Arch. Hydrobiol.	122	2	213–227	Stuttgart, August 1991

Tucurui dam and the populations of the prawn *Macrobrachium amazonicum* in the Lower Tocantins (Pa-Brazil): a four year study

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With 8 figures and 1 table in the text

Abstract

A four year survey of the prawn *Macrobrachium amazonicum* (Heller, 1862) on the Tocantins river studies the short term impact of the Tucurui hydroelectric project on downstream fishery and reservoir populations.

The furthest downstream site below the dam has been the most affected. Before the closure of the dam, the annual prawn catch in Cameta and the flood intensity were directly linked by a linear relation. The prawn production decreased after the closure of the dam from 121 t in 1985 to 60 t in 1986, increased up to 91 t in 1987, but decreased to 62 t in 1988. But the introduction of post-dam data in the linear flood/catch model did not modify the regression slope. The catch variation is partly explained by a stock decrease, and partly by a change in fishing effort. However the seasonal pattern of prawn captures; population size and reproduction intensity have not been affected. Sampling conducted further upriver showed no significant difference in relative abundance, mean size and reproduction characteristics throughout the study period.

Recent reservoir populations displayed a very rapid response to environmental modifications, adopting lacustrine characteristics like size reduction and a female-biased sex ratio. Captures per unit effort increased from 1985 to 1988. Greater abundances were noted in the vicinity of the dam, probably due to an increase of available food.

1. Introduction

There is an extensive literature on the impact of large tropical hydroelectric projects on the aquatic fauna (review in Welcome, 1985). The downstream fish production usually decreases while there is a localized increase of fish abundance, particularly of predatory species, immediately below the dam. Flow rate reduction, higher water temperature and silt deposition occur in the reservoir, affecting adversely the obligate riverine species and cousing a significant increase of predatory and lentic populations (Ferreira, 1984 a and b).

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0003-9136/91/0122-0213 $ 3.75

The freshwater prawn *Macrobrachium amazonicum* (Heller, 1862) occurs in South America throughout the basins of the Orinoco, Amazon and Paraguay rivers (Holthuis, 1952). In the central Amazon, *M. amazonicum* is abundant in the sediment-rich "white" waters of the andean system and in the floodplain lakes. It is scarce in the acid "black" waters and in the small streams draining the highland forest.

M. amazonicum is the only shrimp species taken in traditional fisheries in the Brazilian Amazon States of Amapa and Para (Odinetz Collart, 1987). The prawns are sold dried and salted on local markets and exported to other amazonian States. A preliminary study was conducted to assess the shrimp fishery production in the Lower Tocantins and evaluate the immediate effect of the closure of the dam (Odinetz Collart, 1987).

Numerous laboratory studies have investigated the life history and larval development of *M. amazonicum* (Vargas & Paternina, 1977; Guest, 1979; Romero, 1982; Coelho & Barreto, 1982; Gamba, 1984; Magalhaes, 1985), oxygen consumption (Favareto et al., 1976; Martins, 1977) and tolerance to salinity and temperature (Guest & Durocher, 1979). Little published information is available on the species' life history and ecology in the natural environment (Odinetz Collart, 1987, 1989, in press; Odinetz Collart & Moreira, in press; Moreira & Odinetz Collart, in press).

This paper attemps to evaluate the short-term impact of the Tucurui project on *M. amazonicum* populations by: (1) analysing shrimp fishery data, and (2) comparing the biological parameters of the prawn populations in the two different habitats: a river with a fast current, and a recent large man-made reservoir.

2. Study area and methods

2.1. The Tocantins river

The river Tocantins discharges into the south arm of the Amazon estuary just upstream of Belem (Fig. 1). The Araguaïa and the Tocantins rivers drain the 767 000 km^2 Tocantins basin, joining about 500 km from Belem to form the Lower Tocantins, where Eletronorte built the Tucurui dam. The water flow varies seasonally by a factor of 10 on the Tocantins and a factor of 30 on the Araguaïa. In the south of the basin about 75 % of the annual rainfall is registered in only three months, and the average annual difference in river level at Tucurui between the low waters in September and the high waters in February–March is 10 m. The Araguaïa carries "clear" transparent water (Sioli, 1975) all year round. The Tocantins carries "clear" water during the dry season and "white" water otherwise: the total suspended solids vary from 5 to 250 mg/l and the pH between 6 and 8 (Santos, 1983).

