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Reproductive biology of Silver Croaker *Plagioscion squamosissimus* (Heckel, 1840) species of fishery importance in the Lower Amazon, Pará, Brazil

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Abstract - Fishing is an important commercial activity in the Amazon region. In the Lower Amazon, the species *Plagioscion squamosissimus*, popularly known as silver croaker, is one of the main commercial fish of the region. The objective of this study was to evaluate the reproductive biology of that species commercialized in Santarém-PA in order to quantify the sex ratio, determine the reproductive period, and estimate the average length at the first sexual maturation (L_{50}). The specimens were collected weekly between August 2014 and July 2015 at the main fish landing port of the city. A total of 314 individuals were sampled, being 170 (54.14%) females and 144 (46.85%) males. The total lengths were higher for females, with no significant difference for gender. The maximum reproductive activity was observed in the end of the drought and in the beginning of the flood season (November, December and February). The total length average considering the first sexual maturity (L_{50}) was estimated in 19.6 cm for females. These results can be translated into information of extreme importance for local fishery management, targeting both conservation and rational use of natural stocks of silver croaker.

Keywords: Sciaenidae, reproduction, sex ratio, L_{50}, seasonality.

Biologia reprodutiva da pescada branca (*Plagioscion squamosissimus*) espécie de importância pesqueira no Baixo Amazonas, Pará, Brasil

Resumo - A pesca é uma importante atividade produtiva na Amazônia. No Baixo Amazonas, a espécie *Plagioscion squamosissimus*, popularmente conhecida como pescada branca, é um dos principais peixes comerciais da região. O objetivo deste estudo foi avaliar a biologia reprodutiva da espécie comercializada em Santarém-PA, a fim de quantificar a proporção sexual, determinar o período reprodutivo e estimar o comprimento médio na primeira maturação sexual (L_{50}). Os exemplares foram coletados semanalmente entre agosto de 2014 e julho de 2015 em um dos principais portos de desembarque de peixes da cidade. Foram amostrados 314 indivíduos, dos quais 170 (54,14 %) eram fêmeas e 144 (46,85%) machos. Os comprimentos totais foram maiores para as fêmeas, sem diferença significativa na proporção sexual. A atividade reprodutiva máxima foi observada no final da seca e no início da enchente (novembro, dezembro e fevereiro). O comprimento total médio na primeira maturidade sexual (L_{50}) foi estimado para as fêmeas em 19,6 cm. Estes resultados podem ser traduzidos em informações de extrema importância para a gestão pesqueira local, visando a conservação e a utilização racional dos estoques naturais da pescada branca.

Palavras-chave: Sciaenidae, reprodução, proporção sexual, L_{50}, sazonalidade.

Biología reproductiva de la corvina (*Plagioscion squamosissimus*) especie de importancia pesquera en el Bajo Amazonas, Pará, Brasil

Resumen - La pesca es una importante actividad productiva en Amazonia. En el Bajo Amazonas, la especie *Plagioscion squamosissimus*, popularmente conocida como corvina, es uno de los principales peces comerciales de la región. El objetivo de este estudio fue evaluar la biología reproductiva de la especie comercializada en Santarém-PA, a fin de cuantificar la proporción sexual, determinar el período reproductivo y estimar la longitud media en la primera maduración sexual (L_{50}). Los ejemplares fueron recolectados semanalmente entre agosto de 2014 y julio de 2015 en uno de los principales puertos de desembarque de pescados de la ciudad. Se muestrearon 314 individuos, de los cuales 170 (54,14%) eran hembras y 144 (46,85%) machos. Las longitudes totales fueron mayores para las hembras, sin diferencia significativa en la proporción sexual. La actividad reproductiva máxima fue observada al final de la sequía y al inicio de la inundación (noviembre, diciembre y febrero). La longitud total media en la primera madurez sexual (L_{50}) fue estimada para las hembras en 19,6 cm. Estos resultados pueden traducirse en informaciones de extrema importancia para la gestión pesquera local, con vistas a la conservación y la utilización racional de los stocks naturales de la corvina.

Palabras clave: Sciaenidae, reproducción, proporción sexual, L_{50}, estacionalidad.

