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First estimates of growth, mortality and recruitment parameters of *Macrobrachium macrobrachion* Herklots, 1851 in the Cross River estuary, Nigeria

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Abstract

The growth, mortality and recruitment parameters of the brackish-river prawn, *Macrobrachium macrobrachion* Herklots 1851, in the Cross River Estuary, Nigeria, were estimated based on 12 monthly length-frequency samples (October 1991-September 1992). The estimated growth parameters were: L_∞ = 12.93 cm total length, K = 1.79 per year, C = 0.5, WP = 0.5 of year or 1st July, R_n = 0.259.

Total mortality (Z) was estimated at 10.6 per year, while natural mortality (M) was 3.36 per year, and fishing mortality (F) was 7.24 per year. This gave an exploitation rate (E) of 0.68, indicating heavy fishing pressure on the stock. The yield-per-recruit analysis suggested that the exploitation rate of the fishery is well beyond the level giving optimum yields. Further research effort to ascertain these findings was recommended, to provide the basis for advancing management options for the fishery.

Keywords: shrimp, growth, mortality, estuary, Nigeria.

Introduction

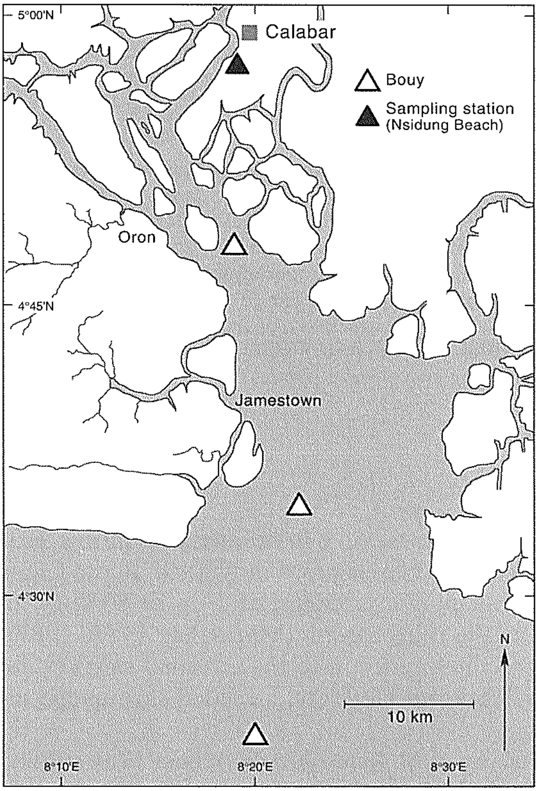
Macrobrachium macrobrachion is an important species in the artisanal shrimp fisheries in the mangrove creeks, estuaries and coastal lagoons in Nigeria. In the Lagos Lagoon, it constitutes about 60% of all prawn landings, and up to 83% of all *Macrobrachium* fishery catches during the rainy season (Marioghae 1982, 1987). In the Niger delta, it is more commercially important to the artisanal catch in the tidal areas than *Macrobrachium vollenhovenii* Herklots, a related shrimp species (Powell 1982).

The systematics, ecology and the fishery of *M. macrobrachion* have been studied by Powell (1982) in the Niger Delta. Marioghae (1982) described the distribution and biology of the species in the Lagos Lagoon and noted the upper limit of salinity tolerance of the species to be 12 psu. Hence, in the peak of the dry season with higher salinities, the shrimps migrate from the estuaries into the fresh waters. Marioghae (1990) studied the fishing methods, gear and marketing of the shrimp in the Lagos area.

Similar to most shrimp species important to the artisanal catches in Nigeria, information on growth, mortality and recruitment parameters of *M. macrobrachion* are lacking. Powell (1982) highlighted this shortcoming and stressed that such information are needed for the effective management of the artisanal shrimp fisheries relying on these species. This study attempts to estimate the growth, mortality and recruitment-related parameters for *M. macrobrachion* of the Cross River estuary, Nigeria.

