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Reproductive biology of *Plagioscion magdalenae* (Teleostei: Sciaenidae) (Steindachner, 1878) in the bay of Marajo, Amazon Estuary, Brazil

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Plagioscion magdalenae (pacora) is a commercially important benthopelagic sciaenid and widely distributed in the Amazon River basin. The present study describes the reproductive biology of this species in the bay of Marajo, Amazon Estuary, Brazil. The gonadal development stage, age and size at first sexual maturity (L_{50}), sex ratio, and reproductive strategy were determined. The data were collected bi-monthly from December 2005 to October 2006. A total of 251 specimens were examined, with the total length (TL) ranging between 220 and 590 mm. The weight-length relationship for females, males and grouped sexes was highly significant, showing a positive allometry. The L_{50} was of 279 mm for grouped sexes, with 305 mm and 269 mm TL for females and males respectively. The sex ratio for the total number of individuals favored the males (2.02 males: 1 female). Macroscopically, the gonads were classified as immature, maturing, mature and spent. Considering the macro and microscopic evaluation of the gonads, an extended spawning period, mainly in August to February, was observed.

Plagioscion magdalenae (pescada-curuca) é um sciaenídeo bentopelágico, de importância comercial, amplamente distribuído na bacia do rio Amazonas. O objetivo deste trabalho foi descrever a biologia reprodutiva dessa espécie na baía do Marajó, estuário Amazônico, Brasil. Neste estudo foi determinado o estádio do desenvolvimento gonadal, tamanho de primeira maturação gonadal (L_{50}), proporção entre sexos, época e o tipo de desova. A coleta foi realizada bimestralmente no período de dezembro de 2005 a outubro de 2006. Foi examinado um total de 251 exemplares, variando entre 220 e 590 mm de comprimento total (CT). A relação peso-comprimento para fêmeas, machos e sexos agrupados foi altamente significativa, com alometria positiva. O L_{50} foi de 279 mm considerando sexos agrupados, 305 e 269 mm CT para fêmeas e machos respectivamente. A proporção entre sexos para o total de indivíduos foi favorável aos machos (2,02 machos: 1 fêmea). Macroscopicamente, as gônadas foram classificadas em imatura, em maturação, matura e desovada. Considerando-se as avaliações macro e microscópicas das gônadas, foi registrado um período prolongado de desova, principalmente entre agosto e fevereiro.

Key words: Reproduction, Amazon, Length maturity, Sexual proportion.

Introduction

The Amazon Estuary, the region where the Amazon and Tocantins Rivers flow into the Atlantic Ocean, is a complex aquatic environment where the Amazon River discharges between 1.0 and 2.8 x 10^5 m^3/s of fresh water (Kineke & Sternberg, 1995) and an average of 3-3.5 million metric tons of sediments in the sea (Meade *et al*., 1985). This region is characterized by its high biological productivity, which supports a substantial fish biomass (Okada *et al*., 1998).

It is estimated that 24% (approximately 125,000 t) of annual Brazilian marine and estuarine catches are derived from its northern coastal and estuarine waters (IBAMA, 2008). The bay of Marajo is part of the estuary system of the Amazon coast. It is one of the most important artisanal fishing areas and represents an important feeding and reproduction area of commercially important species (Barthem, 1985; Isaac & Barthem, 1995).

Among the commercially important families in Brazil' northern region, the Sciaenidae family stands out considering their commercial and subsistence importance, whose population parameters, in particular the reproduction aspects, are largely unknown, especially for freshwater species of the genus *Plagioscion*. *Plagioscion magdalenae* is known from

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the Magdalena River and Amazon River basins in Colombia and Brazil, respectively (Casatti, 2005). This species has heretofore been called *Plagioscion surinamensis* (Bleeker 1873), as first noted by Jordan & Eigenmann (1889). The only information available on the species include general aspects of the genus (Campos, 1942; Casatti, 2003, 2005) and population parameters obtained in the middle Xingu region, Amazon (Camargo & Giarrizzo, 2009). *Plagioscion magdalenae* is often caught in the estuarine region of the State of Para, especially in the bay of Marajo, representing 26% of this bay total fishery catch (Oliveira, 2007).

