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FISHERY PARAMETERS AND POPULATION DYNAMICS OF SILVER CROAKER ON THE XINGU RIVER, BRAZILIAN AMAZON

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ABSTRACT

The study analyzed the fishery parameters and population dynamics of the silver croaker, *Plagioscion squamosissimus*, and its exploitation status, before the damming of the Xingu River by the Belo Monte hydroelectric dam. Silver croaker was caught throughout the year, with a total production of 239 tons. Estimated Catch per Unit Effort (CPUE) was 14.16 kg.fisher^{-1}.day^{-1}. The mean price paid to the fishers for a kilogram of silver croaker ranged from US$1.89 to US$3.28. Mean longevity estimated was 7.68 years. The total mortality (Z) was calculated at approximately 1.44 year^{-1}, natural mortality (M) was 0.76 year^{-1}, fishery mortality (F) was 0.68 year^{-1}, and the current exploitation rate (E) was 0.47 year^{-1}. The study highlights the importance of *P. squamosissimus* as a fishery resource in the Xingu region and provides important insights for the development of future fishery management strategies and conservation of the species stocks.

Key words: hydropower; fish fauna; fishing resources; Amazonian; UHE Belo Monte.

PARÂMETROS PESQUEIROS E DINÂMICA POPULACIONAL DA PESCADA BRANCA NO RIO XINGU, PARÁ, BRASIL

RESUMO

Este estudo analisa os parâmetros pesqueiros e dinâmica populacional da pescada branca, *Plagioscion squamosissimus*, e seu status de explotação, antes do barramento do rio Xingu pela hidrelétrica de Belo Monte. A pescada branca foi capturada durante todo o ano, com uma produção total de 239 toneladas. A captura por Unidade de Esforço (CPUE) foi de 14,16 kg.pescador^{-1}.dia^{-1}. O preço médio pago aos pescadores por um quilo de pescada branca variou entre R$ 4,16e R$ 7,21. A longevidade média estimada para a espécie foi de 7,68 anos. A mortalidade total (Z) foi calculada em aproximadamente 1,44 ano^{-1}, a mortalidade natural (M) foi de 0,76 ano^{-1}, a mortalidade da pesca (F) foi de 0,68 ano^{-1} e a taxa de exploração atual (E) foi de 0,47 ano^{-1}. O estudo destaca a importância de *P. squamosissimus* como recurso pesqueiro na região do Xingu, e fornece informações importantes para o desenvolvimento de futuras estratégias de manejo pesqueiro e conservação dos estoques de espécies.

Palavras-chave: energia hidroelétrica; peixes; recursos pesqueiros; Amazônia; UHE Belo Monte.

INTRODUCTION

Traditionally, Amazonian fisheries are multispecific, and caught an extensive range of fish species (Bayley and Petrere, 1989), although the activity is relatively selective, with most effort being focused on few fish species (Barthem and Fabré, 2004; Hallwass and Silvano 2016). The rivers of the Amazon basin can be divided into three types, based on the physical-chemical properties of their water – whitewater, blackwater, and clearwater (Sioli, 1968). While considered to be oligotrophic, the clearwater rivers have an enormous potential for the generation of hydroelectric energy, and are subject to extensive environmental impacts, as observed in the Tucuruí and Estreito hydroelectric plants, in the Tocantins basin (Fearnside, 2001; Hallwass et al., 2013), Belo Monte on the Xingu River (Fearnside, 2006) and the installations planned for the Tapajós River (Fearnside, 2015). While less productive than whitewater rivers, clearwater systems support important local fisheries, which are fundamental to the survival of riverside populations. The silver croaker is widely targeted on the region's principal clearwater rivers, the Tocantins (Cetra and Petrere Junior, 2001) and the Xingu (Isaac et al., 2015).

Records of fishery catches provide a primary source of data for the study of fish ecology and the status of stocks as well as information on the composition, size, and numbers of fish harvested, and fluctuations related to alterations in the environment (Barthem and Fabre, 2004). In broad terms, fishers exploit natural systems like predatory piscivores, and the analysis of fishery dynamics provides essential insights into the natural fluctuations of fishery resources and the relative abundance of the different stocks. The understanding of the dynamics of fishery parameters also permits the discussion of the factors that account for the behavior of fishers, and their selection of target species (Batista et al., 2012).

On the Xingu, the construction of the Belo Monte Hydroelectric power station (UHE Belo Monte), is likely to have a significant impact on the fish fauna of all the environments affected. In particular, *Plagioscion squamosissimus* is one of the five species most targeted by local fisheries (Isaac et al., 2015). It has been predicted that the change from a lotic environment in the region of the reservoir to a lentic one may have a positive impact on the abundance of the species, at least during the initial stages of the damming of the river. This positive impact is expected because the species is not migratory and is known to be highly flexible in ecological and trophic terms (Hahn et al., 1997, 1999; Stefani and Rocha, 2009), contributing to its capacity to adapt to impacted environments (Lowe-Mcconnell, 1999). On the other hand, the popularity of the species in local markets, and the overall increase in demand for fishery products resulting from the increase in the local population, associated with the installation of the hydroelectric plant, may lead to an increase in fishery pressure, which may ultimately result in the overexploitation of *P. squamosissimus* stocks (Eletrobras, 2008; Isaac et al., 2015). Overall, then, it will be essential to understanding whether or not these two processes will cancel one another out, over the long term, thus guaranteeing the sustainability of the region's fisheries.

