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Population Structure and Recruitment of Penaeid Shrimps from the Pungué River Estuary to the Sofala Bank Fishery, Mozambique

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Abstract—This study characterizes the population structure and identifies nursery areas and recruitment seasons of penaeid shrimps in the Pungué river estuary of Mozambique. Shrimp samples were obtained from 12 trawl stations at monthly intervals during 2004. Six species were found, two of which (*Fenneropenaeus indicus* and *Metapenaeus monoceros*) constituted 99% in numbers of the total. Both had a size distribution of 10-50 mm carapace length. Males represented the dominant sex in both species. The estuary is important in their life cycles in supporting large numbers of juveniles. *M. monoceros* juveniles were abundant in all sections of the estuary during the latter part of the rainy season. *F. indicus*, juveniles were in lower proportion than adults throughout the estuary, but increased in abundance over the rain season. Recruits migrating from the estuary reach adjacent industrial fishing areas after 1-2 months. It is confirmed that the current annual seasonal closure (November-March) of the entire Sofala Bank is adequate for the protection of juveniles in the estuary. Given the contribution of this estuary to the entire shrimp fishing industry of the Sofala Bank there is a need to strengthen enforcement of management regulations.

INTRODUCTION

It is a generally accepted principle that estuaries are nursery areas for juveniles of many penaeid shrimp species (Primavera, 1998; Ronnback *et al.*, 2002) and therefore play an important role in the life cycle of those species. The shrimp life cycle as described by these authors has several stages. Females spawn eggs offshore and after a few weeks post-larvae migrate towards the coast and occupy nursery areas in estuarine waters. Sub-adults then normally migrate back to the oceanic waters, where the fishery occurs (recruitment to the fishery), completing their life cycle (Ronnback *et al.*, 2002).

Studies carried out on the shrimp species *Fenneropenaeus indicus* (de Freitas, 1986; Chong *et al.*, 1990; Forbes & Cyrus, 1991), *Penaeus monodon* (de Freitas, 1986; Forbes & Cyrus, 1991; Primavera, 1998), *Metapenaeus monoceros* (de Freitas, 1986; Forbes & Cyrus, 1991), *P. semisulcatus* (Staples *et al.*, 1985; Robertson & Duke, 1987), *Melicertus latisulcatus* (Primavera, 1998; Tanner & Deakin, 2001), *Metapenaeus stebbingi* (de Freitas, 1986) and *Marsupenaeus japonicus* (de Freitas, 1986; Forbes & Cyrus, 1991) confirm the preference of those juveniles for estuarine nursery areas associated with mangroves and seagrass beds.

The Sofala Bank, in Mozambique, supports a multi-species shrimp fishery, which is being fully exploited by artisanal, semi-industrial and industrial

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fleet sectors. They exploit estuarine, inshore and offshore areas of the Sofala Bank respectively (Brito, pers. comm.; Palha de Sousa *et al*., 2006). The main shrimp target species are *Fenneropenaeus indicus* and *Metapenaeus monoceros*, which constitute 80-90% of the total shrimp landings. Those species are partially protected by a seasonal closure of the fishery from 15 November to 1 March annually, which coincides with the period of recruitment of *F. indicus* juveniles from the estuarine waters (Palha de Sousa *et al*., 2006).

Industrial fishing vessels have been used for survey cruises of the shrimp stocks since the 1980s and most management measures are based on information obtained only from areas deeper than 8-10m where these vessels can operate. It is known from commercial catch data of industrial vessels and research survey cruises that the abundance of *F. indicus*, *M. japonicus* and *P. monodon* on Sofala Bank decreases with increase in sea depth from 10 to 35-45 m. However, the inverse occurs for *M. monoceros* and *M. latisulcatus*, whose abundance increases with depth up to 45 m (Palha de Sousa *et al*., 2006). The size distribution of shrimp also follows the bathymetry of the Sofala Bank, with larger shrimps located in deeper waters (Brito *et al*., 1998; Abdula & Brito, pers. comm.). While these data show that different areas, with different depths and conditions, play a part in the life cycle of those species, the role of the shallow coastal areas (less than 8-10 m) of the Sofala Bank, where estuaries are located, is still not well known.

Due to the lack of knowledge of locations of nursery areas, fishing may occur in areas with large numbers of juveniles. For example, there have been reports of large catches of undersized shrimps, with no commercial value, by the industrial fleet at the start of most fishing seasons. These small shrimps are normally discarded at sea and this destructive fishing practice occurs in shallow waters of the Sofala Bank.

The purpose of this study was to characterize shrimp population structure, identify nursery areas and define the recruitment season of penaeid shrimps in the Pungué river estuary. This information will help in the conservation of the shrimp species and contribute to better understanding of their life cycles.

MATERIALS AND METHODS

Description of the study area

This study was carried out in Pungué river estuary, which is located in the center of the Sofala Bank fishing grounds in Mozambique. The city of Beira lies to the northern side of the estuary. The estuary receives waters from two rivers: the Pungué river, which is the most important, and the smaller Búzi river which enters less than 2 km to the south (Fig. 1). The outflow of these rivers may directly influence an area between 8 to 20 km to the north and south of each river mouth. Mangroves are the dominant vegetation to the south, while the northern shoreline of the estuary, which is urbanized, has sandy beaches and sand dunes. These are more evident in areas adjacent to the urban neighborhoods of Palmeiras, Macuti and Estoril (Fig. 1). Casuarinas are the dominant trees in these areas. Due to the greater influence of the Pungué river on the estuary, the study area is referred to as the Pungué river estuary (Fig. 1).