Materials and methods

Monthly length-frequency data (total length) were collected from the landings of the artisanal fishery on *Macrobrachium* species in the Cross River estuary, Nigeria (Figure 1), from October 1991 to September 1992. The shrimps were caught, with push-nets and beach-seines of 1 cm mesh size throughout, in the mangrove creeks



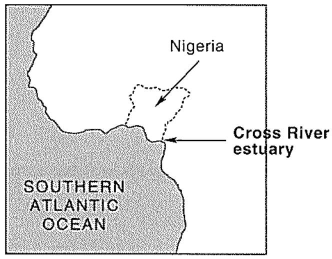


Figure 1. Cross River estuary and the mangrove creeks.

and the mud flats of the estuarine margins. Two subsamples were obtained per month, but were later pooled into single monthly samples. The samples from the catch were sorted into species as identified according to Powell (1982). The length-frequency data of *M. macrobrachion* were grouped into 1-cm intervals after the initial 0.5-cm entries.

The length-frequency data were then analysed using the Compleat ELEFAN package (Gayanilo *et al.* 1989), a software for length-frequency analysis. The theory and assumptions behind ELEFAN programs are described by Pauly & David

(1981), Pauly (1987) and Brey *et al.* (1988). The growth model used in the analysis was the seasonally oscillating version of the von Bertalanffy growth function (Pauly & Gaschütz 1979) which has the form:

$$L_t = L_\infty\,(1 - e^{-[K(t-t_0) + CK/2\pi\,\sin[2\pi(t-t_s)]]})$$

where L_t is the predicted length at age t, L_∞ is asymptotic length, K is the growth coefficient, C is the amplitude of seasonal growth oscillation, t_0 is the hypothetical 'age' at zero length, t_s is the age at the beginning of growth oscillation. Winter point ($WP = t_s + 0.5$) is the time of year when growth is slowest (Pauly 1987).

The modified Wetherall Plot (Pauly 1986) was used to obtain an initial estimate of asymptotic length (L_∞). This method is based on the right-descending part of the length-frequency curve and calculates the regression equation:

$$\bar{L} - L' = a + bL'$$

L' being the cut-off length for each size class, $\bar{L}$ is the mean length from L' upward, and the growth parameters are estimated as $L_\infty = a/-b$, $Z/K = (1 + b)/-b$.

This estimate of L_∞ was then seeded in ELEFAN I to optimize the estimates of the growth parameters, L_∞ and K, of the von Bertalanffy growth function. The seeded K-value was obtained from the formula:

$$K = 3/T_{max}$$

and assuming the longevity of the species to be 2.5 years. Thus K-values ranging from 1.2 to 1.5 were seeded. ELEFAN I identifies the peaks in the length-frequency samples and searches for the best combination of growth parameters (L_∞, K, C, WP) using a goodness-of-fit index (R_n) (Pauly 1987).

From the final estimates of L_∞ and K, the growth performance index (ϕ') of *M. macrobrachion* was calculated by the formula:

$$\phi' = \log_{10}K + 2\log_{10}L_\infty$$ (Pauly & Munro 1984).

Total mortality (Z) was estimated by the length-converted catch curve procedure of ELEFAN II (Pauly 1983, 1984a, 1984b), where the percentage of samples in length groups are pooled to simulate a steady-state population.

Natural mortality (M) was estimated by Pauly's (1980) empirical formula:

$$\log_{10}M = 0.0066 - 0.279\log_{10}L_\infty + 0.6543\log_{10}K + 0.4634\log_{10}T$$

and using a mean environmental temperature of 29°C for the Cross River estuary (Löwenberg & Künzel 1992).

Fishing mortality (F) was calculated from $F = Z - M$, and the exploitation rate (E) from $E = F/Z$, i.e. the fraction of total mortality (Z) caused by fishing mortality (F).

The probabilities of capture were estimated by means of the logistic transformation of the probabilities obtained from the lower-sized shrimp (i.e. from the left hand-side of the length-converted catch curve).

By projecting the length-frequency data backward onto the time axis down to zero length, using the von Bertalanffy growth equation and the estimated growth parameters, the recruitment pattern of the shrimp was estimated (Pauly 1982).

The modified form (Pauly & Soriano 1986) of the Beverton & Holt's (1964) yield equation was used to estimate relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) for *M. macrobrachion*. Both the probability of selection method and the knife-edge selection method were used. From these, the values of exploitation rate giving maximum relative yield-per-recruit (E_{max}) was estimated. Also $E_{0.1}$, the value of E at which the marginal increase in Y'/R is 10% of its value at $E = 0$; and $E_{0.5}$, the value of E corresponding to 50% of the unexploited relative biomass-per-recruit (B'/R), were estimated.