Evaluating the reproductive life history of a commercially exploited species is an important research element of fisheries to provide management options for the protection of spawning stocks (Begg, 1998). It is specifically important to estimate the size at gonadal maturation relative to capture size, in order to minimize the catch of immature individuals (Sadovy, 1996).

This paper describes the reproductive biology of *P. magdalenae* in the bay of Marajo Amazon Estuary, in order to contribute to the region's fishery management.

Material and Methods

The bay of Marajo, within the Amazon Estuary complex, is located south of the Island of Marajo (Fig. 1) and receives the discharge of the Tocantins River (El-Robrini, 2001). Due to the seasonal differences in the rain fall in this area, the discharge of the river greatly varies according to the period of the year and the contact river-sea may be moved in approximately 200km (Egler & Schwassmann, 1962). In the winter rainy season (January to June), this zone is moved offshore, primarily due to the strong river plume and throughout the dry summer months (July to September), the opposite pattern occurs and high salinity water flows into the inner estuary (Egler & Schwassmann, 1962; Schwassmann *et al*., 1989). These seasonal variations influence the biodiversity of the estuary: during the rainy season, freshwater species dominate and throughout the dry season, marine species dominate the local ichthyofauna (Barthem, 1985).

The collections were conducted bi-monthly, from December 2005 to October 2006. Sample (total of 251 specimens of *P. magdalenae*) was obtained from the commercial fleet operating in the bay of Marajo. The specimens were captured using drift nets of 50, 60 and 70 mm mesh size (stretched mesh size). Fish were then placed in ice-packed coolers and transported to the laboratory where they were measured (total length - TL, mm) and weighed (total weight - TW, grams). Gonads were removed, individuals were hence sexed and ovary weight determined to the nearest gramme. The maturity stage was determined macroscopically, utilizing four ovarian stages: immature (A), maturing (B), mature (C) and spent (D) and microscopically considering four ovarian stages: stage I, stage II, stage III and stage IV. Both methodologies followed the maturity key of Vazzoler (1996).

The microscopic analysis was performed on 105 ovaries. Each gonad was divided into three sections and only the middle portion was fixed in Bouin's solution for 24 h. Samples were then dehydrated in alcohol, diaphanized in xylol and embedded in paraffin. Sections (5 mm thick) were stained with haematoxylin and eosin, analyzed and photographed using an Olympus (Tokyo, Japan) CH30 microscope.

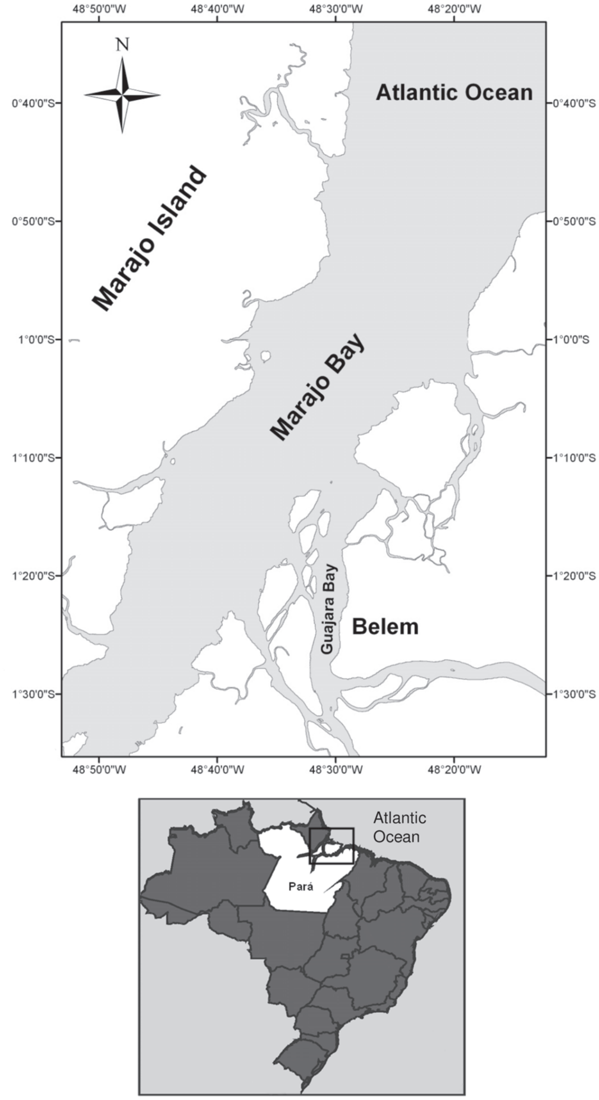

Fig. 1. Study area. Bay of Marajo in the Amazon Estuary, Brazil.