Many economic activities take place in this estuarine area. There are several disembarking areas for small and large vessels, including two harbors that receive industrial vessels along the urbanized shoreline. The estuary supports an artisanal fishery of fish, cephalopods and crustaceans, including penaeid shrimps (Santana Afonso *et al*., pers. comm.). Total landings are estimated at 1800 t a year. The main fishing gears used are beach-seines, gill-nets, hand-line and hook and stow nets locally called chicocotas (Santana Afonso *et al*., pers. comm.).

Sampling design

Twelve stations were sampled in the study area each month from January to December 2004. Trawling was done during day-light hours using a small fiberglass vessel, the *Tainha*, with total length 8.55 m, a covered deck, a 62 HP engine and a gross tonnage of 7.64 t. This stern trawler used a net that was 10 m long from cod-end to mouth opening, 8 m head-rope length and 10 mm cod-end mesh size. The sampling stations were selected by considering 7 reference points from the adjacent shoreline and

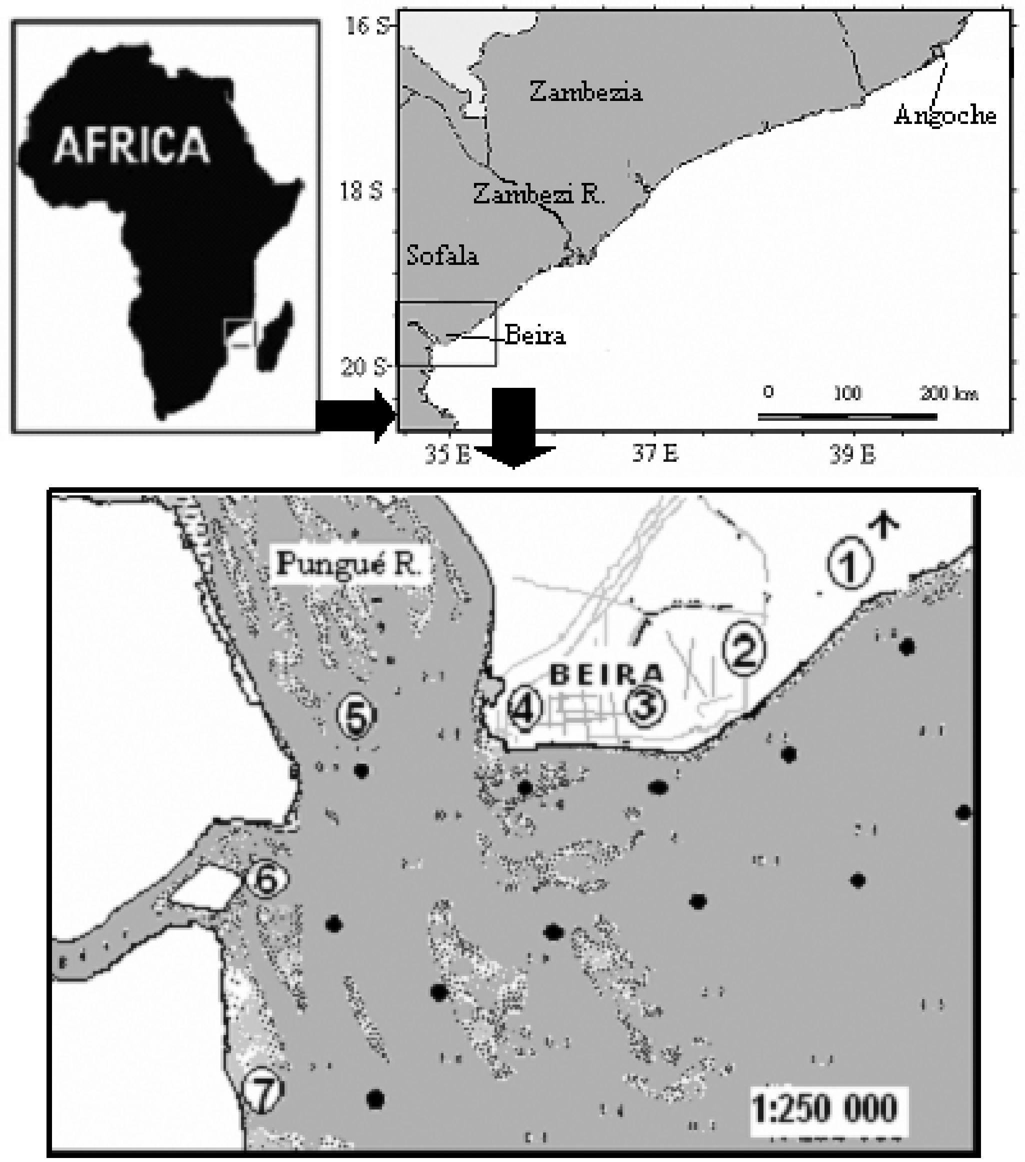

Fig. 1. Map of the Pungué river estuary in central Mozambique indicating monthly sampling stations (dark circles) covered during the year 2004 with shore reference locations (1-Regulo Luis, 2-Estoril, 3-Palmeiras, 4-Grande Hotel, 5-Pungué river mouth, 6-Búzi river mouth, 7-Dingue-Dingue)

were approximately 3 km equidistant as indicated in Figure 1 and Table 1. Each trawl was of 15 minutes duration and was made only during low tide.

Sample collection

After each haul, all shrimps were separated from the other species and placed in a plastic bag tagged with information on date and station. The bags were preserved in a container with ice cubes for later processing in the laboratory. A 0.5 L seawater sample was also taken at each trawl station.