INTRODUCTION

The species *Plagioscion squamosissimus* (Heckel, 1840) is a popular fish belonging to the Order Perciformes and to the Family Sciaenidae. Recently, this species has received substantial attention from scientists, mainly due to its importance as a source of animal protein and as a key species of fish (Batista et al. 2012, Agostinho et al. 2016, Queiroz-Sousa et al., 2018).

In Brazil, this species has an important role in national commercial fishing, since in the last years it is one of the 12 most exploited species in inland fisheries (MPA 2013). In the Amazon, this fish is found commonly in markets and urban fairs (Ferreira et al. 1998; Batista et al. 2004; Tomé- Souza 2007). Additionally, it plays an important role in subsistence fishing, and is highly appreciated in the feeding of the riverine population living on the banks of the rivers and lakes of the region (Goulding 1980; Freitas and Batista 1999; Cerdeira et al. 1997; Soares et al. 2008).

The landing of fish in the Lower Amazon, specifically in the city of Santarém, in the state of Pará, presents characteristics similar to those of other important Amazonian ports, where the biggest share of the production depends on a minority of species (Merona an Bittencourt 1988; Gonçalves and Batista 2008; Doria et al. 2012; Batista et al. 2012). Among the main species landed to supply the local market is *Plagioscion squamosissimus*, popularly known as silver croaker (Isaac et al. 2000; Isaac et al. 2004).

The silver croaker is native to the Amazon Basin and inhabits several Brazilian river basins, as well as in many reservoirs where it was introduced (Sato and Godinho 1999; Bennemann et al. 2006; Agostinho et al. 2016; Bezerra et al. 2017). It is a benthopelagic species of twilight and nocturnal habits that reproduces during the whole year, achieving the highest reproductive rate in the flood, and presents external fertilization with parceled spawning and displays no parental care of the offspring (Suzuki et al. 2005; Camargo and Lima-Júnior 2007; Borie et al. 2014). Regarding its diet, it is essentially carnivorous, feeding on crustaceans and aquatic insects (at young phase), and fish and shrimp (at adult phase) (Ramos et al. 2013; Filho et al. 2014; Pereira et al. 2015).

When it comes to economically important fishery resources, the main objective of the research is to establish rules for its rational exploitation through knowledge of population dynamics, which includes studies related to the reproductive biology of fish species (Fonteles-Filho 2011; Pavlov and Emel'yanova 2016). These studies are important because they allow, on the one hand, the understanding of the processes that involve the perpetuation

of the species and, on the other, they are also useful for fishery supervision and management in captivity (Sparre and Venema 1997; King 2007; Lowerre-Barbieri et al. 2016).

Therefore, the studies that evaluate the reproductive life of species commercially exploited are the key in fisheries research since they provide management options for the protection of breeding stock (Pavlov and Emel'yanova 2016). Taking that into account, the objective of this study was to assess the reproductive biology of *Plagioscion squamosissimus* marketed in Santarém-PA to: (i) estimate the average length at first sexual maturation (L_{50}); (ii) quantify the sex ratio; and (iii) determine the reproductive period. Such biological and ecological knowledge can be translated into information of extreme importance for local fisheries management, aiming at the conservation and rational use of natural stocks of this fish species.

MATERIAL AND METHODS

The Lower Amazon, which extends along the Amazon River from the mouth of the Madeira River to the mouth of the Xingu River, is influenced by the annual hydrological regime. Four distinct hydrologic phases can be defined for the region, namely: high water, ebb, drought and flood (Isaac et al. 2004). In mid-May and June the highest precipitation rates (high water) are concentrated. Between July and September (ebb) the level of the river decreases drastically. In the months of October and November (drought) the precipitation is extremely low, and between the months of December and March (flood) the volume of rainfall in the region is intense (Isaac et al. 2016).

The city of Santarém (2°26'22" S; 54°41'55" W) in the state of Pará, is located on the right bank of the Tapajós River, and represents the main fishing port of the Lower Amazon, supplying the fish market for a population of approximately 300.000 inhabitants (Batista et al. 2004, IBGE 2010). The data used in this work was collected in the Fish Fair (Figure 1), one of the main ports of fish landing in the city of Santarém-PA.