Results

The monthly length-frequency data used for the estimation of growth parameters of *M. macrobrachion* are given in Table 1. The modified Wetherall plot gave preliminary estimates of L_∞ = 11.39 cm total length and Z/K = 3.95 (Figure 2). From

Table 1. Length-frequency data of *Macrobrachium macrobrachion* of the Cross River estuary, Nigeria, October 1991 to September 1992. n = 7904.

Mid-	1991			1992								
length	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
1.45					1						1	
2.45	1	12	218	18	11	2	3	83	2	3	0	
3.45	9	119	358	231	50	20	19	451	81	36	31	7
4.45	144	138	283	431	118	37	44	439	205	110	184	110
5.45	100	142	164	303	112	33	68	283	148	160	109	115
6.45	112	152	139	133	57	23	47	116	105	147	127	196
7.45	79	97	56	47	24	14	34	30	40	44	32	76
8.45	19	40	13	9	8	5	16	11	8	12	15	22
9.45	4	8	3	4	2		1	3	3	2	2	3
10.45	3	4	1	2				1			2	
11.45	2	1		1								
Sum	473	713	1235	1179	383	134	232	1417	592	514	503	529

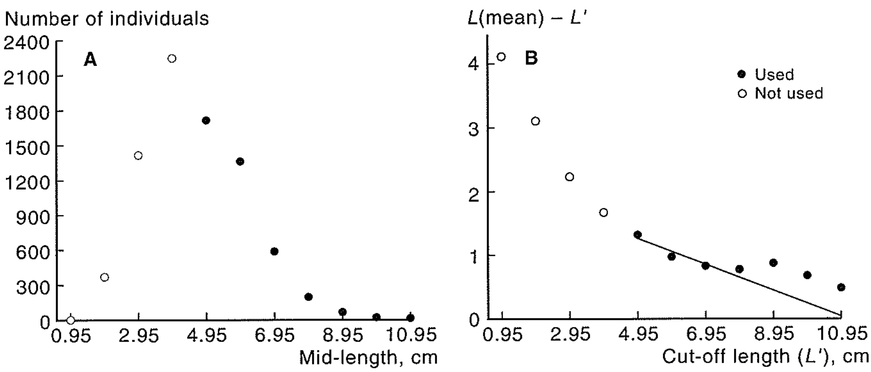


Figure 2. Wetherall plot for the length-frequency data of *Macrobrachium macrobrachion*. A: original length-frequency distribution, with points selected for the plot given as black dots; B: Wetherall plot proper, in which L (mean) is the mean length from L' upwards; estimated parameters were L_∞ = 11.39 cm total length and Z/K = 3.95.

ELEFAN I routines the best estimates of growth parameters obtained were L_{∞} = 12.93 cm total length, K = 1.79 per year, C = 0.5, WP = 0.5 of year or 1st July, R_n = 0.259, using data of 1 cm class intervals. Figure 3 shows the restructured length-frequency data superimposed with the estimated growth curve. The growth performance index (ϕ') of 2.48 was estimated for the shrimp.

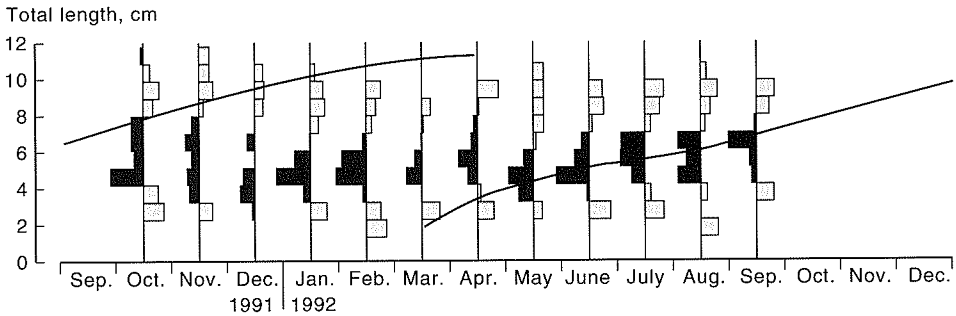


Figure 3. Restructured length-frequency data of *Macrobrachium macrobrachion* superimposed with the estimated growth curve. The estimated growth parameters are L_{∞} = 12.93 cm total length, K = 1.79 per year, C = 0.5, WP = 0.5, R_n = 0.259.