The South American silver croaker, *Plagioscion squamosissimus*, Heckel, 1840, (Perciformes, Sciaenidae) is one of the principal targets of extractive freshwater fisheries in the region, providing 5% of total catches (Brasil, 2011). *P. squamosissimus* is a benthopelagic species initially limited to the Río Orinoco and Río Amazonas basins and rivers of the Guianas (Casatti, 2005), although it has been introduced into areas outside its natural range, being found in many South American reservoirs. In the Amazon basin, the species is found in lakes and along river margins. The adults may exceed 6 kg, with a total length of 70 cm (Silva, 1981).

The juveniles of the smaller size classes feed on Diptera larvae (Chaoboridae and Chironomidae) and other aquatic insects (immature forms) (Stefani and Rocha, 2009), while the adults are predominantly piscivorous, characterizing a wide spectrum of food items in the young and a more specialized, piscivorous diet in the adults. The species has external fecundation and piecemeal spawning, reproducing throughout the year, but most intensively during the flood period (Soares et al., 2008). *P. squamosissimus* is considered to be a sedentary species, given that no systematic trophic or reproductive migrations have been observed (Granado-Lorencio et al., 2005).

Any evaluation of the magnitude of the impacts of a hydroelectric project on the local fish fauna will depend fundamentally on previous knowledge of the biology and population dynamics of the species before the effects. Data from the preceding period are essential, for example, to assess whether the size of a population has been altered, and to what extent fisheries have affected the density of stocks and the viability of fisheries following the modifications of the aquatic environment (Agostinho et al., 1997). Population parameters of *P. squamosissimus* have been recorded at the Barra Bonita reservoir in the Brazilian state of São Paulo (Braga, 1998; Castro, 1999), at other reservoirs in the state of Paraná (Gubiani et al., 2009), and at the Tucuruí reservoir, in the Tocantins-Araguaia basin (Brambilla et al., 2015). Studies in natural environments have included the Orinoco and Apure rivers in Venezuela (González, 2005a, 2005b; Perez-Lozano and Aniello, 2013), and whitewater rivers in the Brazilian Amazon basin (Worthmann, 1980, 1987; Ruffino and Isaac 1995; Cella-Ribeiro et al., 2015; Lima et al., 2017). However, no data are available on the stocks or population dynamics of the silver croaker in the Xingu River, before the installation of the Belo Monte hydroelectric plant.

Therefore, the fishing focus on a small group of target species, combined with the major environmental impacts currently affecting the Amazon region, such as the widespread deforestation, and the construction of hydroelectric reservoirs, are likely to have profound implications for the equilibrium of its fishery stocks. However, few systematic data are available on the populations of the principal target species, given the lack of continuous fishery monitoring or studies on the biology of the fish species. Data on population dynamics and fishery parameters are essential for the development of effective management practices for the maintenance of fishery stocks (Schaefer, 1954; Mace, 2001; Hilborn, 2007). Given this, the present study evaluated the population dynamics and fishery parameter of *P. squamosissimus*, as well as the exploitation status of its stocks on the Xingu River in the period before the damming of the Belo Monte reservoir. The findings will be used to discuss possible future scenarios for the species related to the potential impacts and the novel environmental conditions created by the damming of the river.

MATERIAL AND METHODS

Study area

The Xingu River is more than 2.300 km long, and its principal tributary is the Iriri River, followed by the Bacajá (Figure 1). The Xingu discharges into the Amazon River in the Brazilian state of Pará and has a basin of more than 500.000 km^2. The part of this basin located in Pará covers 24.5% of the total area of the state (Sepaq, 2008). The fluvial regime of the middle and lower Xingu is characterized by a flood period between December and February, high water in March and April, the receding period between May and June, and low water between August and November (Eletrobras, 2011).

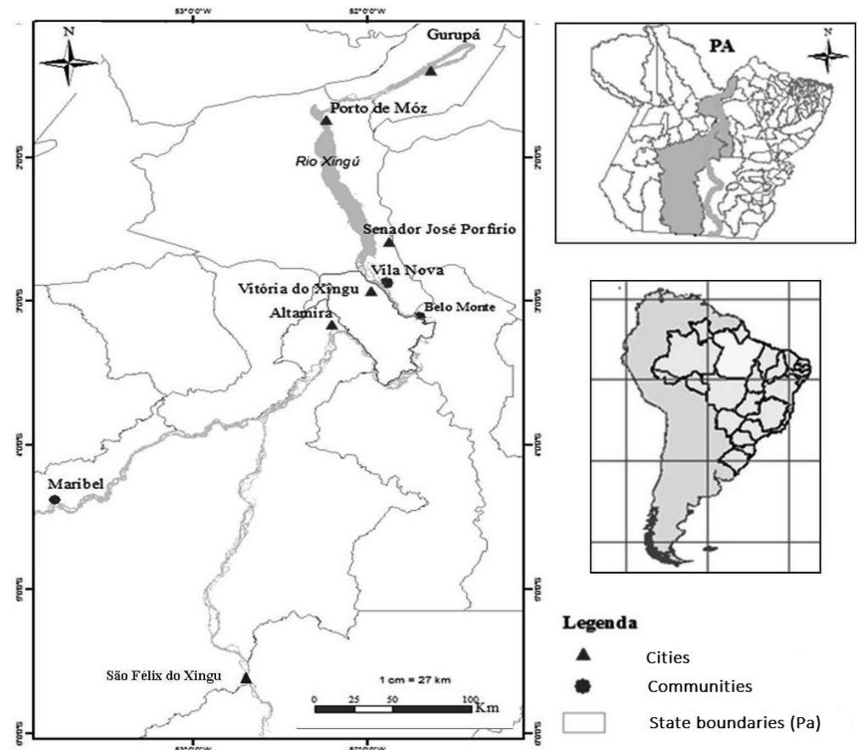

Figure 1. The river sectors and localities at which the fishery catches were monitored on the Xingu River (State of Pará, Brazil) from September 2012 to August 2014.