Figure 1. Map showing the Fish Fair in Santarém-PA. Source: Laboratory of Geoinformation and Environmental Analysis / UFOPA, 2016.
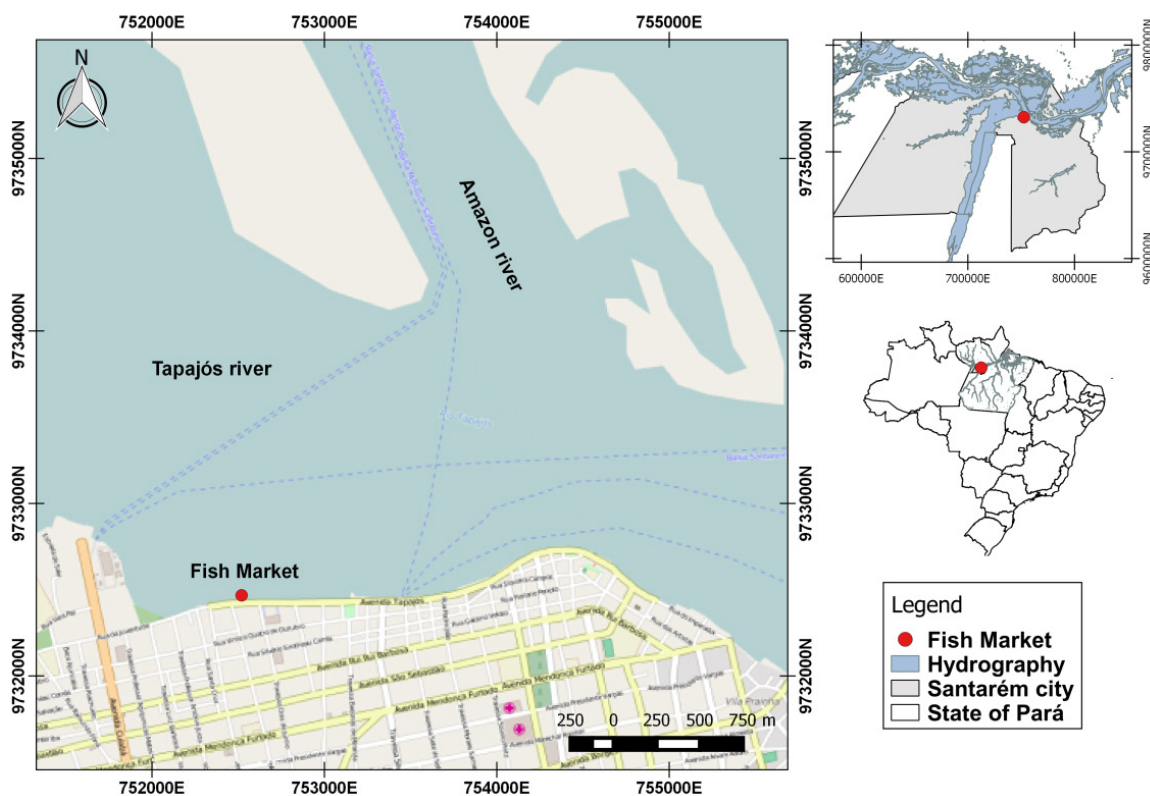
To obtain the data, specimens of *P. squamosissimus* were collected between August 2014 and July 2015. The fishes were collected by the morning shift, when the fishing boats from Santarém and other neighboring municipalities are arriving to supply the city. The specimens were identified according to the specialized literature (Ferreira 1998; Santos 2006; Casatti 2013). For each specimen, the following data was collected: total length (Lt), total weight (Wt), gonadal weight (Wg). And by macroscopic analysis, from an abdominal incision to expose the gonads, the identification of the sex and stages of gonadal maturation of the females was performed. This procedure was performed by the same observer throughout the sampling period.

The maturing stages were adapted according to Vazzoler (1996), indicating four phases, namely: immature (A), maturing (B), mature (C), and spawned (D). This classification followed macroscopic evaluations of ovary for staining, size, presence of oocytes, structure (turgid or flaccid) and vascularization. The sex ratio was determined by the frequency (monthly) of occurrence of males and females and for the total sampling period. The sex ratio was studied for each month of collection and the differences tested using the χ^2 test (chi-square).