The relationship between total length and total weight was established by non-linear regression represented by the mathematical expression $TW = a \times TL^b$, and adjusted by the least-squares method, with a confidence level of ±95% ($p < 0.05$) where a and b are parameters of the equation (Sokal & Rohlf, 1987). Coefficient b was compared between males and females by the Student's t test (Zar, 2009). The relation is said to be isometric when $b = 3$ (Froese, 2006) and the weight of the fish is proportional to the cube of its length, based on its dimensional equality (Harish Kumar *et al*., 2006).

The sex ratio was obtained for the total period, bi-monthly and by total length. The χ^2 test with Yates correction (Snedecor & Cochran, 1980) was applied in order to evaluate possible sex ratio differences.

The reproductive period of *P. magdalenae* was defined by the ovaries and determined by bi-monthly frequency analysis of the maturity stages and the variation of mean values of the gonadosomatic relationship (ΔRGS) and the condition factor (ΔK). The values of ΔRGS better illustrate the physiological variation of the gonads and, the breeding season is given by the highest value of this index followed by its decrease (Vazzoler, 1996). The condition factor (ΔK) expresses the amount of reserves which is transferred to the gonads. The period immediately anterior to its peak corresponds to the breeding period (Isaac & Vazzoler, 1983).

The gonadosomatic relationship (ΔRGS) is the difference between RGS and RGS* (gonadosomatic indexes), given according to the formulae:

$$RGS = \frac{GW}{TW} \times 100$$

and

$$RGS = \frac{GW}{BW} \times 100$$

Where GW is the ovary weight and BW (body weight) is TW – GW.

The condition factor (ΔK) is the difference between K and K*(condition factor indexes), given according to the formulae:

$$K = \frac{TW}{TL^b}$$

and

$$K^* = \frac{GW}{TL^b}$$

Where b is the coefficient obtained by the length-weight relationship.

The distribution differences of the bi-monthly values for ΔRGS and ΔK were tested using the Kruskal-Wallis nonparametric method (Kruskal & Wallis, 1952).

To analyze the size at first maturity (L_{50}) (length at which 50% of the individuals attain gonadal maturity for the first time), the percentage of adults (ovary stages B, C and D) by length was calculated and considered as dependent variable (Y), and the total length as the independent variable (X). Next, these values were adjusted by the least-squares method to a logistic curve which is given according to the formula: $P = 1/(1 + \exp[-r(TL - L_{50})]$, where P = proportion of mature individuals, r = slope curve and L_{50} = mean length of sexual maturity are parameters of the equation to be estimated by the model.

Results

Of the 251 specimens of *P. magdalenae*, 168 were males and 83 were females. The length and weight relationship for females, males and grouped sexes was highly significant ($p < 0.01$) (Table 1). A positive allometry was recorded for males, females and grouped sexes. The regression coefficient (b) was significantly different between males and females ($t = 1.43$, $p < 0.05$).

The sex ratio, considering the total number of individuals, favored males (2.02 males: 1 female) ($p < 0.05$). Males outnumbered in most length classes and in the bi-monthly periods ($p < 0.05$). Significant differences ($p < 0.05$) for males were observed in the classes included between 360-417, 447-475 and 563-591 mm TL and in almost all months (Tables 2 and 3).

The L_{50} for *P. magdalenae*, considering both males and females, was of 279 mm TL. Males reach maturity at sizes greater than those recorded for females, 305 and 269 mm TL, respectively (Fig. 2).