The Xingu River is distinct from most other tributaries of the Amazon, due to its restricted floodplain and abundance of islands. The topological diversity found along the Xingu River contributes to its unique configuration, creating distinct environments, such as anastomosed channels, rapids, cascades, and waterfalls. In addition to the existence of fluvial plains, which are wider or narrower, depending on the slope and velocity of the river, as well as the features associated with the flood period, when the riparian forests are inundated, forming "igapós" or blackwater swamps (Eletrobras, 2008). Cyclical fluctuations in the level of the river and the backwaters found along its margins are related to the seasonal variation in precipitation and have a profound impact on the behavior of many species, in particular, fish. This variation also determines the spatiotemporal dynamics of the local fisheries (Isaac et al., 2015).

Data collection

The data were collected at 21 fishing ports on the middle and lower Xingu River, arranged in nine localities (Figure 1). All the catches were recorded daily (Monday through Saturday) at these ports between September 2012 to August 2014, by trained workers. During this period, a total of 7688 fishing trips were monitored.

During the landing of the catches, the data collectors interviewed the fishers or owners of all the boats that arrived to land their catches. During these interviews, information was obtained on the total production per species, the type of vessel and fishing technique used, the period, fishing ground and the type of environment, and the mean price of the catch.

Data on the total length (TL) of the *P. squamosissimus* specimens were obtained through the random selection of individual during the landing of the catches at the ports of Altamira, Vila Nova, Vitória do Xingu, Belo Monte, and Senador José Porfirio, with a total of 7776 specimens being measured. Data on the discharge of the Xingu River, measured at the town of Altamira, during the study period, were obtained from the records compiled by Norte Energia, S.A.

Data analysis

Fisheries

The descriptive statistics of the catches included: total production, fishery effort (number of fishers and number of days fishing), the type of vessel, the mean price of the first sell of the product, total income, and the mean CPUE (Catch Per Unit Effort), that is, productivity, per month, year or season. To analyses the mean price and total income we did the currency conversion from Brazilian Real (R$) to American Dollar ($), using the dollar quotation to the studied period, thereby $1,00 equivalent R$ 2,20.

The fishery productivity was evaluated based on estimates of the CPUE 2, calculated using Petrere Junior et al. (2010) equation.

$$CPUE_2 = \frac{\sum \text{ Captura total (Kg)}}{\sum (n° \text{ de pescadores x } n° \text{ dias de pesca})} \quad (1)$$

To calculate the CPUE, the data from the three principal kinds of "fishery production systems". The "fishery production system" is the combination of the type of vessel and fishing equipment, which was used here to standardize the fishing effort and the effect of selectivity (Gulland, 1956). The systems of fishery production considered were the canoes with long-tailed outboards and nets, canoes with longtailed outboards and lines, and canoes with long-tailed outboards and nets and lines, which together, represent 74% of the total croaker catch.

For the analysis, the catches in which the silver croaker contributed more than 40% of the total of catch, which assumes a degree of selectivity (even though the fisheries are essentially multi-specific), were considered (Cruz et al., 2017). The nonparametric Kruskal Wallis test was used to evaluate the variation in productivity according to the fishery system and season, with a 5% significance level and multiple comparison tests.

Population Dynamics

For analysis, the measurements of the specimens were grouped in monthly frequency classes, with a 3 cm total length interval. The mean, minimum, and maximum lengths were also calculated, with the respective standard deviations. The analyses of population dynamics were run in FISAT II, using the Electronic Length-Frequency Analysis (ELEFAN I) approach (Pauly and David, 1981), which is based on the modal shift of the temporal sequences of the length data to adjust them to von Bertalanffy's somatic growth model.

$$Lt = L\infty \left[1 - e^{-K(t-t_0)} \right] \quad (2)$$

Longevity was calculated using the formula of Taylor (1960). The total mortality rate (Z) was calculated in FISAT II, based on the linearized capture curve, converted to body lengths (Pauly, 1980). Pauly, (1980) empirical equation was used to calculate the natural mortality rate (M), where the mean annual temperature of the surface water was considered to be 28 °C.

$$Log(M) = -0{,}0066 - 0{,}279\ Log(L\infty) + 0{,}6543 Log(K) + 0{,}463 Log(T°) \quad (3)$$

The natural (M) and total (Z) mortality rates were used to calculate the fishery mortality (F = Z-M), and the exploitation rate (E = F/Z), described by Baranov (1918 apud Sparre and Venema, 1997). The model of the yield per recruit of Beverton and Holt (1957) was used here, assuming a "knife edge" type of selectivity, with the parameters being estimated using a macro programmed in Excel. The parameters L∞, K, M and F, obtained above, were used to develop this model, with the value of W∞ being calculated based on the weight x length ratio estimated for the species by Giarrizzo et al. (2015). This approach determines the exploitation rate, obtained for the maximum yield (E_{max}), with E_{50} being the rate at which the spawning biomass would be 50% of the virgin biomass, while $E_{0.1}$ represents the optimal exploitation rate when the slope of the model in 10% of the initial slope.