In order to estimate the average length at the first sexual maturation (L_{50}), the females sampled were classified as young and adult from the maturational stages of the gonads. The immature and maturing females were considered young, and all the others considered adults. The ratio between young and adult was calculated per total length class. The percentage of adults per length class was calculated and considered as a dependent variable (Y) and the total length as an independent variable (X). Afterwards, these values were adjusted by the method of least squares for a logistic curve using the following equation (King 1995): $P = 1/(1 + exp\ [-r\ (L - L_{50})]$, where *P* is the ration of mature individuals, *r* is the slope of the curve, *L* is the lower limit of the total length class, and L_{50} means the length of first sexual maturation (corresponds to the inflection point of the curve).

The reproductive period was determined by the methods of temporal variation of the frequency of maturity stages and the temporal variation of the gonadosomatic index (IGS) according to Vazzoler (1996). The first method calculated the relative frequency (per month) of females in relation to the number of females collected at each stage of maturity, considering the individuals collected at each stage of maturity per month as 100%. For IGS analysis, only females were used since the variation of the weight of the ovaries is more evident than the testicles. This index was calculated using the equation $IGS = W_g/W_t * 100$, where W_t is the total weight of the animal and W_g is the weight of the gonads.

The differences in the distribution of the monthly IGS values were tested through the analysis of unifactorial variance, at a significance level of 5%. The Tukey test was used for a posteriori analysis. The analyses were performed in PAST software 3.14 (Hammer et al. 2001).

RESULTS

In total, 314 specimens of *P. squamosissimus* were examined, being 170 (54.14%) females and 144 (46.85%) males. The total length (Lt) of the individuals (males and females) ranged from 19 to 42 cm, with an average (standard deviation) of 26.83 cm ($\pm$ 2.64). Females were larger on average than males (27.20 $\pm$ 2.65 and 26.58 $\pm$ 2.57, respectively). The average length at the first sexual maturation (L_{50}) obtained for the females was estimated at 19.6 cm of total length (Figure 2).

Figure 2. Average length in the first sexual maturation of *P. squamosissimus* females marketed in Santarém-PA from August 2014 to July 2015.
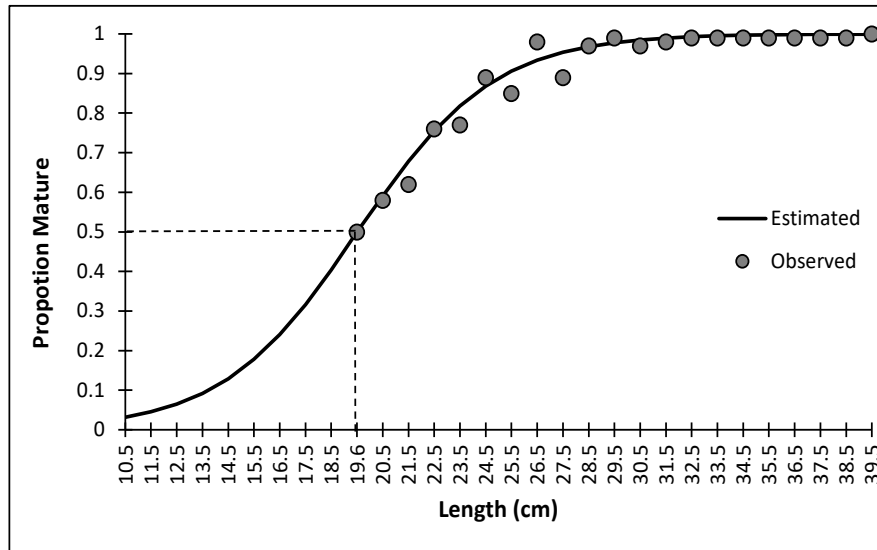

The analysis of sex ratio did not show significant difference in the majority of the months sampled. However, there was a predominance of females in the months of September 2014 and January 2015. In May of 2015, the males predominated. Considering the total number of individuals analyzed, there was no relevant difference, being the ratio 1: 1 for females and males (Table 1).