The ovaries of *P. magdalenae* are approximately equal size pairs and have different patterns of color, size, consistency and vascularization, depending on the ovary development stage (Table 4).

The following stages of oocyte development were identified based on the analysis of the histological cross-sections and the germ cell types were described following the sequence of the oogenesis and folliculogenesis. Immature ovaries exhibit numerous oocytes in the chromatin nucleolus (stage I) and perinucleolar stage (stage II) (Fig. 3). These cells are clustered and inserted into the ovuligera lamellae. The maturing ovaries have a large amount of oocytes in the perinucleolar stage (stage II) and cortical alveoli oocytes (stage III). The mature ovaries present four types of oocytes in different development stages: chromatin nucleolus (stage I), perinucleolar (stage II), cortical alveoli (stage III) and fully vitellogenic (stage IV), which dominates (Fig. 3). The parenchyma of the spent/spawned ovary is characterized by the presence of postovulatory and atretic follicles, and oocytes in the chromatin nucleolus and perinucleolar stages, indicating occurrence of the ovary reorganization before a new reproductive cycle.

The mean values of ΔRGS and ΔK for *P. magdalenae* were not significantly different between the months (Kruskal-Wallis Test; $p > 0.05$) and an extended spawning period was reported, mainly in August to February (Figs. 4a and 4b). Mature individuals of both sexes were observed throughout

Table 1. Parameters of the length-weight relationship for males, females and groups sexes of *Plagioscion magdalenae*, collected in the bay of Marajo.

	n	TL (Min-Max)	A	b	r^2	Allometry
Males	169	220-555	0.000002	3.23	0.96	+
Females	84	245-590	0.000004	3.13	0.96	+
Grouped sexes	252	220-590	0.000003	3.19	0.96	+

Table 2. Sex ratio by bi-monthly period for *Plagioscion magdalenae* in the bay of Marajo. *Significant at 5% level.

Month	% Males	% Females	χ^2
Dec	67.5	32.5	4.9*
Feb	50.0	50.0	0.0
Apr	62.5	37.5	2.5
Jun	69.0	31.0	6.1*
Aug	86.0	14.0	25.9*
Oct	61.5	38.5	2.1
Total	66.9	33.1	28.8*

Table 3. Sex ratio by total length class for *Plagioscion magdalenae* in the bay of Marajo. *Significant at 5% level.

Length class (TL, mm)	% Females	%Males	χ^2
215-243	0.0	100.0	1.00
244-272	75.0	25.0	1.00
273-301	100.0	0.0	3.00
302-330	45.5	54.5	0.82
331-359	26.1	73.9	3.52
360-388	19.2	80.8	15.38*
389-417	44.6	55.4	5.79*
418-446	16.7	83.3	3.43
447-475	32.6	67.4	14.70*
476-504	26.7	73.3	0.07
505-533	29.4	70.6	2.88
534-562	66.7	33.3	0.67
563-591	100.0	0.0	25.00*
Total	33.1	66.9	28.78*

the year (Fig. 4c). This pattern was confirmed by microscopic analysis, which registered the occurrence of oocytes in various stages of development, indicating the release of gametes throughout the year, which points out an asynchronous spawning.