Sample processing

Processing of samples in the lab on shore consisted of identifying the shrimp species (using de Freitas, 1972), determining their sex and measuring the

Table 1. Number and location of trawl stations in the Pungué river estuary

Stations	Shore Reference Locations	Nº trawls stations
1	Régulo Luís	2
2	Estoril	2
3	Palmeiras	2
4	Grande Hotel	2
5	Pungué river mouth	1
6	Búzi river mouth	2
7	Dingue-dingue	1

carapace length (CL) of each specimen using a dial caliper. Individuals less than 21 mm CL were regarded as juveniles. Total weight of each species grouped by sex was recorded using a digital scale (3 kg ± 0,0001). Macroscopic examination of gonads of all females was carried out to determine their reproductive condition or maturity stage using a scale of four stages (Cristo & Mascarenhas, 1986). The carapace residual color effect was avoided by dissecting the carapace following the method of Relini & Relini (1979).

Seawater samples were analyzed for salt content using a hand-held salinity refractometer.

Data processing

Data were processed mainly as number of shrimps by age groups, adults and juveniles, sex groups and carapace length frequencies. Females with maturity stages 1 and 2 were classified as immature and those with maturity stages 3 or 4 were classified as mature. Comparison of quantities of males vs. females was done using a chi-square test (at 5% significance level). The recruitment curves of shrimps were determined using the number of juveniles caught each month as a proportion of the total number of juveniles observed in the year. The results from each of the 7 stations (Table 1) were then combined. To test abundance differences in the number of juveniles between locations and months two separate one-factor ANOVA were carried out, using the different sites and months as replicates respectively.

RESULTS

Species composition

The following species were found in the Pungué estuary: *Fenneropenaeus indicus*, *Metapenaeus monoceros*, *Penaeus monodon, M. stebbingi*, *Marsupenaeus japonicus* and *P. semisulcatus*. There were 2380 individuals of *F. indicus* (74%) and 807 specimens of *M. monoceros* (representing 25% of the total shrimp catch). The latter four species combined represented only less than 1%. Due to the small numbers of these four species they were excluded from further analysis.

Population structure and sex ratio

The monthly size distribution of the main species, *F. indicus*, is shown in Figure 2. There were smaller individuals, with sizes ranging from 10 to 40 mm, from January to April and from September to December. There were more specimens in March, November and mainly in December. In December, 341 male individuals were measured with a mean CL of 24.60 ± 3.53 mm. For females, 301 individuals were measured with mean CL 24.25 ± 4.30 mm. There were more females than males in February and May. Immature females were normally more abundant than mature ones in all months of the year 2004 (Fig. 2 and Table 2). In the period between May and August 2004, the size distribution of *F. indicus* varied between 16 and 50 mm CL. There was a peak of males in July, totaling 163 individuals with a mean CL of 28.82 ± 5.43 mm and a peak of 71 females with 30.86 ± 6.46 mm of mean CL. The largest *F. indicus* specimens were collected in June and July. The mean CL of both sexes was relatively low in the first and last four months of the year, compared to the mid-year months (Fig. 3).

Size ranges in the monthly population structure of *M. monoceros* (Fig. 4) differed slightly. Most males were observed in February and mainly in March, while the peak occurrence of females was in March (Fig. 4 and Table 2). This peak month yielded 94 males with a mean CL of 16.84 ± 4.40