In September 1984, the fourth largest dam in the world (4000 MW in a first stage) was closed in Tucurui, creating a man made lake with an area of 2430 km^2 and an average depth of 15 m. On filling the reservoir, oxygen decreased to 1–2 mg/l in all the lake waters below 1 m depth and the temperature rose to 29 °C without any stratification.

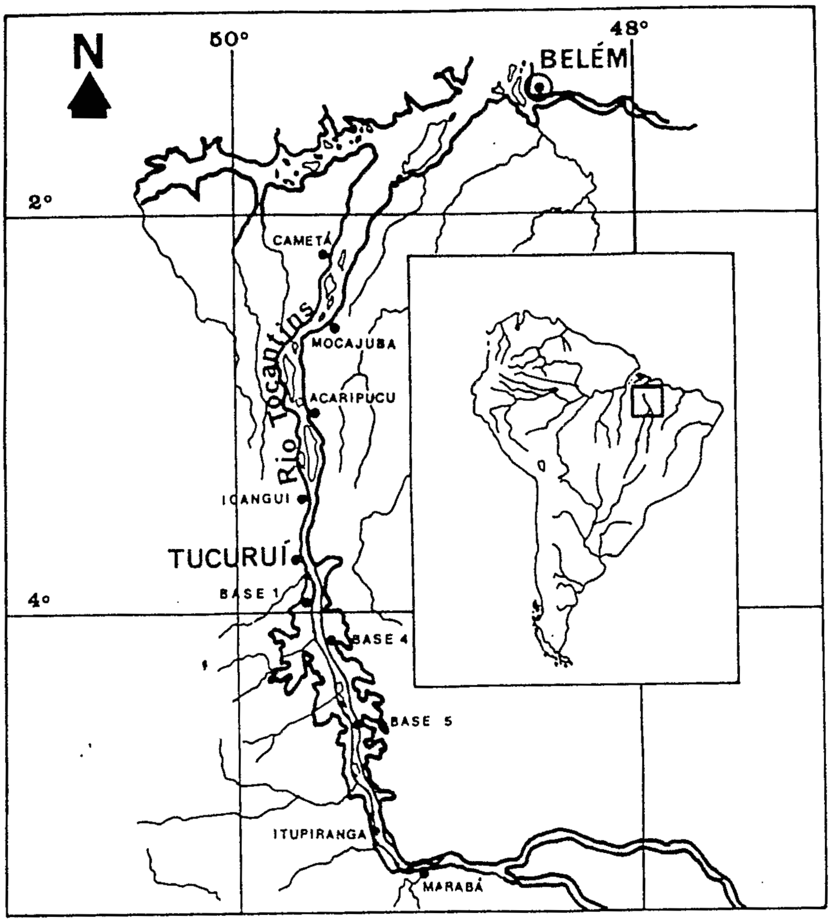

Fig. 1. Map of the study area showing the location of the sampling sites in the Lower Tocantins river and in the Tucurui reservoir.

By March 1985, oxygen increased to 4–4.5 mg/l in the surface water near the dam and to 5–6.5 mg/l at Itupiranga. The pH remained between 6.6 and 7 throughout the water column.

2.2. Sampling sites

Four sampling sites were chosen downstream of the dam. The stations 1–4 will be refered to hereafter as the Lower Tocantins area. Four others (stations 5–8) were located in the reservoir (Fig. 1). Site 1 was established 200 km downstream from Tucurui, in Cameta, where the traditional shrimp fishery accounts for 20 to 30% of the total (fish and prawn) local catch (Odinetz Collart, 1987). The current reverses with the tide and daily fluctuations of water level may reach 4 m during the dry season but the water is always fresh. Site 2 at Acaripucu is 120 km from the dam where the current still reverses with the tide; site 3 at Icangui is 70 km upstream where the current does not reverse but the water level oscillates about one meter with the tide. At site 4, the shrimps were collected in front of the Tucurui village, a few km below the dam spillway. In the reservoir, Eletronorte Base 1 and Base 4 (St5 and St6) are situated in an area which had over 80 km of rapids before the construction of the dam. Base 5 (St7) and Itupiranga (St8) are located on an ancient flood plain. The shrimps collected in the Lower Tocantins will be referred to as the river population and these above the dam, as the reservoir population.