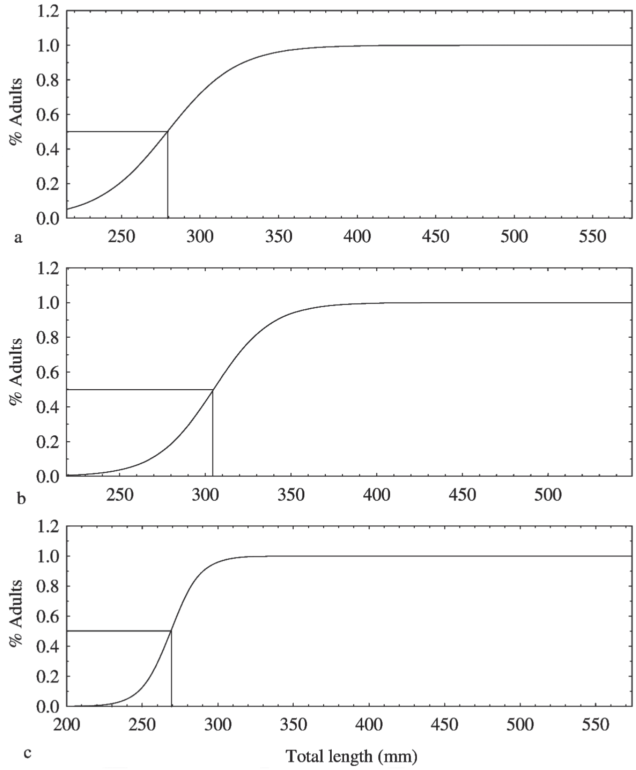

Fig. 2. Size of first maturity (L_{50}) of *Plagioscion magdalenae* for grouped sexes (**a**), males (**b**) and females (**c**) in the bay of Marajo.

Discussion

In the Amazon, fishing is an extremely important socio-economic activity, accounting for a source of food and income for much of the population. This region is renowned for its rich fishery resources. Notwithstanding, the biological information accumulated in recent decades is still limited and concentrated in the central Amazon basin (Isaac *et al.*, 2000) and more recently in the Xingu region (Camargo & Guillard, 2009). Regarding the marine and estuarine species, information on the population dynamics is restricted to specific areas of the Amazon Estuary, considering a few species, such as *Scomberomorus brasiliensis*, *Macrodon ancylodon*, *Cynoscion acoupa*, *Sciades parkeri*, *Cathorops spixii*, *Stellifer rastrifer*, *S. naso* and *Aspredo aspredo* (Camargo & Isaac, 1998; Espírito Santo & Isaac, 1999; MMA, 2006). With regards to freshwater sciaenids, some studies on ecology and population dynamics are mainly available for the cogeneric species, the white hake, *P. squamosissimus* (Rodrigues *et al.*, 1988; Braga, 1997, 2001; Castro, 1999; Carnelós & Benedito-Cecilio, 2002; Stefani *et al.*, 2005; Bennemann *et al.*, 2006). In relation to *P. magdalenae*, only some information is available on the population parameters in the middle Xingu (Carmargo & Giarrizo, 2009).

The length-weight relationship has important applications in terms of fishery biology. It may be useful to calculate a population's production and biomass (Anderson & Gutreuter, 1983) and check for seasonal variations in growth (Richter *et al.*, 2000). It is also relevant for comparing the morphology between species or populations from different habitats and/or regions (Gonçalves *et al.*, 1997). Positive allometry ($b > 3$) was observed for the length weight relationship of *P. magdalenae* as obtained by Camargo & Giarrizo (2009) in middle Xingu. Similar results were attributed to *P. squamosissimus* in the surroundings of Mosqueiro Island, bay of Marajo (Viana *et al.*, 2006). Positive allometry was also dominant for most fish species in Brazilian estuaries, including those on the Amazon Estuary (Joyeux *et al.*, 2009). This relatively more gain in weight in relation to length, are possible under certain conditions such as fish farming and stress-free environments (Sarkar *et al.*, 2009), but may also be attributed to a high availability of food arising from the structural complexity of estuaries (Kennish, 1990; Knox, 1986) as it was reported for most species that inhabit Guajará Bay, adjacent to Marajo Bay, which use the environment as feeding grounds (Viana *et al.*, 2010).

In general, for fishes, males tend to mature earlier and at a smaller size, whereas females grow larger, mature later and tend to invest relatively more resources in their reproduction

Table 4. Macroscopic description of the ovarian stages of female *Plagioscion magdalenae*.

Characteristics	Immature	Maturing	Mature	Spent
Size in relation to abdominal cavity	<1/4	1/2	3/ 4 - 4/4	1/3 - 1/2
Perception of oocytes	No	Yes	Yes	Few
Aspects of oocytes	-	Whitish, small and large	Yellow and large	-
Vascularization	No	Little	High	Hemorrhagic
Coloration of the ovaries	Translucent	Clear Pink	Yellow	red