RESULTS

Total catches and fishery effort

During the study period, the silver croaker catches represented as much as 20% of the total fishery catch landed on the Xingu River. A total catch of 239 (t) of croaker was recorded during the 7688 trips monitored during the two years of the study period (2012-2014), with the largest monthly catch being obtained in March 2013 (19.8 t), followed by April and May of the same year. These months correspond to the high-water period. The smallest catch (3.2 t) was recorded in December 2012, followed by November and December 2013, which correspond to the beginning of the flood period (Figure 2).

The total fishing effort over the study period consisted of 19,892 days of fishing, involving and 10,737 fishers. Effort peaked in March 2013, with 887 fishers, and 1413 days of fishing (Figure 2), while the lower effort was recorded in December 2013, with only 167 fishers and 322 days. The amount of the total catches landed was highly correlated with fishery effort (Figure 2), regarding both the number de fishers ($r^2 = 0.87$) and the days spent fishing ($r^2 = 0.81$). The mean (± SD) catch landed was 30±40 kg per fishing trip. The average trip lasted 2.64±1.9 days, with crews of between one and nine fishers (Table 1).

Characteristics of the fishery fleet

The fishery fleet that targets silver croaker on the Xingu River is made up of approximately 1005 vessels, which can be divided into three types: (i) canoes with paddles, (ii) canoes with long-tailed outboards, and (iii) motorboats. A total of 68 wooden canoes with paddles were registered during the study. These were the smallest vessels, with a mean length of 4.0 m (SD = 1.0 m), and the mean capacity for the storage of 12 kg (SD = 14 kg) of ice. The bulk of the fleet is made up of canoes with long-tailed outboard motors, known locally as "rabetas," a term that will be adopted here to denominate the canoes with long-tailed outboards. The fleet had 839 rabetas, with a mean length of 7.2 m (SD = 1.0 m) and a mean ice capacity of 70 kg (SD = 75 kg). These vessels were powered by motors of 5.5 to 7.5 Hp. The motorboats (a total of 98 units) were also made of wood, and were the fleet's largest vessels, with a mean length of 10.0 m (SD = 2.0 m), and a much larger ice storage capacity (192 kg; SD = 260 kg). These boats were powered by motors ranging from 10 Hp to 90 Hp.

The rabetas were the most important productive units in the croaker fishery, being responsible for 85% of all the fishing trips recorded, and 80% of the silver croaker catch. Together, the other canoes and the motorboats contributed 15% of the total number of trips, and 20% of the catch landed. The motorboats undertook the most extended trips with the largest number of fishers, given the autonomy of the vessels, and their storage capacity (Table 1).

Fishing techniques

Lines and gill nets were the main techniques used to target the silver croaker, corresponding to 37% (line) and 32% (gillnet) of the total catch, and 2766 and 2930 of the catches landed,

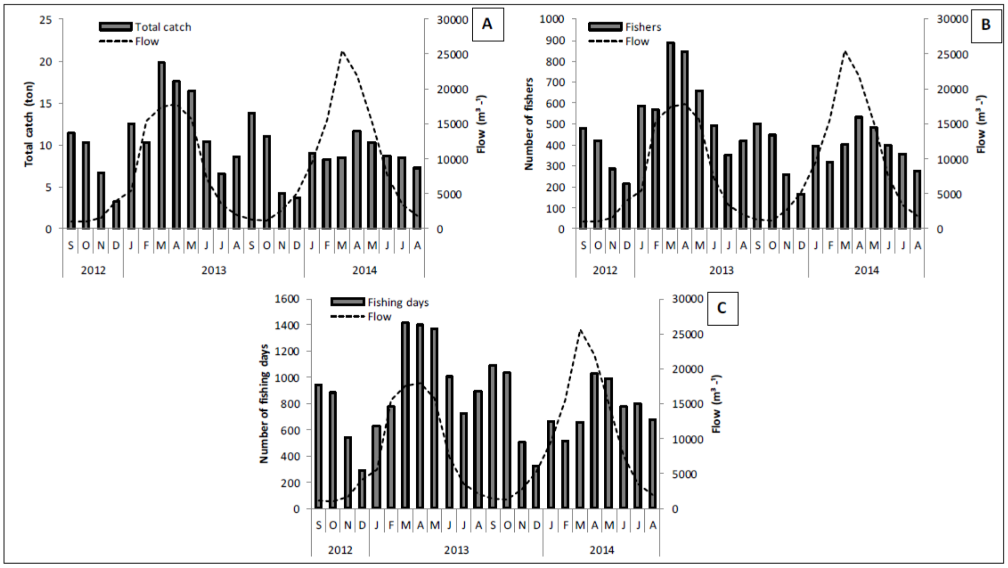

Figure 2. A - Total catch (t) of the South American silver croaker (*P. squamosissimus*); B - Cumulative effort (number of fishers); C - Cumulative effort (number of fishing days) per month, based on the catches landed by the commercial fishing fleet on the Xingu River (State of Pará, Brazil), between September 2012 and August 2014, and the mean discharge of the Xingu River.