For data of 0.5-cm length classes, the best estimated of growth parameters were:

L_{∞} = 13.8 cm, K = 1.5 per year, C = 1.0, WP = 0.5, R_n = 0.187.

However, because of the poor fit of growth curve to the data (R_n = 0.187), these estimates were not used for further analysis.

From the length-converted catch curve procedure (Figure 4), total mortality (Z) was estimated at 10.6 per year, while natural mortality (M) of 3.4 per year was obtained. By subtraction, the fishing mortality (F) of 7.2 per year was obtained. The exploitation rate (E) was estimated at 0.68. The probability of capture routine gave an estimate of length-at-first capture (L_c) at 4.04 cm total length (Figure 5). The re-

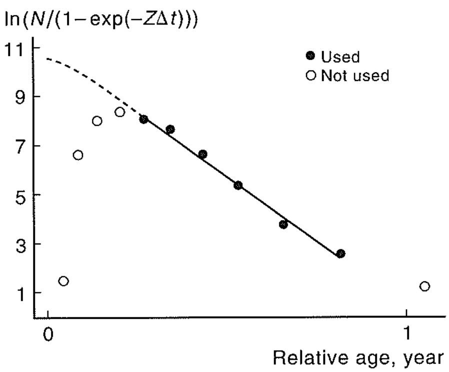


Figure 4. Length-converted catch curve of *Macrobrachium macrobrachion* of the Cross River estuary. Estimated Z = 10.6 per year.

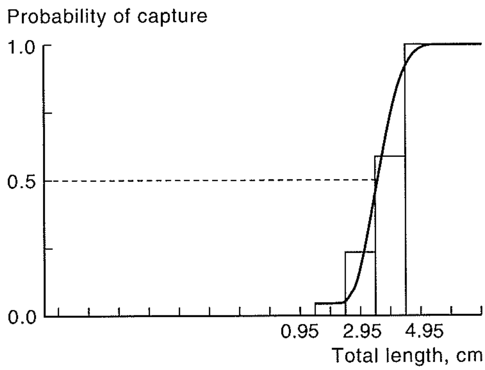


Figure 5. Selection curve of *Macrobrachium macrobrachion* of Cross River estuary. Estimated L_c = 4.04 cm total length.

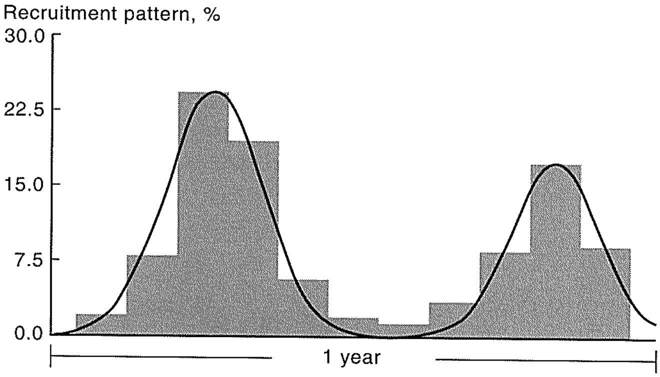


Figure 6. Recruitment pattern of *Macrobrachium macrobrachion* of the Cross River estuary.

cruitment pattern established in Figure 6 indicates a year-round recruitment for *M. macrobrachion*, but with two peaks of recruitment during one year.

Figures 7 & 8 show the results of relative yield-per-recruit and relative biomass-per-recruit analysis using the probability of selection method and by assuming knife-edge recruitment, respectively. The computed optimal exploitation rates are

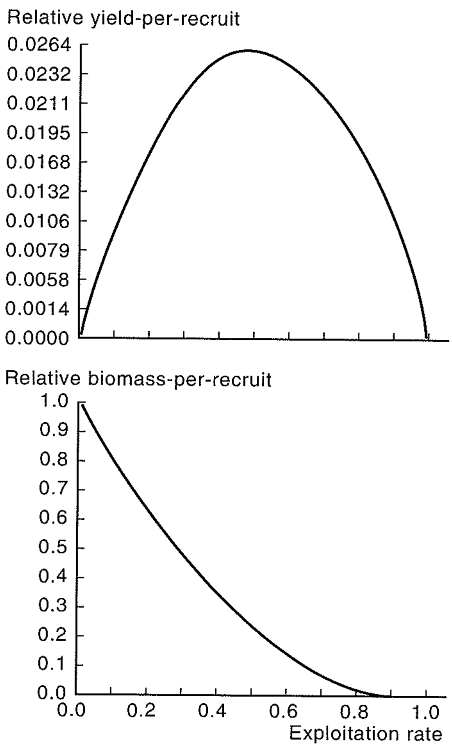


Figure 7. Relative yield-per-recruit and relative biomass-per-recruit of *Macrobrachium macrobrachion* in Nigeria, using the probability of selection method (see Table 2 for estimates).