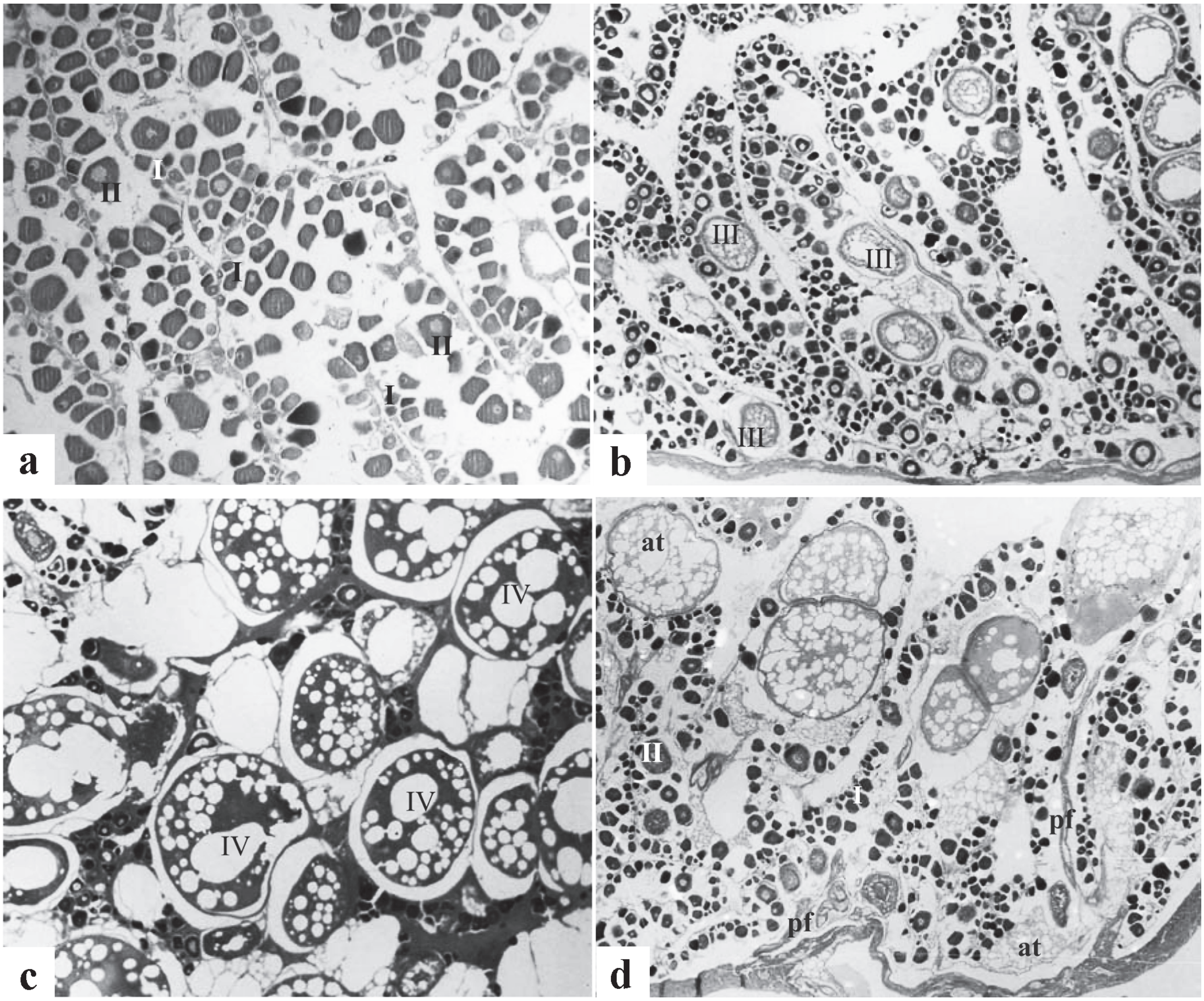

Fig. 3. Photomicrographs of *Plagioscion magdalenae* ovarian tissue at various maturity stages. **a**) Immature, HE, 100x. **b**) Maturing, HE, 100x. **c**) Mature, HE, 40x. **d**) Spawned/spent, HE, 40x. I. chromatin nucleolus (stage I); II. perinucleolar stage (stage II); III. cortical alveoli oocytes (stage III); IV. full vitellogenic (stage IV); pf. postovulatory follicles; at. atretic follicles.