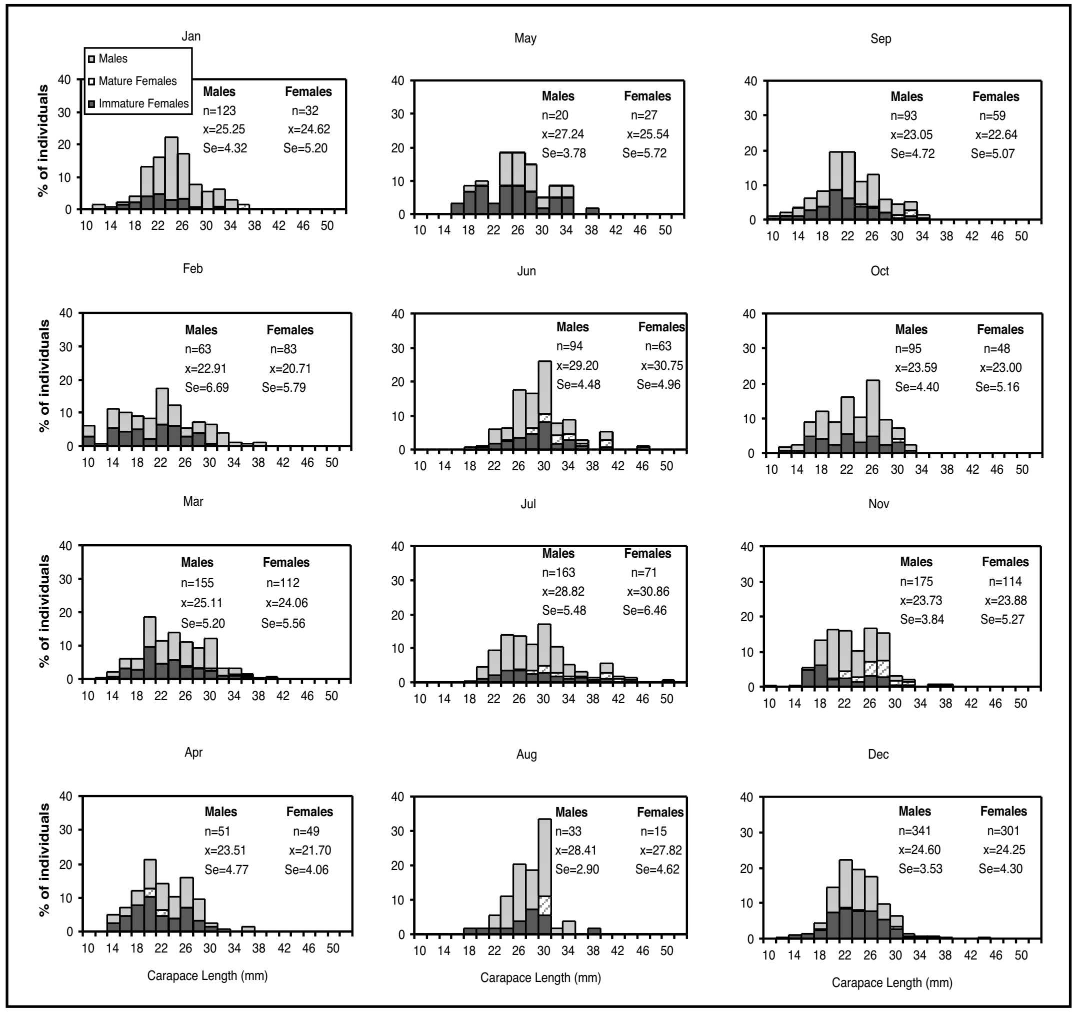

Fig. 2. Monthly size frequency distribution of *F. indicus* collected in Pungué estuary during 2004 (X=mean carapace length, Se=standard error)

mm and 94 female specimens, with a mean CL of 17.04 ± 6.11 mm. For the second half of the year, the peak in numbers of both males (78) and females (62) was in December. These males were larger in size with a mean CL of 24.30 ± 5.78 mm, while the females had a mean CL of 22.98 ± 5.98 mm. There was a monthly variation in the values of the mean CL of the males and females, with peaks in both values in January, July and December (Fig. 5).

Sex and maturity ratios of both species are shown in Table 2. The monthly sex ratios of *F. indicus* do not show any particular trend. There were significantly more males in January, July, October, November and December ($p<0.01$) and also in June ($p<0.05$) and more females in February and May ($p<0.05$). The mature/immature ratio of females fluctuated throughout the year (Table 2). Sex ratios of *M. monoceros* were not significantly different in all months except for February and December, when males were significantly more numerous than females ($p<0.01$). There were more immature than mature *M. monoceros* females in nearly all months except February when a 1:1 ratio was observed.

The numbers of juveniles and adults within each month are shown in Table 3. *F. indicus* juveniles were less abundant than adults throughout the year, but their abundance was significantly different by month ($p=0.0072$) with the highest numbers in

Table 2. Monthly sex and maturity ratios and χ^2 statistic probabilities for sex ratios of *F. indicus* and *M. monoceros* (p=probability of chi-square statistic; levels of significance: *** p<0.001, * p<0.05, ns=not significant; I:M=immature:mature; M:F= male:female)

	F. indicus					*M. monoceros*				
	Numbers			p (χ^2)	Female	Numbers			p (χ^2)	Female
Month	Males	Females	M:F ratio	M:F ratio	I:M ratio	Males	Females	M:F ratio	M:F ratio	I:M ratio
Jan	123	32	3.84:1	0.0000***	9.67:1	19	4	4.75:1	0.1770 ns	3.00:1
Feb	63	83	0.76:1	0.0000***	0.00:1	78	0	78.00:1	0.0000***	1.00:1
Mar	155	112	1.38:1	0.0535 ns	15.00:1	94	94	1.00:1	0.3971 ns	30.33:1
Apr	51	49	1.04:1	0.3397 ns	11.25:1	12	13	0.92:1	0.9161 ns	13.00:1
May	20	27	0.74:1	0.0185*	27.00:1	21	15	1.40:1	0.8898 ns	14.00:1
Jun	94	63	1.49:1	0.0476*	2.32:1	22	22	1.00:1	0.5026 ns	10.00:1
Jul	163	71	2.30:1	0.0000***	2.23:1	52	30	1.73:1	0.4442 ns	5.00:1
Aug	33	15	2.20:1	0.1288 ns	4.00:1	16	15	1.07:1	0.9272 ns	14.00:1
Sep	93	59	1.58:1	0.1484 ns	7.43:1	15	12	1.25:1	0.7294 ns	11.00:1
Oct	95	48	1.98:1	0.0008***	23.00:1	46	29	1.59:1	0.3690 ns	13.50:1
Nov	175	114	1.54:1	0.0000***	1.48:1	32	26	1.23:1	0.7490 ns	7.67:1
Dec	341	301	1.13:1	0.0000***	19.07:1	78	62	1.26:1	0.0000***	61.00:1

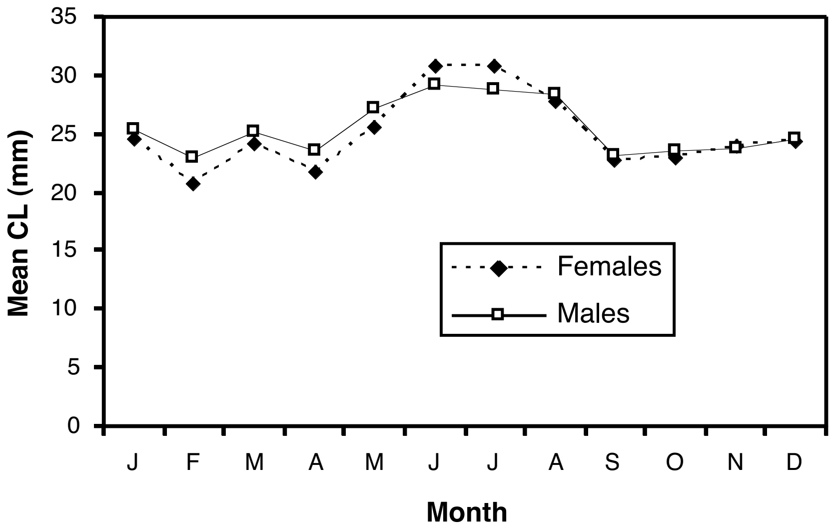

Fig. 3. Monthly mean CL of *F. indicus* population (males and females) for the Pungué estuary during the year 2004

October, November and December. Conversely, juveniles of *M. monoceros* were present in a much higher proportion than adults mainly in February and March. Similarly, the abundance of juveniles varied significantly by month (p=0.0002) (Table 3).