2.3. Sampling methods

Pre-dam fishery statistics from Cameta market have been furnished by the Brasilian Fishery Development Service (SUDEPE: Superintendência de Desenvolvimento da Pesca) for the 1976–1980 period: monthly fish and prawn catches have been noted, but no fishing effort data. In 1981, the SUDEPE stopped its survey and a local observer has been contracted by INPA in Cameta: fishing site, fishing gear, fishing effort (number of fishermen, number of each gear, fishing duration), and capture weight for each species were recorded for every boat trip. No statistics were available in 1982–84, during the construction of the dam: fishing activities went on but the INPA/ELETRONORTE contract for the ecological survey has been suspended.

Post-dam fishery statistics were available from September 1984 to the end of 1988. Due to the unequal number of registered days, monthly catches were extrapolated from the available records to the total number of days for every month. The difference between the shrimp production reported in 1987 by Odinetz Collart (111 t in 1985 and 49 t in 1986) and the catches cited in the present paper are due to different computation methods, taking into account only the statistics of the recorded days in the first case, and the total estimated production in the second case.

Prawn samples have been collected from 1985 to 1988 to estimate the dam effect on reproduction and population mean size:

- at St1, a 500 g shrimp sample was bought at the local market, every month or twice a month, from January 85 to July 86, and from March to August 88;
- at sites 2–4, six samplings were conducted in 85, four in 86, one in 87 and three in 88;
- in the reservoir, the shrimps has suffered mass mortality in December 1984 during the filling of the dam but the population had reestablished after a few months, making sampling possible from September 85 onwards. A total of ten samplings were conducted until November 88 at sites 5–8.

All collections were carried out with traditional shrimp traps called "matapi" in the State of Para (Fig. 2). The trap is made of narrow sticks of "juba" palm bark (*Astrocarium* and *Batarix* spp.) or "jupaty" (*Raphia vinifer*), tied together with a liana "cipo titica", to form a cylindrical frame closed at both ends by a funnel. One funnel can be removed to set the bait and withdraw the catch. The traditional shrimp bait, dried powdered fruits of "babaçu" palm tree (*Orbinya speciosa*), was used. At each site, five shrimp traps were set at dusk along the river bank, 50 cm below the water surface, attached by a rope. The traps were retrieved next day at dawn. The shrimps of a particular site were pooled and preserved in 70 % ethylalcohol.

Every shrimp (from St 1–8) was counted, sexed, measured, and ovigerous females noted. Carapaca length (CL mm) was measured from the posteriormost margin of the orbit to the posterior edge of the carapace.

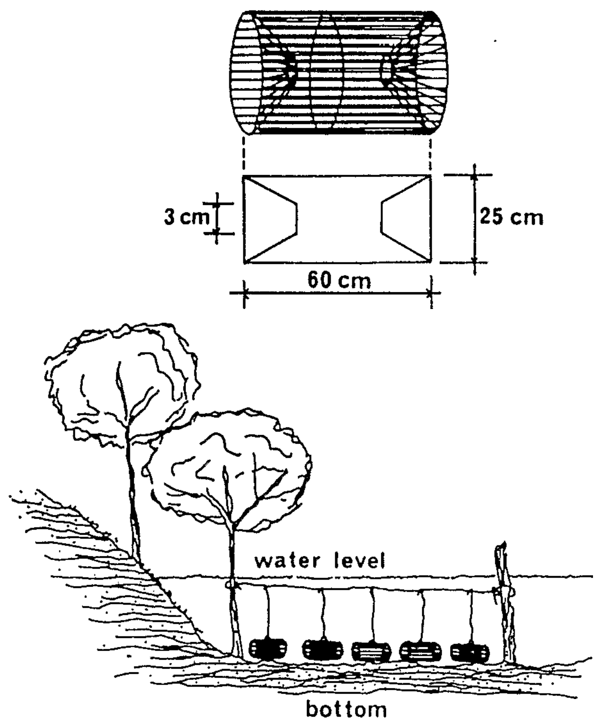

Fig. 2. Traditional prawn trap, the "matapi" used in the Tocantins river, Parà, Brazil.

