; * P = 0.025–0.05; ** P = 0.01–0.025; *** P = 0.001–0.01.

Table 4. Chi-square values for monthly sex ratio of *Penaeus monodon*

Month	Numbers		M:F ratio	χ^2	Significance level
	Male	Female			
January	80	94	0.85 : 1	1.126	–
February	42	29	1.45 : 1	2.38	–
March	4	6	0.67 : 1	0.4	–
April	31	37	0.84 : 1	0.53	–
May	21	25	0.84 : 1	0.348	–
June	62	74	0.84 : 1	1.058	–
July	11	8	1.38 : 1	0.474	–
August	3	12	0.25 : 1	5.4	**
September	2	7	0.29 : 1	2.778	–
October	6	6	1.0 : 1	0	–
November	10	7	1.43 : 1	0.53	–
December	30	22	1.36 : 1	1.23	–

– = not significant; * P = 0.025–0.05; ** P = 0.01–0.025; *** P = 0.001–0.01.

Size at first maturity

Although *F. indicus* males attained sexual maturity at 3.4 cm carapace length, and females became sexually mature at 3.9 cm carapace length, maturing males first appeared at 2.8 cm carapace length and maturing females appeared at 3.5 cm carapace length, with their percentage increasing thereafter (Fig. 4). The percentage of mature males at 3.5 cm is greater than that of females, implying that males attained sexual maturity while slightly smaller than females. In *P. monodon*, males attained sexual maturity at 3.51 cm carapace length and females at 4.22 cm carapace length (Fig. 5). Mature males however first occurred at 3.1 cm, while mature females occurred at 3.6 cm.

The percentage of mature males at 3.6 cm carapace length was greater than that of females; therefore, males seemed to attain sexual maturity at a size smaller than females. Although *F. indicus* males attained sexual maturity at 3.4 cm carapace length, and females became sexually mature at 3.9 cm carapace length, maturing males first appeared at 2.8 cm carapace length and maturing females appeared at 3.5 cm carapace length, with their percentage increasing thereafter (Fig. 4). The percentage of mature males at 3.5 cm is greater than that of females, implying that males attained sexual maturity at a size slightly smaller than that of females. In *P. monodon*, males attained sexual

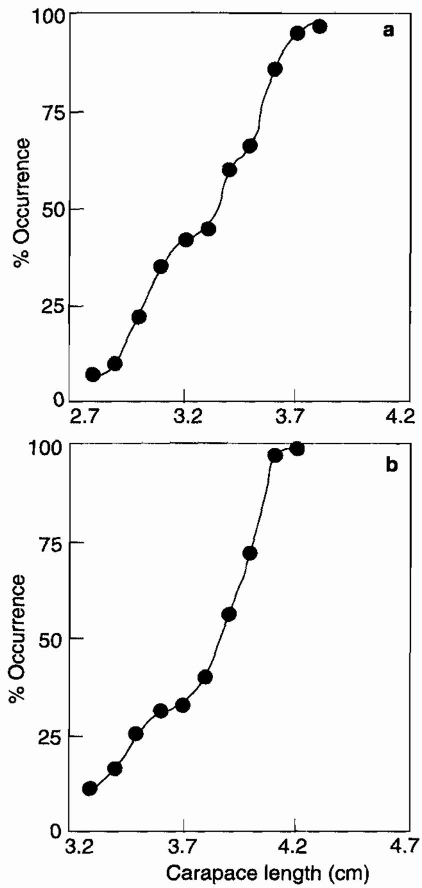

Fig. 4. Percentage of sexually mature *Fenneropenaeus indicus*. (a) Male, (b) Female. Size at first maturity is the length at which 50% of all individuals are sexually mature

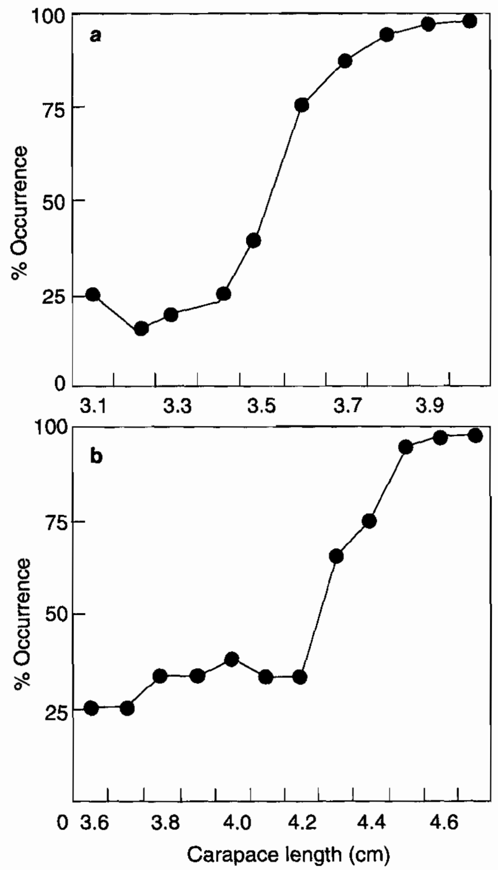

Fig. 5. Percentage of sexually mature (a) male and (b) female *Penaeus monodon* in Bagamoyo

maturity at 3.5 cm carapace length while females attained sexual maturity at 4.2 cm carapace length (Fig. 5). Maturing males however first occurred at 3.1 cm, while maturing females occurred at 3.6 cm. The percentage of mature males at 3.6 cm carapace length was greater than that of the females; therefore, males seemed to attain sexual maturity at a size smaller than females.