The number of juveniles and adults within each of the 7 sampling areas of the Pungué estuary are shown in Table 4. Abundance of juveniles showed no significant differences by section of the estuary for both *F. indicus* (p=0.0614) and *M. monoceros* (p=0.6126).

Recruitment

Recruitment curves of shrimps were based on the number of juveniles in each month as a proportion of the total number of juveniles observed in the year.

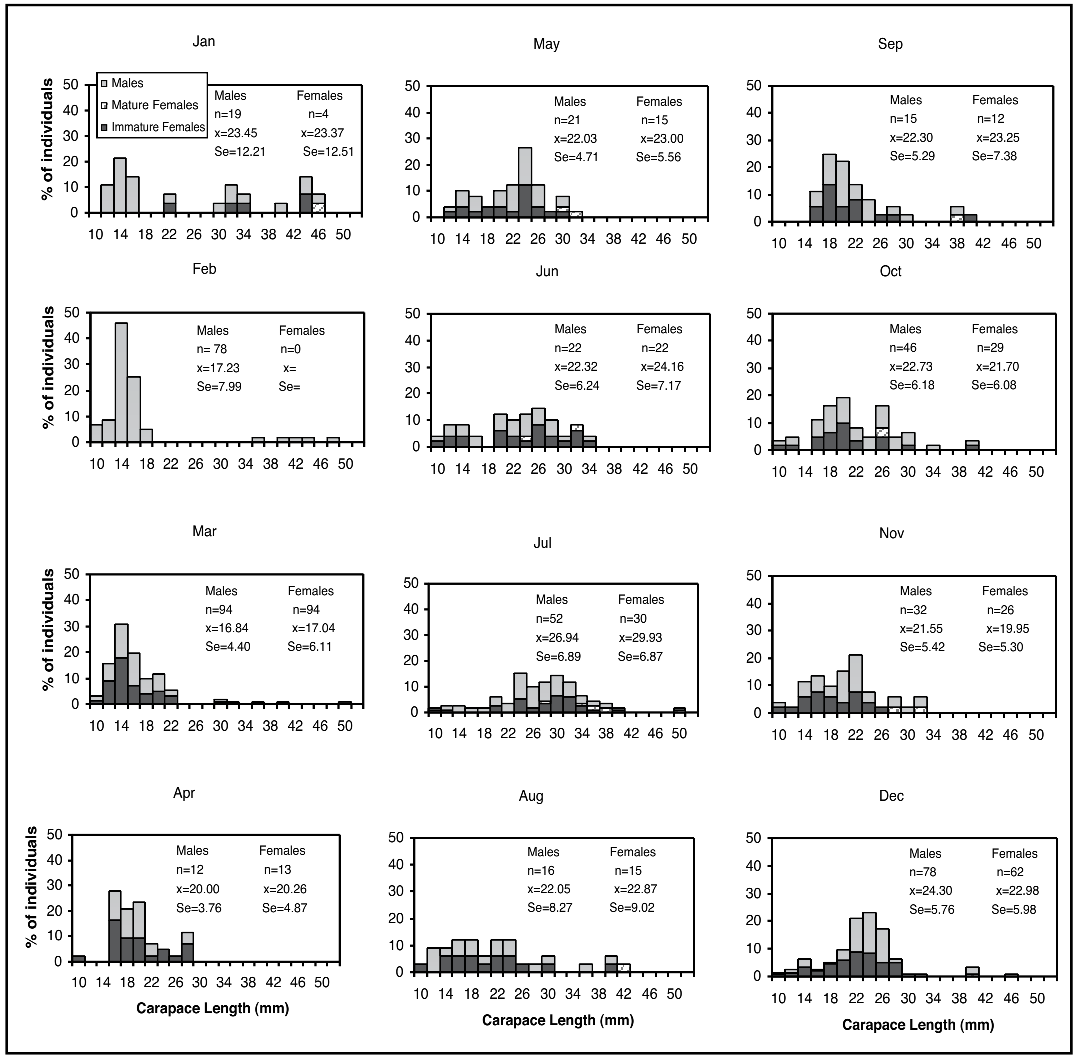

Fig. 4. Monthly size frequency distribution of *M.monoceros* collected in Pungué estuary during 2004 (X=mean CL, Se=standard error)

Table 3. Comparison of the number of shrimp juveniles and adults within each month and test of significance for the juveniles abundance by month (one-factor ANOVA) in the Pungué estuary in 2004

		Month												
Species	Age group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*P-value*
F. indicus	Juveniles	25	51	44	25	6	2	6	2	38	57	109	116	*0.0072*
	Adults	130	95	223	75	41	155	228	46	114	86	180	526	
	Total number	155	146	267	100	47	157	234	48	152	143	289	642	
M. monoceros	Juveniles	14	74	158	14	11	14	12	14	14	31	28	28	*0.0002*
	Adults	9	4	30	13	25	30	70	17	13	44	30	112	
	Total number	23	78	188	25	36	44	82	31	27	75	58	140	