3. Results

3.1. The shrimp fishery

The shrimp production in Cameta, estimated from the fishery statistics, decreased significantly after the closure of the dam. In 1981, the total catch was 179 t. It decreased from 121 t in 1985 to 60 t in 1986, increased up to 91 t in 1987, and decreased to 62 t in 1988. Before 1984, the year to year variations in stock abundance were directly linked to the Tocantins hydrological regime (Fig. 3). The relationship between the total annual catch in Cameta and the maximum water level measured the same year in Tucurui during the flood was =

$$\text{catch}_{\text{year i}}\,(\text{t}) = 28.63 \text{ water level}_{\text{year i}}\,(\text{m}) - 142.97 \quad (r = 0.976;\ P < 0.01)$$

This linear relation does not include the 1980 prawn catch: that year, fishery statistics were differently computed by the Fishery Development Service, following the Belem Fishing Service who published only an approximate annual production without detailing the monthly catches. The introduction of the 1980 "supposed" catch would render insignificant the correlation between

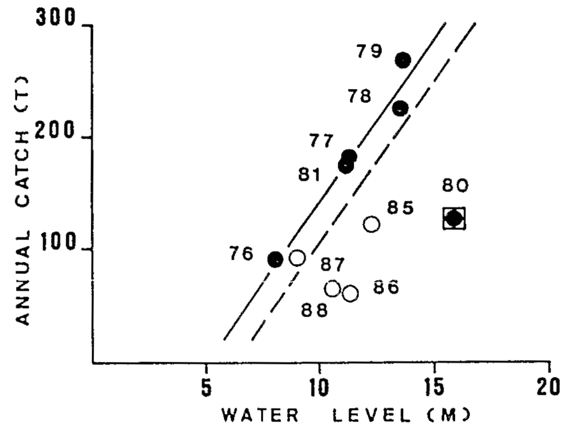

Fig. 3. Best-fit regression lines for the relationship between the annual prawn catch in Cameta (t) and the Tocantins flood intensity (m), considering the pre-dam 1976–1981 data (——) and all the 1976–1988 data (· - - - ·).

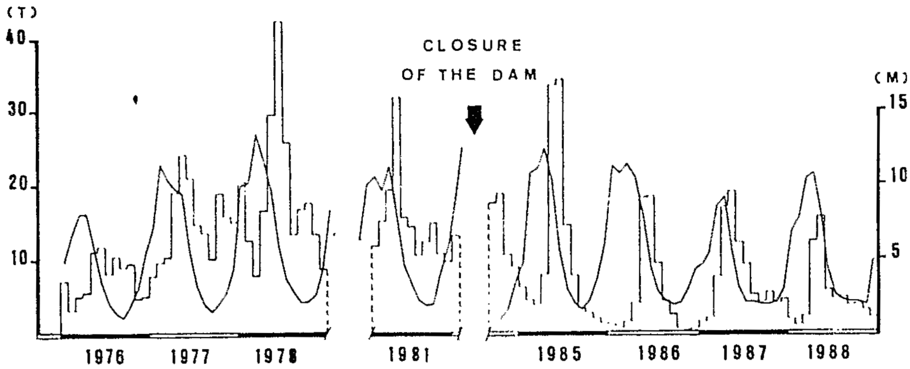

Fig. 4. *M. amazonicum*. Seasonal variations from 1976 to 1988 of the Tocantins water level (mean monthly value measured in Tucurui) and the prawn catch commercialized in Cameta (tons).

prawn production and flood water level ($r = 0.412$; $N = 6$; $P > 0.05$). Correlation of catch with flooding in preceding years (year i-1; year i-2) was not significant, neither was a combination of flood of the year (year i) with the preceding years.

The introduction of the post-dam data did not modify the slope of the linear regression between catch and flood water level, even if the probability level of the correlation coefficient was lower:

$$\text{catch}_{\text{year i}}(\text{t}) = 28.59\ \text{water level}_{\text{year i}}(\text{m}) - 180.05 \quad (r = 0.711;\ P = 0.025)$$

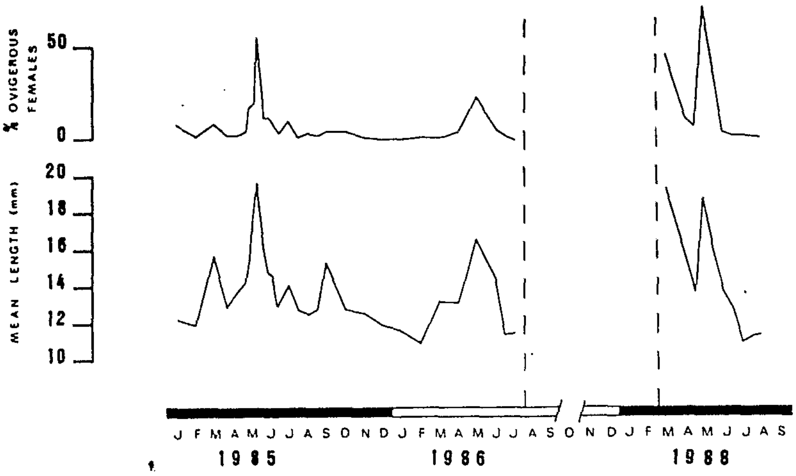

Fig. 5. *M. amazonicum.* Seasonal variations of mean carapace length (mm) and percentage of ovigerous females of the Cameta prawn population.