Fecundity

The estimated fecundity of *F. indicus* varied between 98,000 and 222,000 eggs per specimen for individuals of 15.8–37.9 g body weight and from 40,000 to 222,000 eggs for individuals of carapace length from 3.5–4.2 cm. Correlation analysis showed that there was no significant relationship between fecundity and body weight ($r = 0.7795$; $P = 0.0676$), but there was a significant one between carapace length and fecundity ($r = 0.9914$; $P = 0.0001$).

For *P. monodon,* fecundity varied from 72,000 to 314,000 eggs per specimen for individuals ranging from 25.7 g to 43.6 g and 72,000 to 314,000 eggs for individuals ranging from 3.6 to 4.5 cm carapace length. Significant relationships between fecundity and body weight ($r = 0.9438$; $P < 0.001$) as well as fecundity and body length ($r = 0.9711$; $P < 0.0001$) were observed for *P. monodon.*

DISCUSSION

The present study has revealed that *Fenneropenaeus indicus* is the most dominant prawn species in the coastal waters of Bagamoyo, followed by *Penaeus monodon* (Table 1). The observation is in agreement with Subramaniam (1980) who reported that *F. indicus* was the most important prawn species in the shallow water prawn fishery, constituting almost 60% of the trawl catches in Tanzania. The dominance of *F. indicus* indicates that the area provides ideal conditions for the species. The beach seine fishing ground is close to a mangrove ecosystem, which provides *F. indicus,* a species with non-burrowing habits, with protection and food (Hughes, 1966). In contrast, *Metapenaeus monoceros* and *Penaeus japonicus* occurred in low abundance suggesting that either they are less dependent on this area during their life cycle or they migrate at a very small size and were hence missed by the beach seine. Coles & Greenwood (1983) observed that penaeid prawns are capable of successfully completing their life cycle without entering less saline nursery grounds. Emigration of *M. monoceros* at a small size from the estuary to oceanic waters has been reported by George (1969) at the Godavary estuarine system in India. Young (1975) observed that *P. plebejus* stays for only a short time within the river and begins emigrating to the sea immediately after settling out.

In fisheries research length–weight relationships are important for the estimation of weight where only length data are available and as an index of the condition of the animal (King, 1995). It is often assumed that heavier prawns of a given length are in better condition. *Fenneropenaeus indicus* and *P. monodon* maintained dimensional equality with b value of ca. 3.0 indicating isometric growth. It is worth noting that deviation from isometric growth is often observed, as most animals change their body shape as they grow (i.e. allometric growth). The present study revealed a high relative abundance during the wet season than the dry season, suggesting that rainfall strongly influences prawn catches. Rainfall initiates the migration of prawns from estuaries either by lowering salinities or simply by mechanical flushing of water run-off and by disturbing bottom sediments (Ruello, 1973). Working with *Penaeus merguiensis*, Staples & Vance (1986) found that juvenile prawns are less tolerant to fresh water as they grow. Thus, when the salinity of the water in the nursery areas decreases, the juveniles tend to move to the more saline open ocean. The onset of the wet season will therefore trigger an offshore migration of the juveniles, which are then recruited to the fishery areas. An earlier study in Bagamoyo coastal waters (Semesi et al., 1998) also reported increased prawn catches during the rainy season (March–May). Gammelsrød (1992) reported similar observations on *Fenneropenaeus indicus* from Sofala Bank, Mozambique.

Fenneropenaeus indicus exhibited a deviation from the overall expected 1:1 sex ratio in favour of females. An inspection of the monthly sex ratio revealed that there is also a female bias in sex ratio except in the months of February, March, October, November and December. The overall ratio for *P. monodon* was not significantly different from the theoretical 1:1 ratio. The monthly sex ratio was also found to be 1:1 except in August when the ratio was in favour of females. Dominance of one sex is uncommon in penaeid prawn fisheries (Courtney et al., 1996). A possible explanation for the preponderance of one sex in the catch could be differences in the selectivity of the mesh size between sexes (Courtney et al., 1996). No information is available on the selectivity of the gear used for *F. indicus* and *P. monodon*, although size-specific selectivity could account for the differences in the number of males and females captured over the entire sampling period. Another possible explanation could be general size–depth spatial distributions (Garcia & Le Reste, 1981), combined with the fact that the maximum attainable size of most of penaeid females is greater than that of males (Glaister et al., 1987).

Our study found that both *F. indicus* and *P. monodon* females attained sexual maturity at a larger size than males. This may be related to the preparation of females to sustain the eggs (Charniaux-Cotton, 1964). The present study confirms the work of Motoh (1981) and Subrahmanyam (1965), who found that males attain maturity at a size smaller than females in *P. monodon* and *F. indicus* populations respectively.

The present study has revealed strong relationships between fecundity and carapace length in both species, as well as between fecundity and body weight in *Penaeus monodon*. The results showed that there is a tendency for fecundity to increase with prawn size, suggesting that there are differences in the pattern of allocation of food energy by the animals at different sizes. Usually, in larger individuals, which have low growth rates, much of the available energy is devoted to egg production as compared to smaller individuals in which a large fraction of the energy may be devoted to growth rather than egg production (Cox & Dudley, 1968). The increase of fecundity with body size seems to be a rule that is applicable to many crustaceans (Udo & Ekpe, 1991). Contrary opinion has been documented by Courtney et al. (1996) who reported on the decline in number of eggs with an increase in the size of *Penaeus plebejus,* and found that this could possibly be due to ovarian senescence in large (old) females, which has not been recorded previously in penaeid prawns.

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