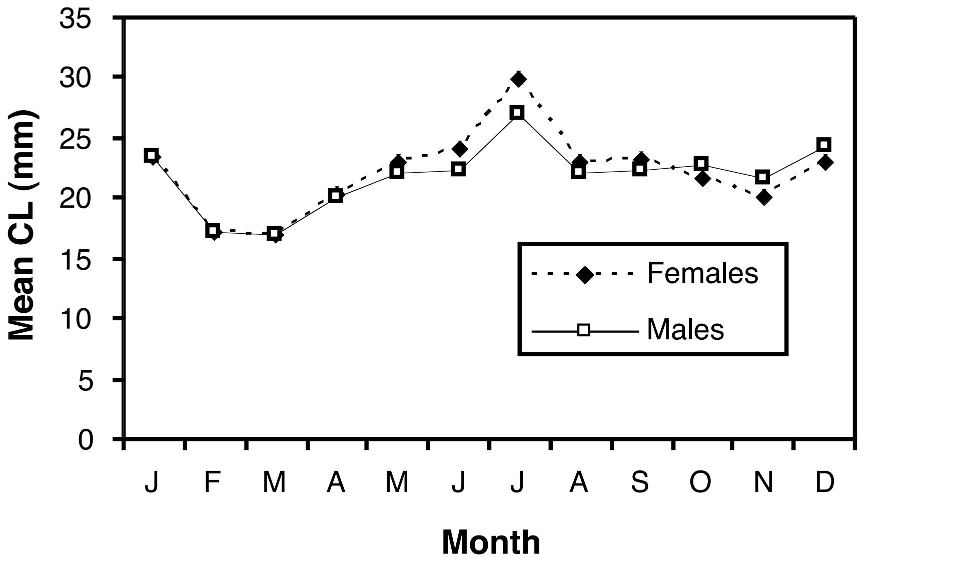

Fig. 5. Monthly mean CL of *M. monoceros* population (males and females) for the Pungué estuary during the year 2004

Table 4. Spatial variation of number of juveniles and adults of F. indicus and M. monoceros within each area of the Pungué estuary in 2004 and test of statistical differences of juveniles by area (one-factor ANOVA)

	Area							
Species/Age group	**Régulo Luis**	**Estoril**	**Palmeiras**	**Grande Hotel**	**Pungué Mouth**	**Búzi Mouth**	**Dingue-Dingue**	***P-value***
F. indicus								
Juvenile	82	117	24	5	38	81	133	*0.0614*
Adults	343	153	86	43	314	468	493	
Total number	425	270	110	48	352	549	626	
M. monoceros								
Juveniles	65	50	35	41	121	48	52	*0.6126*
Adults	123	115	12	8	22	5	111	
Total number	188	164	47	49	143	53	163	

Young *F. indicus* recruited from the estuary in two main pulses, during the first and last four months of the year. Recruitment peaks occurred in February and in November-December (Fig. 6). The November-December peak contributed 47% of the total annual recruitment. During that period *F. indicus* juveniles had low mean CL (i.e. 19.30 ± 1.00 mm at Pungué and 18.30 ± 2.20 mm at Estoril). The recruitment pattern in deeper waters of the Sofala Bank over the 12 years from 1988 to 1999 indicated by industrial fishery catch data (Brito, 2001) shows a similar trend to that described for the estuary, but with a lag of one to two months, i.e. recruits leaving the estuary in November are available to the industrial fishery in the Sofala Bank fishery in February (Fig. 6). Monthly salinity records of the estuary show an inverse trend to that of estuarine shrimp recruitment, but this relationship is not very evident.

The recruitment pattern of young *M. monoceros* from the estuary shows a clear peak in February-March and another smaller peak in the period from October to December. The first peak accounted for 56% of the total recruitment of the year (Fig. 7).

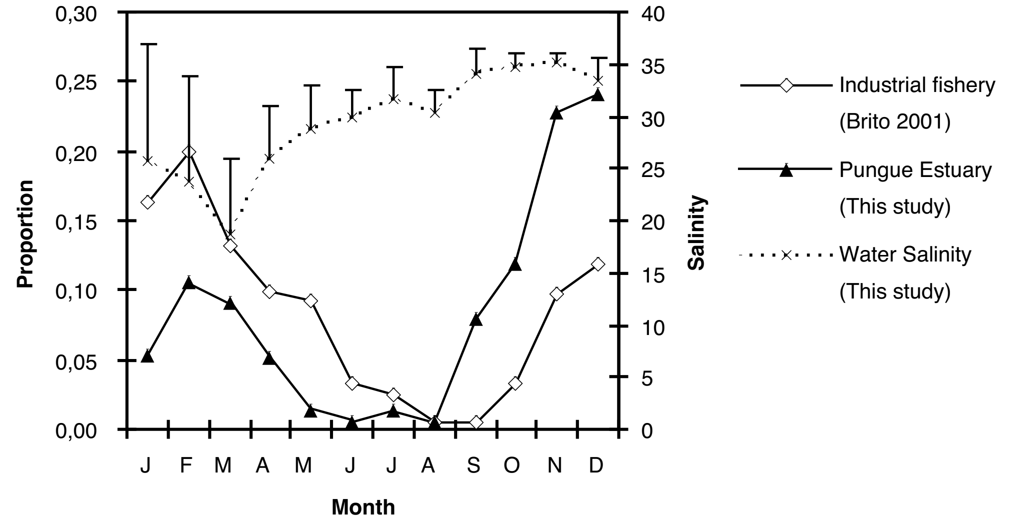

Fig. 6. Comparison of recruitment patterns of F. indicus from the Pungué estuary (this study) and from the adjacent waters used by the industrial fishery (Brito, 2001). Seawater salinity records (with standard deviation bars) of the estuary are also displayed (this study)