However, a separate analysis of the post-dam 1985–1988 data did not show any significant relation between prawn catch and flood (r = 0.305).

The hydroelectric project has affected the catch, but it has not modified the seasonal pattern of the prawn captures (Fig. 4): highest catches were noted in April–May or May–June during the falling waters, just like before the closing of the dam. The reproductive peak of the population was found in May throughout the study period; the prawn mean size showed the same seasonal pattern as the percentage of ovigerous females, with maximum values in May. Both parameters, the population mean size and the percentage of ovigerous females, showed the same interannual variations during the study period (Fig. 5) with a decrease in 1986, and an increase in 1988 (Spearman r = 0.83; df = 38; $P < 0.01$).

3.2. The river population

Samplings in the Lower Tocantins at St2–St4 showed no significant difference in catch per unit effort between 1985 and 1986, considering the January, March and November collections (Wilcoxon matched-pairs signed test; T = 15.5; $P > 0.05$), neither between 1986 and 1988 considering the March, June and November collections (T = 19) (Fig. 6).

There was no significant difference in mean population size between 1985 and 1986 (T = 15), nor between 1986 and 1988 (T = 19), as well as in the percentage of ovigerous females (T = 10 and T = 11 respectively). Comparison of the four November samples from St2–4 confirmed the absence of significant