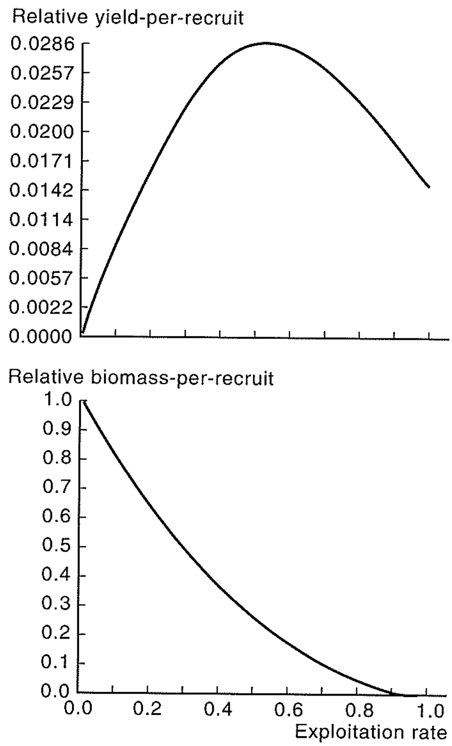


Figure 8. Relative yield-per-recruit and relative biomass-per-recruit of *Macrobrachium macrobrachion* in Nigeria, using the knife-edge recruitment method (see Table 2 for estimates).

Table 2. Estimates of optimum levels of exploitation rate (E) of *Macrobrachium macrobrachion* of the Cross River estuary, Nigeria (L_∞ = 12.93 cm total length, K = 1.79 per year, M = 3.36 per year, L_c = 4.04 cm total length).

Selection type	Exploitation rates E_{max}	$E_{0.1}$	$E_{0.5}$
Selection ogive	0.494	0.464	0.254
Knife-edge selection	0.536	0.505	0.305

provided in Table 2. The exploitation rate giving maximum relative yield-per-recruit (E_{max}) was 0.494 using selection ogive, and 0.536 using knife-edge recruitment.

The exploitation rate ($E_{0.1}$) at which the marginal increase in relative yield-per-recruit is 10% of its value at $E = 0$, was estimated at 0.464 (selection ogive) and 0.505 (knife-edge recruitment). The exploitation rate ($E_{0.5}$) which corresponds to 50% of the virgin relative biomass-per-recruit was estimated at 0.254 (selection ogive) and 0.305 (knife-edge recruitment).

Discussion

The L_∞ of 12.93 cm total length estimated here for *M. macrobrachion* of the Cross River estuary, Nigeria, is slightly lower than the L_{max} of 13.8 cm total length reported for the species in Nigeria (Marioghae 1982, 1987, 1990). This is acceptable since L_∞ is supposed to be a mean value (Ricker 1975, Pauly 1981). However, Marioghae (1982, 1990) asserted that *M. macrobrachion* specimens in catch samples rarely exceed 12.0 cm total length. In the present analysis the largest mid-length was 11.45 cm total length.

The growth performance index (ϕ') of 2.48 estimated here for *M. macrobrachion*, will allow for interspecific comparison of growth performance among *Macrobrachium* and other shrimp species in Nigeria, when estimates for other species become available. The index can also be used to back-calculate L_∞ or K for related shrimp species if either of the parameters is known.

The winter point (WP) of 0.5 indicates that growth of the animal is poorest in the period of June-July of the year. This may be due to the reproductive activity of the species which comes to a peak from July to October (Marioghae 1982), whereby ingested energy may largely be diverted into reproductive material. This same phenomenon may account for the estimated amplitude of seasonal growth oscillation ($C = 0.5$).