Table 1. Number of vessels and trips, total catch (t), mean and standard deviation (SD) of the number of fishing days and the number of fishers per trip, according to the type of fishery vessel used to target the South American silver croaker (*P. squamosissimus*) on the Xingu River (State of Pará, Brazil), between September 2012 and August 2014.

Vessels	Number of vessels	Number of trips	Total catch (t)	Fishing days	SD	Number of fishermen	SD
Canoes with paddles	68	594	5	1,05	0,38	1,13	0,38
Canoes with long-tailed	839	6535	192	2,73	1,91	1,44	0,67
Motorboats	98	559	42	3,38	1,92	1,95	0,88
General Total	1005	7688	239	2,64	1,90	1,44	0,68

Table 2. The number of trips and the total catch (t) of the South American silver croaker (*P. squamosissimus*) by fishing technique and type of vessel on the Xingu River (State of Pará, Brazil) between September 2012 and August 2014.

Fishing Technique	Canoes with paddles		Canoes with long-tailed		Motorboats		General total	
	Number of trips	Total catch (t)	Number of trips	Total catch (t)	Number of trips	Total catch (t)	Number of trips	Total catch (t)
Lines	522	4,32	2221	67,57	187	16,64	2930	88,54
Gillnet	59	0,35	2507	66,79	200	8,56	2766	75,70
Gillnet/lines	5	0,08	1277	41,88	82	8,68	1364	50,64
Other combinations	6	0,02	456	14,07	29	2,23	491	16,31
Other techniques	2	0,00	74	1,59	61	6,22	137	7,81
General total	594	5	6535	192	559	42	7688	239

respectively. Trips based on mixed techniques (Lines and gillnet) contributed 21% of the total catch. Other methods, including hook lines, free diving, and different combinations of these and the other techniques, contributed the remaining 10% of the catches landed (Table 2).

Overall, 78% of the catches landed, and 74% of the total catch was produced by the rabetas using lines or gillnetting, separately or combined (Table 2). Line fishing was more frequent during the high-water period that gillnetting which was more common at low water (Figure 3).

Fishing grounds

The commercial silver croaker fisheries on the Xingu River and its tributaries, the Iriri and Bacajá, target mainly the main river channel, where 90.4% of the total fish was caught, with a mean catch of 0.03 t (SD = 0.05 t) per trip, with 86% of the catches landed being derived from fishing grounds located on the principal rivers. Together, the other environments (streams, swamps, and lakes) accounted for less than 10% of the total catch, harvested during 1059 trips (Table 3).

Commercial aspects

The production of silver croaker on the Xingu generated gross receipts of US$ 627,142 between September 2012 and August 2014 or US$ 313,571 per year. The highest monthly revenues coincided with the largest catches, that is, in the high-water months of March 2013 (first year) and April 2014 (second year). The mean price paid to the fishers for their catch was US$ 2.54 (SD=1.11) per kilogram. The mean cost of the fish increased 13% over the two years of the study period. The lowest mean price (US$ 1.89 kg^{-1}) was recorded in February 2013, and the highest (US$ 3.28 kg^{-1}), in August 2014. No relationship was found between the price of the fish and the size of the catches landed (Figure 4).

Fishery productivity (CPUE)

The mean Catch per Unit Effort (CPUE) recorded between September 2012 and August 2014 was 14.16 $kg.fisher^{-1}.day^{-1}$ (SD = 12.24 $kg.fisher^{-1}.day^{-1}$). The CPUE varied significantly ($H_{(2,3116)} = 71.46$; $p = 0.0000$) among the main fishery systems, being highest for the rabetas operating gillnets, and lowest for the rabetas operating with gillnets and lines combined or lines on their own (Figure 5A). The CPUE also varied among seasons ($H_{(3,3116)} = 11.67$; $p = 0.009$), with the highest values being recorded during the high-water period, and the lowest, during the receding period (Figure 5B).

Population dynamics and the evaluation of stocks

The total length (TL) of 7776 specimens was recorded in the present study, the total lengths ranged from 7.5 cm to 68.0 cm, with a mean value of 34.45 (±8.96) cm.

The plot derived from the ELEFAN I routine (Figure 6) indicated the existence of an annual cohort, which may join the population (spawning) in September and survive for more than six or seven years. The somatic growth of the species was associated with a minor oscillation in the growth rate (C), with the lowest annual growth rate being recorded in February, which corresponds, approximately, with the beginning of the flood period. The adjustment indicated by this routine resulted in the following growth parameters: $L\infty = 70.35$ cm, $K = 0.39$ $year^{-1}$, $C = 0.30$ and Winter Point = 0.16.