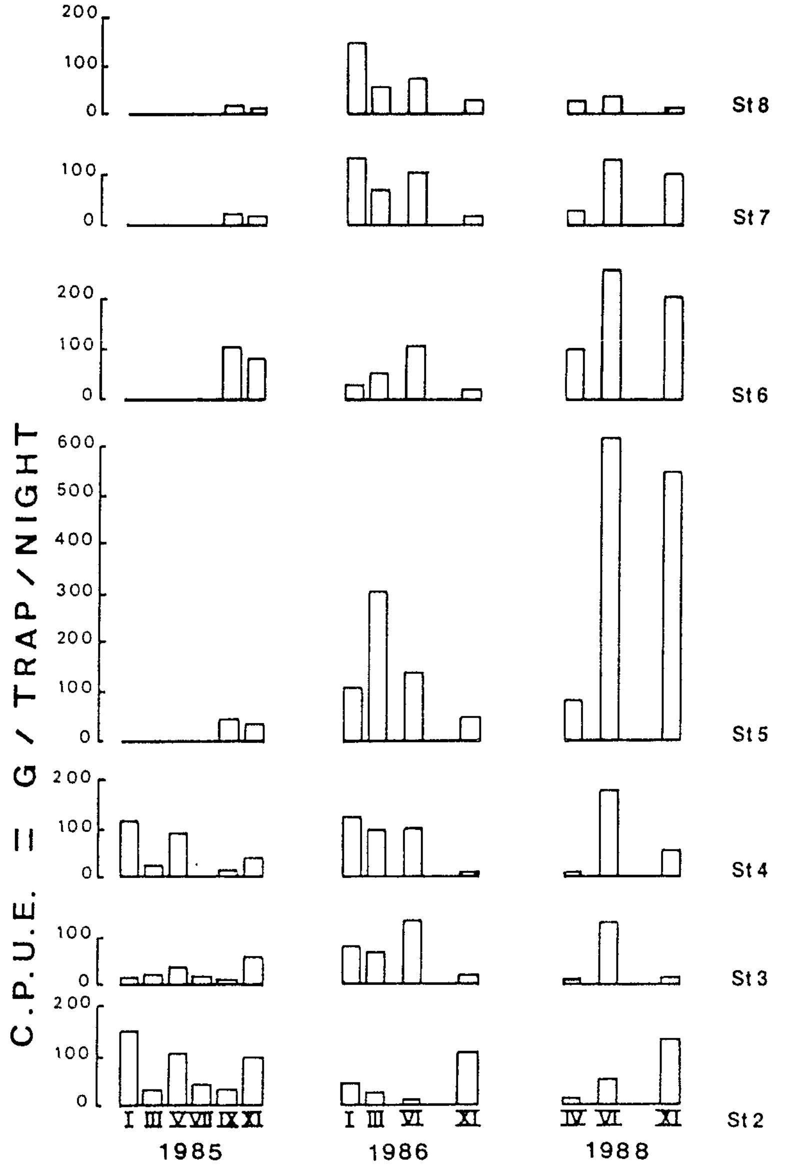

Fig. 6. *M. amazonicum*. Monthly CPUE of prawn populations (g/trap/night) sampled downstream of the dam (St2–St4) and in the reservoir (St5–St8), from 1985 to 1988.

variation from 1985 to 1988 of: (1) the catch per unit effort (Friedmann non-parametric two-way analysis of variance: X2 = 1.8; P = 0.727), (2) the mean population size (X2 = 3.8; P = 0.342) and (3) the percentage of ovigerous females (X2 = 5.8; P = 0.148).

3.3. The reservoir population

During the four year survey, significantly higher abundances were noted in the reservoir, at St5 and St6 than at St7 and St8 (X2 = 7.5; P = 0.05; Fig. 6). Females were more abundant closer to the dam (a mean of 93.3 % at St5, and 90 % at St6) than further up the lake (85.1 % at St7 and 68.5 % at St8) (X2 = 12.12; P < 0.01).

Comparing the four November samples from St 5–7, a significant increase of the catch per unit effort was noted from 1985 to 1988 (X2 = 8.2; P = 0.017). The abundances observed at St8, further up the lake, remained relatively constant (Fig. 6). Comparison of the 1986 samples from St 5–7 to the 1988 ones,

Table 1. *M. amazonicum*. Mean carapace length (mm) and sex-ratio (percentage of females) of the prawn populations sampled in the Tucurui reservoir (St 5 – St 8) from 1985 to 1988.

	Station 5	Station 6	Station 7	Station 8
09/85				
Cl mm	11.03 ± 1.28	12.3 ± 1.62	14.09 ± 2.52	11.75 ± 1.62
% fem.	92.38	84.10	74.19	47.91
11/85				
Cl mm	10.37 ± 1.14	8.25 ± 1.86	9.65 ± 2.2	11.41 ± 2.45
% fem.	98.43	79.49	84.80	52.94
01/86				
Cl mm	11.17 ± 1.24	10.43 ± 1.04	10.75 ± 1.73	9.48 ± 1.69
% fem.	93.15	95.14	90.57	67.30
03/86				
Cl mm	11.91 ± 1.66	12.45 ± 1.41	13.4 ± 1.91	12.84 ± 1.67
% fem.	94.38	88.83	93.92	75.55
06/86				
Cl mm	13.25 ± 1.77	12.92 ± 2.12	12.84 ± 2.34	13.27 ± 1.81
% fem.	89.06	84.64	87.76	85.40
11/86				
Cl mm	10.53 ± 1.62	10.15 ± 1.25	10.06 ± 1.77	12.25 ± 1.86
% fem.	81.66	88.52	83.14	89.02
11/87				
Cl mm	8.63 ± 1.5	9.0 ± 1.09	8.77 ± 1.08	
% fem.	100.0	93.41	66.51	
04/88				
Cl mm	13.67 ± 1.23	13.21 ± 1.89	12.56 ± 1.82	12.75 ± 1.84
% fem.	93.44	91.60	87.18	78.40
06/88				
Cl mm	10.71 ± 1.80	10.88 ± 1.89	10.36 ± 1.47	14.16 ± 2.12
% fem.	97.09	94.09	98.69	86.36
11/88				
Cl mm	9.22 ± 1.09	8.96 ± 1.19	9.35 ± 1.3	11.87 ± 1.74
% fem.	93.43	95.00	89.83	43.75

considering the March, June and November collections, showed a significant decrease of the mean shrimp population size (Wilcoxon matched-pairs signed test: $T = 7$; $0.027 < P < 0.048$) as well as an increase of the female relative abundance ($T = 6$; $P = 0.027$; Table 1).

4. Discussion

4.1. Impact on the river population

In the Tocantins river, the shrimp fishery statistics showed a strong capture decrease in 1986, one year after the closure of the dam, while samplings conducted more upstream (St2 – St4) displayed no significant difference in relative abundance from 1985 to 1988. The same impact had been reported by MERONA et al. (1987) on the ichthyofauna: "...The most downstream area suffered rapidly strong modifications of water quality... The physico chemical transformations due to accelerated eutrophication induced the runaway of numerous fish populations, that is illustrated by a general density decrease and an extreme variability of community richness and diversity, as well as trophic structure."