Table 1. Monthly sex ratio of *P. squamosissimus* marketed in Santarém-PA from August 2014 to July 2015. *E* is the expected sexual ratio. The * following the numbers in a column indicate significant differences at level of 5% when $\chi^2 > 3.84$.

| Months	Females		Males		Total	E	χ^2
	N	%	N	%			
Aug/2014	17	44.73	21	55.26	38	19	0.42
Sep	**33**	**67.34**	**16**	**32.65**	**49**	**24.5**	**5.89***
Oct	9	69.23	4	30.76	13	6.5	1.92
Nov	23	45.09	28	54.90	51	25.5	0,49
Dec	9	50	9	50	18	9	0
Jan/2015	**18**	**75**	**6**	**25**	**24**	**12**	**6***
Feb	22	62.85	13	37.14	35	17.5	2.31
Mar	5	71.42	2	28.57	7	3.5	1.28
Apr	13	46.42	15	53.57	28	14	0.14
May	**4**	**23.52**	**13**	**76.47**	**17**	**8.5**	**4.76***
Jun	2	40	3	60	5	2.5	0.2
Jul	15	51.72	14	48.27	29	14.5	0.03
Total	170	54.14	144	45.85	314	157	2.15

During the sampling period, the percentage of mature females ranged from 3% to 22%, with highest values (19-22%) between November 2014 and February 2015. The highest frequencies of mature females occurred in the months of November, December, and February. Thus, spawning peak occurs at the end of the drought period (November) and in the flood (December and February) (Figure 3). This inference follows Vazzoler (1996), whose spawning peak should be indicated by the higher frequency of individuals with gonads in the mature stage.

Figure 3. Monthly frequency of the different gonadal maturity stages of *P. squamosissimus* females marketed in Santarém-PA from August 2014 to July 2015.
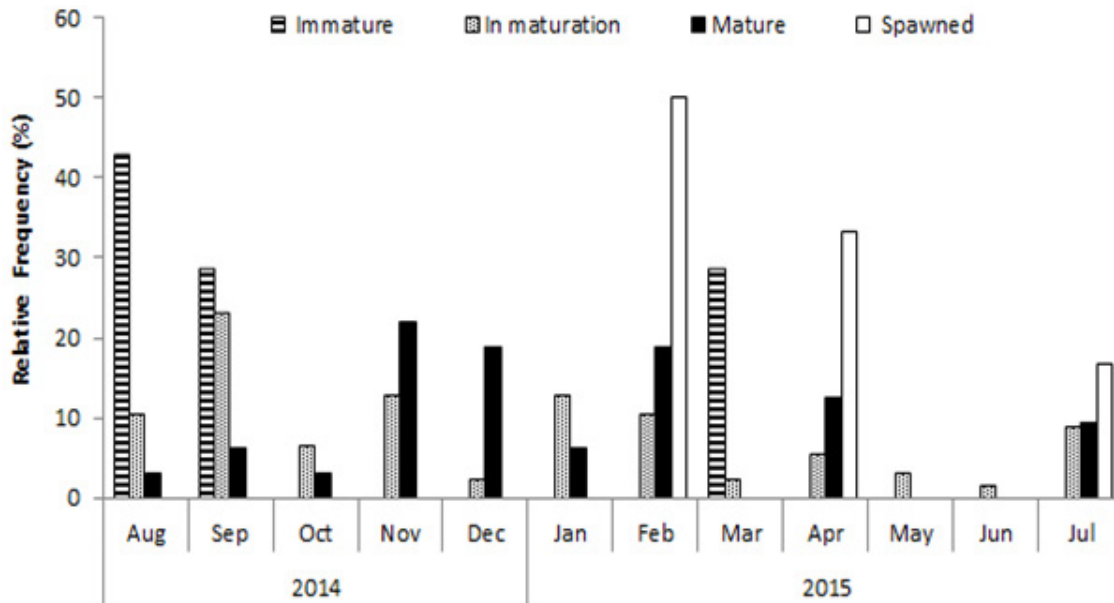
The monthly values of the gonadosomatic index (IGS) showed significant differences for females ($F = 6.474$; $p < 0.05$). The IGS showed a remarkable variation throughout the year, with a higher value (4.13) in December and lower value (0.37) in March (Figure 4).