Mean longevity was estimated at 7.68 years. Estimated total mortality (Z) was approximately 1.44 $year^{-1}$ (Table 4), while natural mortality (M) was 0.76 $year^{-1}$, fishery mortality (F) was 0.68 $year^{-1}$, and the current exploitation rate (E) was 0.47

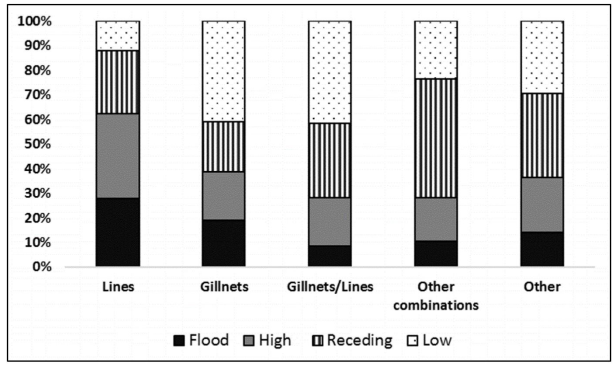

Figure 3. Fishing gear used by the commercial fishery of Silver croaker (*P. squamosissimus*), on the Xingu River (State of Pará, Brazil) according to the hydrological cycle.

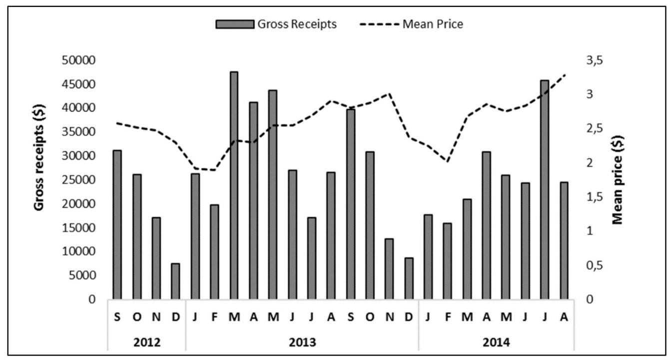

Figure 4. Gross receipts and the mean monthly price paid to the fishers of the South American silver croaker (*P. squamosissimus*) at the ports on the Xingu River (State of Pará, Brazil) between September 2012 and August 2014.

Table 3. The total number of trips, total catch (t), mean catch per trip (t), and the standard deviation (t) of the fisheries of the South American silver croaker (*P. squamosissimus*) by the type of fishing environment on the Xingu River State of Pará, Brazil) between September 2012 and August 2014.

Fishing environment	Number of trips	Total catch (t)	Mean catch per trip	Standard deviation
Swamps	279	6	0,02	0,03
Streams	755	17	0,02	0,03
Lakes	25	1	0,02	0,03
River	6629	216	0,03	0,05
General total	7688	239	0,03	0,04

Table 4. The relationship between the age (t), in years, and mean length (Lt), in cm, of *P. squamosissimus* caught on the Xingu River (State of Pará, Brazil) between 2012 and 2014, based on the adjusted von Bertalanffy model.

t	1	2	3	4	5	6	7	8
Lt	23	39	49	56	61	64	66	68

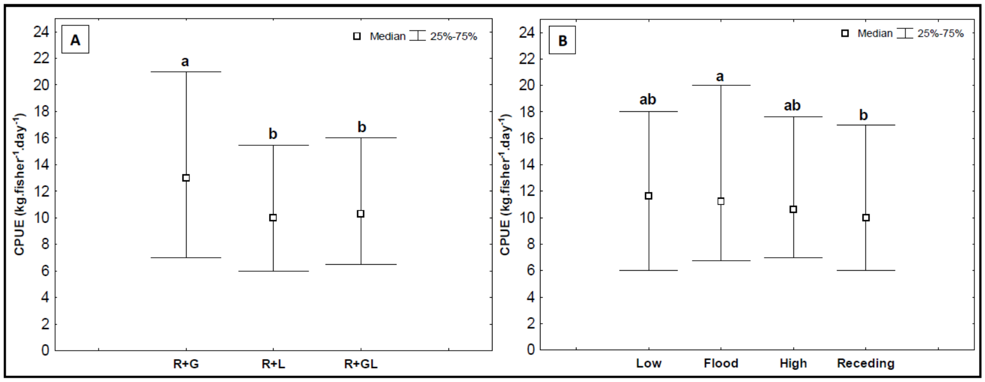

Figure 5. Comparison of the median Catch per Unit Effort (kg.fisher^{-1}.day^{-1}) among the three main types of fishery system (A) and hydrological periods (B) recorded for the commercial South American silver croaker (*P. squamosissimus*) fisheries of the Xingu River, between September 2012 and August 2014. Multiple comparison test: a > b, ά=0.05.

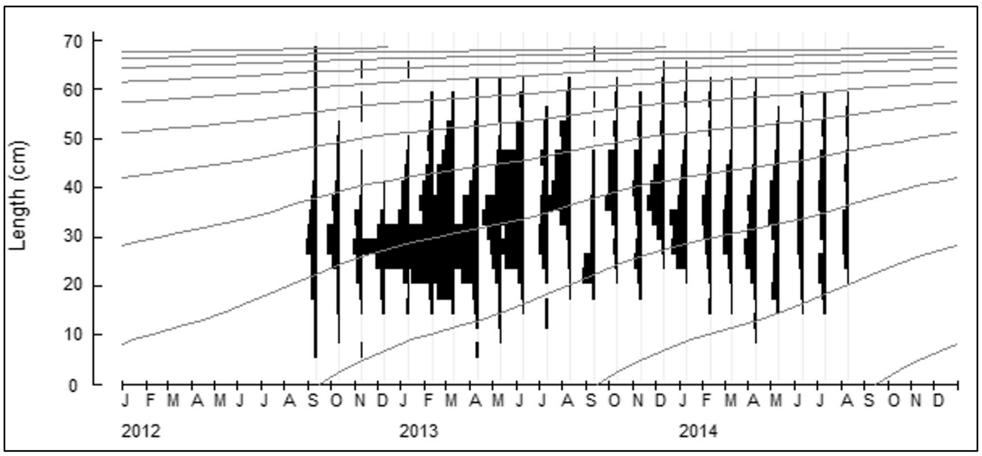

Figure 6. Plot generated by the ELEFAN I routine, showing the monthly length total (cm) frequencies recorded for *P. Squamosissimus* caught on the Xingu River State of Pará, Brazil) between 2012 and 2014, and the adjustment of the seasonal model of somatic growth of von Bertalanffy.