The relation between fishery production and flood intensity is a well known phenomenon that has been well documented by WELCOMME (1985). Because fisheries in most tropical rivers are based on fish that are one or two years old, the best correlation appears between fish catch in the year i and flood regime in preceding years i-1 and i-2. But as *M. amazonicum* life cycle hardly reaches two years, and the major reproductive season in the Tocantins (May) involves six months old females (recruitment in November), it might be expected that the catch is affected by the flood regime of the same year. The flood intensity affects survival and growth: (1) the explosive expansion of the floating meadows during rising waters reduces intraspecific competition by increasing nursery habitats, and (2) the deposition of suspended matter during rising flood increases productivity in the floodplain lake.

The catch depends not only on the stock abundance but also on the fishing effort. The modification of the relation between prawn production and flood after the closure of the dam, suggests that the catch decrease in Cameta may be partly related to a real modification of the stock abundance in the environment, and partly to a change in prawn fishing effort. The simultaneous decrease in 1986 of prawn commercial catch, population mean sizes and percentage of ovigerous females, suggests that the dam closure affected the prawn reproduction in the previous year, and consequently the stock abundance. But, on the other hand, the global fishing strategy in the Lower Tocantins changed from 1985 to 1987 (ODINETZ COLLART, 1987). After the closure of the dam, most of the fishermen gave up with the scarce local fish around Cameta (4726 boat trips in 1985; 1893 in 1986 and 831 in 1987). They left the Lower To-

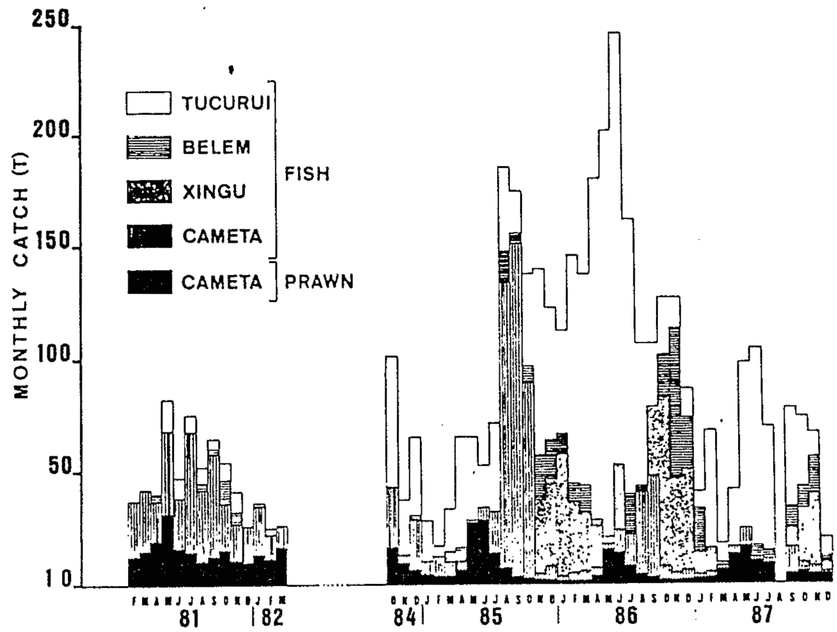

Fig. 7. Prawn and fish production commercialized in Cameta from 1981 to 1986: catches and fishing areas.

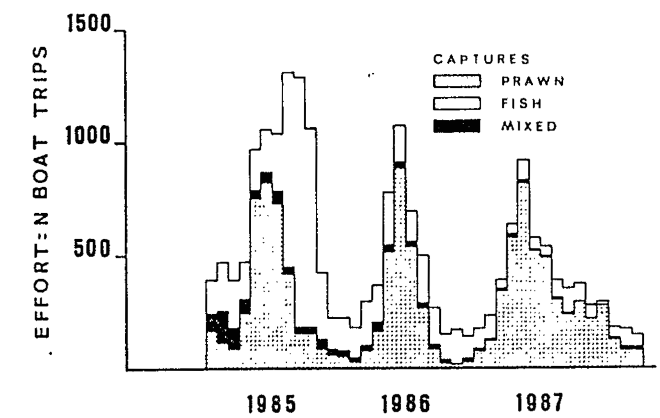

Fig. 8. Fishing effort variations: seasonal changes in boat trips number and captures composition on the Cameta market in 1985–1987.

cantins, to go fishing with large boats upstream in Tucurui, following an increased amount of fish accumulated in the vicinity of the dam (Fig. 7). The prawn fishing effort in Cameta decreased from 3803 boat trips in 1985 to 2771 in 1986, but increased to 4138 boat trips in 1987 (Fig. 8).