Figure 4. Monthly average values of the gonadosomatic index (IGS) of *P. squamosissimus* females landed at the Fish Fair in Santarém-PA from August 2014 to July 2015.
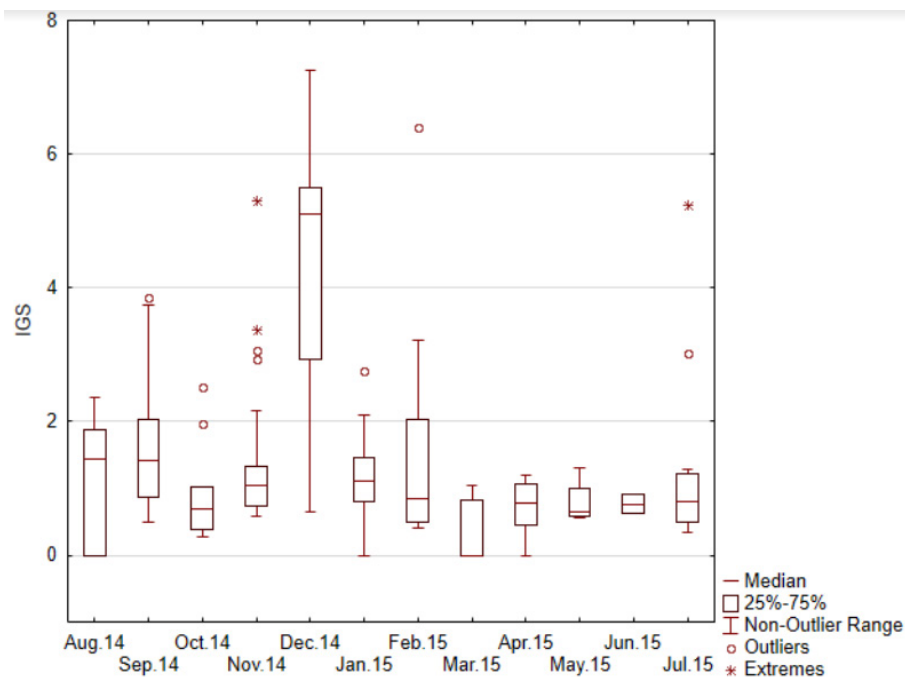
DISCUSSION

The research showed that the capture of *P. squamosissimus* commercialized in Santarém-PA, is mainly focused on individuals with in average total length of 26 cm. Thus, considering the average length at the first sexual maturation (L_{50}) estimated in this study at 19.6 cm for the females of the species studied, these are adult individuals, and therefore, have already reproduced at least once.

There is a wide variation regarding the L_{50} for females of the species in question. In the estuary of the Pará river, Barbosa et al. (2012), indicated the average length of first sexual maturation equal to 16.14 cm (Lt). Carvalho et al. (2017), estimated average of 15.3 cm for the specimens in an area of environmental protection in Northeast Brazil. Other authors, such as Carnelós and Benedito-Cecílio (2002), evaluated the average in 17.8 cm for the females in the Itaipu reservoir, and Loubens (2003) evaluated the average in 24 cm for females on the Mamoré River, in the Bolivian Amazon. According to Lasso-Alcalá et al. (1998), the differences of those averages may be related to three factors, namely: i) the confinement effect; ii) climatic and/or water seasonality, and iii) the effect of the contribution of primary productivity on lake environment.

The L_{50} calculated by this study can be applied in practice by fisheries managers as the basis for establishing the minimum catch size for silver croaker, being an important mechanism to protect the catchable stock, as it ensures the recruitment and the accomplishment of at least one spawning by the breeding stock. It is important to emphasize the need for studies that estimate other variables of the *P. squamosissimus* fishery in the municipality of Santarém, such as estimates of mortality, growth rates, rate of exploitation, maximum sustainable catch, among others, since all this information analyzed together with the L_{50} may reveal the current status of yield of local stocks of this important species of commercial interest.

Regarding the sex ratio analyzed in this study, the results corroborate those presented by Felix (2008) for silver croaker in the Pedra reservoir, Bahia, which did not observe a difference in sex ratio. Similarly, Riofrío (2009) also found no difference between genders of this species landed in a port on the Ucayali river in Peru. On the other hand, there are studies that differ from these results, such as Barbosa et al. (2012) and Sousa et al. (2015), who affirm to have found significant difference in the proportion between males and females, with predominance of females, in the Pará estuary and in a reservoir in the Brazilian semi-arid region, respectively.

According to Nikolsky (1963), most species of fish tend to have a sex ratio of 1:1. However, there may be considerable variation in this estimate between species. For Vazzoler (1996) and Rodrigues et al. (1988), the sex ratio of fish can change along their life cycle, due to successive biological events, such as growth and mortality rates, which operate differently for males and females and may facilitate the catching of individuals of one gender.