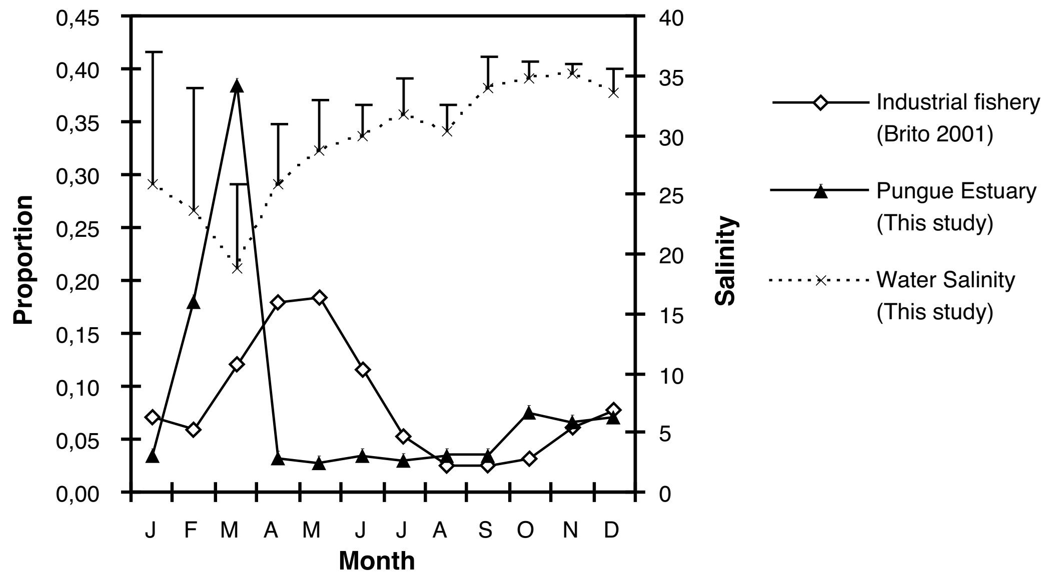

Fig. 7. Comparison of recruitment patterns of *M. monoceros* from the Pungué estuary (this study) and from the adjacent offshore waters exploited by the industrial fishery (Brito, 2001). Seawater salinity records (with standard deviation bars) of the estuary are also displayed (this study)

February and March recruitment was associated with water salinity generally below 25‰ with values reaching 8.50‰ at the Pungué river mouth in March (Fig. 8). The smallest recruits in the Pungué river mouth area measured only 13.67 ± 2.35 mm mean CL in March. The lag of one or two months between recruitment peaks from the estuary and the industrial fishing areas (Brito, 2001) is also observed for *M. monoceros* (Fig. 7). Monthly salinity records of the estuary also relate inversely to the estuarine shrimp recruitment, but this relationship is not clearly shown for periods without peaks in both variables.

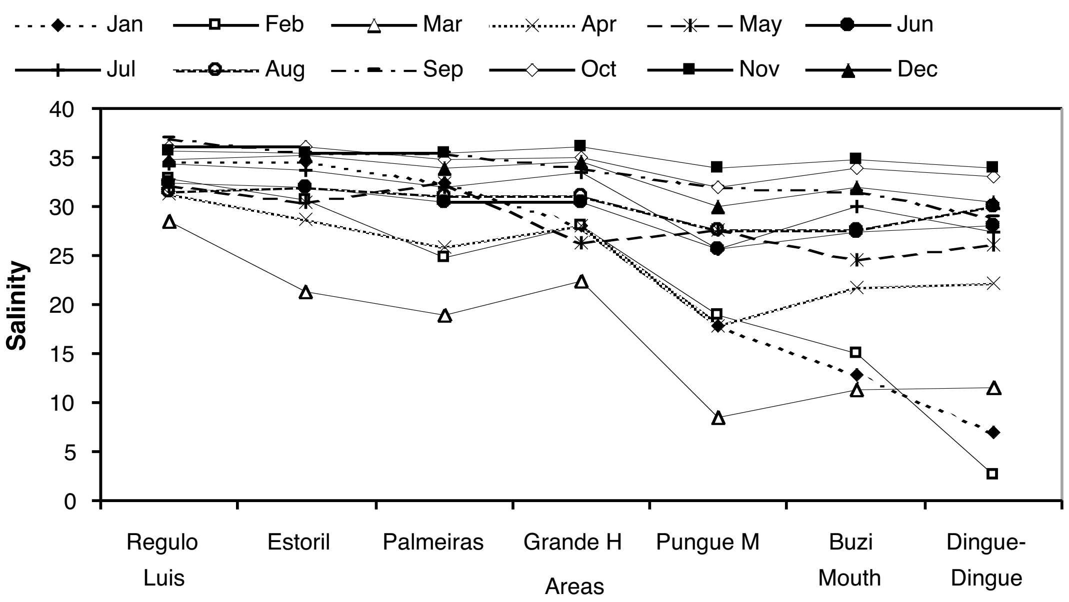

Fig. 8. Monthly salinity records by area in Pungué estuary (areas are ordered north to south)