The captures per unit effort have been affected by the closure of the dam: the maximum value during high fishing season decreased from 1000 g/trap/night in 1981 to 370 g in 1985. Afterwards, it remained relatively constant between 1986 and 1987 (250 g/trap/night), indicating that the prawn production increase in 1987 was related to a higher fishing effort. The absence of fishing effort records in 1988 does not allow further discussion of prawn catch decrease.

The environmental disturbances of the river Tocantins have not affected the prawn life cycle, although the stock has decreased. The seasonal variation pattern of abundance, population mean size and reproduction did not change from 1985 to 1988: the highest catches, sizes and percentage of ovigerous females were obtained during the normal fishery high season, during the time of falling waters. All these biological parameters showed a rapid recovery two years after the 1986 population decrease.

4.2. *Impact on the reservoir population*

Negative impacts of tropical hydroelectric projects on downstream fish populations are generally balanced by a greater production in the reservoir (JUNK & NUNES DE MELO, 1987). The same phenomenon was observed with *M. amazonicum*. Mass mortality in December 1984, during the filling of the dam, was followed by recovery within a few months to a commercially interesting abundance two years later.

The shrimp accumulation just above the dam may be related to an increased rate of silt deposition as well as changes in quantity and type of available food. The same phenomenon has been described in the amazonian Curua-Una reservoir (JUNK et al., 1981) where the lowest zooplankton "standing-stock" was measured at most distant sites and the highest in the vicinity of the dam. This change in available food along the reservoir, related to the accumulation of sediments and organic matter, also affects higher trophic levels: predatory and carnivorous fish became much more abundant near the dam (FERREIRA, 1984 a). Moreover, the same species may show different feeding habits along the reservoir: in Curua-Una, the usually herbivorous *Hemiodopsis* sp. and *Hemiodus maculatus* prey on crustaceans and insects near the dam as does *Serrasalmus rhombeus*, mainly piscivorous elsewhere (FERREIRA, 1984 b). Changes in available food may also affect the shrimp growth: *M. amazonicum* is omnivorous, feeding on fungus, insects, vegetal tissue, small crustaceans and detritic organic matter.

The reduction of flow rate rate and higher mean water temperature in reservoirs affect the rheophilic community: obligate riverine species are replaced by lentic ones. *M. amazonicum* is a widespread amazonian species with very variable biological characteristics related to the diversity of colonized habitats (ODINETZ COLLART, in press; ODINETZ COLLART & MOREIRA, in press). Strongly female biased sex ratio (75 to 90 %) occur in lake or floodplain populations in Colombia (VARGAS & PATTERNINA, 1977) and the Central Amazon in comparison with river ones (ODINETZ COLLART, 1987; ODINETZ COLLART & MOREIRA, in press).

M. amazonicum is very tolerant to dissolved oxygen decrease (FAVARETO et al., 1976) or water temperature elevation (ROMERO, 1982). It has been introduced in the reservoirs of the northeast of Brazil as live fish food but has become one of the most important constituents of commercial catches (BOSCHI, 1974; PINTO, 1977). In Tucurui, *M. amazonicum* has not been affected so much by the hydroelectric project. The recent reservoir population has showed a very rapid response to the environmental change, adopting lacustrine characteristics like size reduction and female biased sex-ratio. The success of *M. amazonicum* in colonizing its wide geographical range in South America results from this plasticity of rapid ecological adaptations under different environments.

Acknowledgements

This research has been conducted at the Instituto Nacional de Pesquisas da Amazônia (INPA) within the ORSTOM/INPA/CNPq convention and has been partly financed by ELTRONORTE. The author would like to thank S. GARCIA, L. LE RESTE, W. MAGNUSSON and C. POWELL for valuable suggestions. She is grateful to CARLOS PALACIO for technical help and drawings. Thanks are also due to the INPA Tocantins Fish Study group for their help in field and to Bosco FERREIRA RAMOS for laboratory work.

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