In the present study, the temporal variation of the frequency of maturity stages of female gonads leads to the conclusion that the reproductive period of silver croaker occurs throughout the year, however, with spawning peaks in November, December and February (end of drought and beginning of flood). This pattern of prolonged reproductive activity of the species is confirmed by several studies (Santos et al. 2003; Camargo and Lima-Júnior 2007; Riofrío 2009; Barbosa et al. 2012, Sousa et al. 2015).

In the Lower Amazon, the catch of silver croaker is permitted throughout the year. The results presented here are important to assist in the creation of local measures of protective fishing for the species, such as the period of the closed season. According to Agostinho et al. (2007) and Morgan (2008), the determination of the reproductive period of a species represents an important data for its management, since its success guarantees the recruitment and, consequently, the maintenance of viable populations.

Probably the long reproductive period verified, is due to the multiple spawning of the species, which is characterized by the irregular and continuous maturation of the gametes and their release according to the partial evolution of the maturation process (Vazzoler 1996; Braga 1997). According to Fonteles-Filho (2011), multiple spawning is more common in the Intertropical Zone, and reflects an adaptation of the species to the environmental conditions, in order to optimize the release of the gametes within a synchronized process with the availability of food for the larvae and post-larvae, aiming at greater offspring survival.

The temporal variation of the IGS (gonadosomatic index) in this study, when analyzed with the temporal variation of the frequency of maturity stages of the female gonads, reinforced that the peak of the reproductive period of silver croaker occurs at the end of the drought and at the beginning of the flood. The delimitation of this period, according to McPherson et al. (2011), requires the use of more than one method, associating the analysis of the temporal variation of ovarian frequencies in the different stages of maturity to the analysis of quantitative

indicators of the phase in which the gonads are within the maturation process, such as the gonadosomatic index. The highest IGS mean value for females occurred in December 2014 (beginning of flood). In this period, the individuals evaluated presented the heaviest gonads, as they were mature and consequently reflected in high IGS values. According to Fonteles-Filho (2011), the gonadal maturity is indicated by the increase of the weight of the gonads.

The comparison between the IGS values and the values of the condition factor determined by Lima *et al.* (2017) for species in Santarém-PA, showed that they were inversely related. The condition factor is considered a quantitative indicator of the degree of the fish health or well-being in the environment, reflecting recent food conditions or the use of reserves in cyclical activities (Le Cren 1951). The annual variation observed by the aforementioned authors in the condition factor for *P. squamosissimus* in Santarém-PA suggests that the accumulation of energy occurs during the period of ebb/drough, in mid-September.

The dynamics of the river level contributes to the energy accumulation occurring during this time of water fall because the retraction of the aquatic environment facilitates the detection and capture of prey by silver croaker (Lima et al. 2017). This available energy allocated to the formation of oocytes consists of fat accumulated during the falling/dry, when the fish are feeding intensely, and that later is consumed during the maturation of the gonads. Thus, the gonadosomatic index in this study can be considered a good indicator of the reproductive period of *P. squamosissimus*.

According to Godinho *et al.* (2010) the reproductive period of *P. squamosissimus* is similar to most tropical freshwater fish, where gonads are mature at the time of river level rise. Lowe-McConnell (1999), Agostinho et al. (2004), Bailly et al. (2008), Hashiguti et al. (2017) also affirm that the period of rising waters is the most favorable for spawning because it provides a greater supply of shelter and food for the offspring, as this reproductive strategy should ensure the survival of as many offspring as possible.

CONCLUSIONS

Considering the current importance of silver croaker (*P. squamosissimus*) as a target species for fishing, especially in the Lower Amazon, and the lack of specific local legislation for this species, the present study showed indicators that could potentially be used to subsidize the formulation of management measures for white hake stocks, such as establishing a minimum catch size based on the L_{50} results presented here, as well as the restriction of fishing in periods of reproduction (spawning), aiming at the sustainability of exploitation of this resource. In addition, the methodology for collecting fish used in this work, considered with relatively simple logistics, can also be replicated to other fish species in the region, since there is a high diversity of target species of fisheries and the urgent need for further studies that contribute to the conservation and sustainable management of local fishery resources.

ACKNOWLEDGMENTS

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