DISCUSSION

Species composition

The species composition results show that *F. indicus* is the dominant species (74%) followed by *M. monoceros* (25%) and the remaining 1% comprise the other four species. A similar species composition was reported by Santana Afonso *et al.*, (pers. comm.), who analyzed artisanal fishery data from coastal waters off Beira City in 2002 and by Brito, (pers. comm.), using semi-industrial fleet catch data from 2004 to the south of Beira City. Uetimane & Mualeque (unpublished data) also observed a dominance of *F. indicus* in Angoche and Moma, 500 nm to the north of Pungué estuary in the same year. In all cases, fishing occurred within 3 nm of the coastline, which suggests that this pattern of species composition is typical for the coastal waters of the Sofala Bank. The industrial fishery, which occurs outside the 3 nm of the coastline to the north of this estuary until Angoche district (500 nm away), catches a species composition of 50-40% for *F. indicus* and *M. monoceros*, mainly in depths from 25-35 m (Palha de Sousa *et al.*, 2006). The shallow waters of the Sofala Bank such as the Pungué estuary are therefore dominated by *F. indicus* followed by *M. monoceros*, while in deeper waters the two species are more equal in abundance. This suggests that in the estuary, due to prevailing habitat conditions a high number of *F. indicus* juveniles remain in the estuarine waters up to adult sizes, probably, only migrating offshore when in need of spawning to complete their life cycle. This is shown by the population structure (Fig. 3 and Table 2), when in most months the sex ratio is dominated by males and although the mean CL values correspond to adults, most females are commonly immature throughout the year. This implies that mainly the mature females emigrate from this estuarine population to offshore waters. Conversely, offshore data obtained from the industrial fishery seems to show that the mature *F. indicus* females on average dominate immature females by 3 to 1 throughout the year (Palha de Sousa & Brito, 2004; Palha de Sousa *et al.*, pers. comm.) and a sex ratio (M:F) of 1:3.6 was reported (only available for the month of February 2004) (Brito & Abdula, unpublished data).

Population structure

The mean carapace length of males and females of *F. indicus* are similar (around 25 mm). This was also found for both sexes of *M. monoceros* (both with mean CL around 21 mm). However, this size for both sexes is not found in deeper waters of the Sofala Bank, where females of both species are generally larger than males and the mean CL show higher values than the estuarine values (Abdula & Brito, pers. comm.; Palha de Sousa *et al.*, pers. comm.). This spatial distribution of relatively small shrimps in near-shore waters and larger sizes in deeper waters is probably associated with their life cycle and reproductive behavior.

Recruitment

The life cycle of these shrimps starts in deep oceanic waters where the adult spawn. A few weeks later, larvae are carried towards the coastal and estuarine waters, which they use as nursery areas for growth and development (Primavera, 1998; Ronnback *et al.*, 2002). Recruitment of the sub-adults to marine (deeper waters) areas, where they become adults and spawn, completes their life cycle.

This study measured the sub-adult stage of recruitment to the fishery and did not include earlier life history stages usually associated with upper estuarine waters due to difficulties in accessing the areas commonly used by larvae as nursery grounds. De Freitas (1986), studying the selection of nursery areas by penaeid shrimps in a similar tropical area (Maputo Bay), found that *F. indicus* and *M. monoceros* used soft mud channels and shallow creeks in mangrove swamps as nursery areas. Macia (unpublished data), during 2007, collected 59 postlarvae specimens of *F. indicus* measuring 12 mm total length (TL) and one specimen of *M. monoceros* with 7 mm TL in shallow mangrove creeks in the Pungué estuary. For present study, juvenile shrimp or recruits were considered as those less than 21 mm CL, or in terms of age, those of about 2.5 months for *F. indicus* and of 3 months for *M. monoceros* (Brito, 2001). This follows the work of Brito (2001) and Glaister *et al.*, (1990), who used this size to delimit juveniles of a similar species (*Penaeus plebejus*) in Australia.

The recruitment curves of both *F. indicus* and *M. monoceros* from the Pungué estuary show a similar trend to that of the adjacent deeper waters of the Sofala Bank (Brito, 2001), with a lag of 1-2 months, indicating the time required for recruits to reach industrial fishing areas. Specifically, *F. indicus* abundance peaks in November-December and in February-March are reflected "offshore" in January-February and in April-May, respectively. For *M. monoceros*, there is an estuarine abundance peak in March that is followed in the industrial fishery in April-May. Brinca & Palha de Sousa, (1984) suggest a similar time for the recruitment of *M. monoceros* from Maputo Bay, in southern Mozambique, in reaching the adjacent fishing area.

The lower number of juveniles than adults of *F. indicus* suggests that the Pungué river estuary is not a nursery area for this species. Although the early rainy season months showed high abundance of juveniles, they were accompanied by a larger increase of adult abundance, indicating that the juvenile increase is a result of a general immigration of shrimp from elsewhere. Further studies of other areas are therefore required to determine the source of juveniles. During October-December, salinity in the estuary was generally high (>30‰), typical of oceanic waters, which usually favors the occurrence of *F. indicus* adults. However, the Pungué estuary acts as nursery area for *M. monoceros* during February and March, when water salinity values could reach as low as 8.5‰. These results suggest that environmental conditions in the estuary affect each species differently. As implied by Dall (1981), Rulifson (1981) and de Freitas (1986), each organism shows different levels of tolerance to an array of environmental factors, which makes each habitat species-specific. Water salinity affects each shrimp species differently (Primavera, 1998) and this factor drives recruitment of shrimp in the Sofala Bank (da Silva, 1986). Young *M. monoceros*, for instance, seem to be more tolerant to low salinity, i.e. more euryhaline, than *F. indicus* (de Freitas, 1986).

To achieve a rational exploitation of fisheries resources the Fisheries Administration of Mozambique requires that juveniles not be fished in order for new recruits to supply the Sofala Bank fishery at larger sizes and thus higher values. The results of this study show that it would be desirable to have a closure of the artisanal shrimp fishery in the Pungué estuary between November and March. At present, the Fisheries Administration has a closed season in place during that period for the entire Sofala Bank fishery, including the estuary, which is in agreement with this study's findings. Given the contribution of this estuary to the entire shrimp fishery of the Sofala Bank it would be appropriate to strengthen enforcement measures of this closure, especially in the Pungué estuary.

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