Considering the suitability of length-frequency data used for the estimation of growth parameters for the shrimp species, a number of criteria exist for judging this. Firstly, the presence of modal groups should be discernible from the raw data (Wolff 1989), with apparent shifts in the modal length over time. These features could be observed in the length data used in the present analysis. Furthermore, Pauly (1984c) developed a system for assessing length data for growth studies, based on the need to obtain a sufficient number of measurements, well distributed over time. Pauly's rule-of-thumb provides on an increasing scale of 0-5, the total sample size and the number of months over which sample is accumulated. A total sample size of 1500 and above, accumulated over a period of six months and above, is regarded as excellent for such analysis (see also Hoenig *et al.* 1987). The sample used in the present analysis is far in excess of this criterion.

However, simulation studies have shown that growth parameter estimates from ELEFAN I are often biased due to such factors as individual variability in growth parameters, seasonal oscillations in growth, size-dependent selection, variable recruitment period and large length-class intervals used in grouping length data (Isaac 1990). The first of these factors, which is not taken into account in the deterministic VBGF, was found to be the principal source of error in K.

Isaac (1990) also showed that ELEFAN I tended to overestimate L_∞ and underestimate K as the width of the length-class intervals increased. This tendency was not observed in the present study. Instead the 0.5 cm length intervals gave higher L_∞ (13.8 cm) and lower K (1.5 per year) than the 1 cm class intervals which gave 12.93 cm and 1.79 per year, respectively. The decision to use 1 cm class intervals in this study was influenced by the poorer fit of the growth curve to the initial 0.5 cm entries ($R_n = 0.187$) compared to the 1 cm class intervals ($R_n = 0.259$).

The double recruitment peaks per year obtained here conforms to the assertion of Pauly (1982) that the double recruitment pulses per year is nearly a general feature of tropical fish species. Since t_0, the third parameter of the von Bertalanffy growth equation, cannot be estimated from length-frequency data alone (Pauly 1987), the absolute position of the recruitment peaks in terms of month-of-year cannot be calculated. However, the position of the peaks can be inferred approximately by examining the length-frequency data used, where the peaks of the smaller sized shrimps could be noted in December-January and again in May-June.

Both the estimates of total mortality (Z) and fishing mortality (F) obtained here (10.6 and 7.2 per year, respectively) seem rather high. However, Pauly *et al.* (1984) obtained Z values of up to 7.07 per year for *Penaeus duorarum* in Florida, which is a larger species with L_∞ of 17.6 cm total length. Mathews *et al.* (1987) obtained values of Z up to 7.08 per year for penaeid species in Kuwait waters. Also, Sumiono (1988) obtained values of F up to 8.99 per year in some years for *Penaeus merguiensis* in Indonesia.

Nonetheless, the mortality estimates might be biased upward to some extent due to the migration of *M. macrobrachion* to fresh waters during periods of high salinity in the estuary (Marioghae 1982). Such a behaviour in animals is known to affect the representativeness of the length-frequency data obtained from catch samples, which in turn leads to biased fishery parameter estimates (Pauly 1987), by introducing an emigration term into the right-descending arm of the catch curve (Caddy 1987). This could be observed in the length-frequency data analysed here, where specimens of *M. macrobrachion* in the multispecies catch samples were quite scanty during the high salinity months of February, March and April (end of dry season).

The exploitation rate (E) of 0.68 estimated here indicates that the stock of *M. macrobrachion* of the Cross River estuary is probably experiencing excessive fishing pressure. This is based on the assumption that in an optimally exploited stock, natural and fishing mortalities should be equal or $E = F/Z = 0.5$ (Gulland 1971).

The exploitation rate (E_{max}) that gives maximum relative yield-per-recruit, estimated at 0.494 (probability of selection method) and 0.536 (knife-edge recruitment method), approximates the 0.5 level of exploitation of Gulland (1971), but is much smaller than the exploitation rate of 0.68 estimated for the fishery. This suggests that the stock of *M. macrobrachion* is probably being overfished both in terms of yield-per-recruit and biomass-per-recruit.

The analysis of mortality rates, exploitation rate, yield-per-recruit and biomass-per-recruit carried out here all suggest that the artisanal fishery on *M. macrobrachion* of the Cross River estuary is experiencing intensive fishing pressure. To be able to proffer an informed management advice for the fishery, further research will be needed to obtain a time series of annual catch and effort data (to capture variability in CPUE or abundance), and of size structure in the population. Research will also be needed to ascertain the influence of environmental conditions on the recruitment of the shrimp species. The uncertainty in optimal *E* or *F* introduced by this factor should be taken into account in the elaboration of the management advice (Garcia 1988). Caution and flexibility in management is expected to compensate for the uncertainty in optimum effort.

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