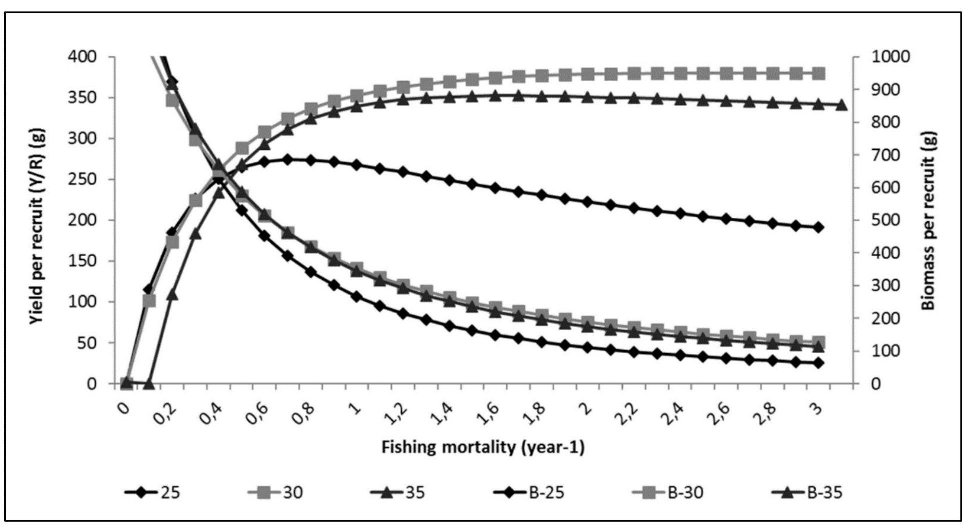

Figure 7. Yield per recruit (Y/R), based on the Beverton and Holt model for the *P. squamosissimus* population from the Xingu River (State of Pará, Brazil) between 2012 and 2014.

year^{-1}. At this exploitation rate, croakers with a total length of 25 cm, which is equivalent to an age of 1.12 years, have a 50% probability of being caught. In this scenario, the fishery is close to its maximum exploitation rate (E_{max}), which was estimated at 0.579 year^{-1}. The most conservative values for E_{10} and E_{50} were 0.455 year^{-1} and 0.317 year^{-1}, respectively. In the current scenario, the biomass of fish found in the wild is approximately 34% of the virgin biomass, that is, around one-third of the biomass that existed before the beginning of the fishery exploitation (Figure 7). An increase in the length at first capture (Lc) from 25 cm to 30 cm would contribute improvement of approximately 18.3% in production, once an equilibrium is reached. In this case, the fishery would be in a more favorable position about its sustainable maximum. It would permit an increase in catches of up to 14.5% without any significant risk for the stocks.

DISCUSSION

The results of the present study indicate that the silver croaker, which may be harvested more intensively during the high water months, is a valuable resource to guarantee the income and food security of the riverside fishing communities of the Xingu River during the period when the yields of other species decline (Figure 2), specially considering that the species does not present a migratory pattern (Granado-Lorencio et al., 2005).

During high water, when occurring the inundation of the large floodplain regions, resulting in the dispersal of stocks over a wide area, and thus, hampering fishery efforts, and reducing productivity (Bayley and Petrere, 1989). The increase in effort observed during the high-water period can be accounted for by the decrease in capturability seen during this period, which means that more effort is needed to obtain the same level of productivity (Mota and Ruffino, 1997). A similar pattern has been recorded on the lower Tocantins River, where the silver croaker represents almost half of all the catch landed during high water, where it is fished mainly using lines (Hallwass et al., 2011).

On the Xingu River, the silver croaker is targeted mainly by wooden canoes powered by long-tailed outboards, using gillnets and lines. In general, the vessels of the Amazon fishermen fleet vary considerably in length, cargo capacity, type of fishing ground, and the stock exploited (Petrere, 1996; Hallwass et al., 2011; Isaac et al., 2015). In most cases, however, relatively simple fishery technology is used, which is appropriate for both commercial and subsistence fishing. The vessels used typically on the Xingu River are low-powered and have a limited range, which restricts the distances traveled by the fishers from their home ports (Isaac et al., 2015), indicating that these fisheries typically target local stocks of silver croaker. Given this, it will be essential to focus management strategies on the local level, with the involvement of the fishers that will benefit from these actions over the long term.

In the Amazon basin, the silver croaker spawns in piecemeal fashion, with a reproductive cycle that extends over the whole year (Ruffino and Isaac, 2000), but is more intense between October and February (Braga, 1990, 1998). The peak in the silver croaker catches recorded on the Xingu River occurred right after this spawning period, which would be advantageous for the conservation of the species.

On the middle Orinoco River, Gonzalez et al. (2005b) observed marks in otoliths, recording an L∞ value of 69.34 cm, which is similar to that recorded in the present study, but a much lower K value, 0.12 year^{-1}, which may be related to the low temperatures found in the study region. In the same study, estimates based on body length frequencies indicated an L∞ value of 62.6 cm and K = 0.16 year^{-1}. In environments with high temperatures and abundant food supply, growth rates may accelerate, as will physiological aging (Fonteles-Filho, 2011). In most previous studies, estimates of K were lower than those recorded in the present study (Braga, 1998; Nomura and Oliveira Chacon, 1976; Loubens, 2003). However, this is the first study to focus on the population dynamics of *P. squamosissimus* in a clearwater river. One possible explanation is that, as *P. squamosissimus* is a fish predator, the greater visibility of the water in the Xingu may contribute to an increase in foraging efficiency and, consequently, higher growth rates. On the Xingu River, *P. squamosissimus* presented moderate growth, associated with mean longevity of approximately 7.68 years.

On the Pará River, in the municipality of Barcarena (Pará), which is within the species' natural range, Barbosa (2009) estimated that first sexual maturation (L_m) occurred at 14 cm in the females, and 21.43 cm in the males. In the Tucuruí reservoir, by contrast, the L_m of the females reaches 32.4 cm (Santos et al., 2003; Rocha et al., 2006). In this case, the mean size at first capture (L_c50) estimated for the species in the present study (25 cm) is within the size range of first maturation, which may also be considered to be a parameter appropriate for the avoidance of overfishing over the long term.

Based on the Beverton and Holt model (Figure 6), an increase in the mean size at first capture from 25 cm to 30 cm would be enough to guarantee higher yields and greater stability in the *P. squamosissimus* stocks, which would enable them to withstand an increase in fishery effort. As the region is currently undergoing significant environmental and socioeconomic changes resulting from the implantation of the hydroelectric power plant at Belo Monte, the adoption of this measure may contribute to the avoidance of overfishing in the future, assuming that fishery pressures increase in the region.

Given the characteristics of the silver croaker fisheries, the implementation of this recommendation would be possible through the adoption of measures, such as an increase in the mesh size of gillnets and the size of the hooks used in lines. In this case, a mesh size of 80 mm would be appropriate to guarantee an L_{50} of approximately 30 cm. Considering that the *P. squamosissimus* doesn't have any law that could protect or prohibited the captured of small individuals in the Xingu Basin.

A prolonged period of reproduction, favorable relative growth rates, moderate rates of somatic growth and mortality, and larger catches during the period of lowest capturability, indicates the silver croaker may support the current fishing pressure. These characteristics may account for its success in the study region, despite so many years of intense fishing, being able to sustain high exploitation rates, not only on the Xingu but also on other rivers, such as the Tocantins (Hallwass et al., 2011).

The construction of a reservoir has a significant impact on the hydrological characteristics of a river, which changes from a lotic environment to a lentic or semi-lentic one (Agostinho et al., 2007). The impacts of the formation of reservoirs on fish communities and fishery parameters are relatively well studied. In the reservoirs of the Paraná basin in southern Brazil, for example, fishery productivity declined following the damming of the river (Petrere and Agostinho, 1993; Petrere, 1996).

The reproductive biology of *P. squamosissimus*, which allows this fish to spawn in shallow, lentic environments (Britski, 1972; Chacon and Silva, 1971) is a crucial element in the ability of the species to colonize Brazilian reservoirs (Cruz et al., 1990; Torloni et al., 1993; Agostinho et al., 1995), making the silver croaker one of the most abundant fish in artificial lakes. The adaptive capacity of this species is further enhanced by its trophic plasticity (Hahn et al., 1999). Agostinho et al. (1995) related the variation in the feeding behavior of the species to the extreme fluctuations in the availability of resources among habitats and seasons.

Given its ecological characteristics, the silver croaker would be expected to adapt successfully to the novel conditions of the Belo Monte reservoir and adjacent stretches of the Xingu River and its tributaries affected by the damming. It would be expected to increase in abundance following the flooding of the reservoir. Even so, the construction of the UHE Belo Monte will result in the growth of the region's human population, which will lead to an increase in fishery pressure, with the most abundant and easily-captured species, such as *P. squamosissimus*, being targeted most intensively. The silver croaker is currently one of the most popular food fish species in the study region. Given this, effective measures of stock monitoring and fishery controls should be implemented to ensure the conservation of the species and the food security of the local population.

CONCLUSIONS

The South American silver croaker is fished intensively on the Xingu River and is an important resource for both commercial and subsistence fisheries.

The species has moderate somatic growth, the longevity of approximately seven years, and moderate to high natural mortality.

At present, exploitation rates are considered adequate, and still below the maximum sustainable level.

A small increase of the average catch size from 25cm to 30cm could avoid the overfishing and ensure the sustainability of stocks and fishery of *P. squamosissimus* over time.

It seems likely that the species will be able to adapt to the new scenario, given its trophic and ecological plasticity.

However, the implantation of the Belo Monte power station may increase fishery effort, in which case, the alteration of fishing techniques to guarantee an increase in the mean size of capture would be recommendable.

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