(Bromley, 2003). This is recorded for most marine sciaenids (Lowerre-Barbieri *et al*., 1996; Hutchings *et al*., 2006). However, the opposite was recorded for freshwater sciaenids, as observed in this study for *P. magdalenae* (305 mm and 269 mm for males and females, respectively), and obtained by Castro (1999) and Marciano *et al*. (2005) for *P. squamosissimus*. This may be an specific characteristic of the genus *Plagioscion* or a diferential response to fishery exploitation. Lower values of length-at-first-maturity (222.5 mm TL) were obtained by Camargo & Lima (2007) in middle Xingu River, although higher estimates were also obtained in other study in Xingu River by Camargo & Giarrizzo (2009).

The sex ratio represents important information to characterize the population structure, in addition to providing specifics for studying other aspects, such as the evaluation of reproductive potential and stock size estimates (Vazzoler, 1996). According to Nikolski (1969), the sex ratio in most species is 1:1, varying according to food availability and favoring females when the food supply is adequate. For several species of the lower Amazon, a predominance of females is recorded, mainly due to the fact that males go deeper in the middle of the river, while females migrate close to the shore (Isaac *et al*., 2000). However, in this study, the sex ratio showed significant differences for *P. magdalenae,* indicating a male predominance. This difference may be related to sex segregation for feeding since it has been reported that males, in Marajo and Guajará Bays, mainly fed on crustaceans and females on teleosts (Barbosa, 2009; Luz, 2009).

Wallace & Selman (1981) describe an asynchronous spawning by the concurrent presence of oocytes at all stages of development in fully-developed and partially spent ovaries. This was observed for *P. magdalenae* in the study area by the presence of oocytes in stages I and II, and postovulatory follicle and atretic oocytes, which indicates the elimination of mature oocytes. Macroscopically, the asynchronous spawning was suggested and an extended spawning period

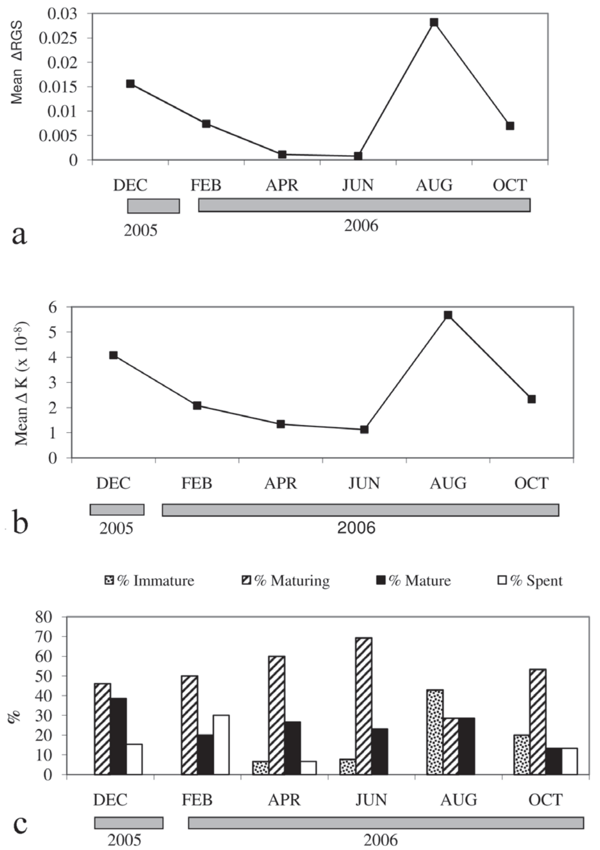

Fig. 4. Mean values of ΔRGS (**a**) and ΔK (**b**) and frequency of bi-monthly percentage of the maturational stages for the females (**c**) of *Plagioscion magdalenae* in the bay of Marajo.

was reported, mainly in August to February. Asynchronous spawning were described for other sciaenids, as is the case of *Micropogonias furnieri* (Lowe-McConnell, 1999), *Umbrina coroides* (Gomes & Guzmán, 1997) and *Stellifer rastrifer* (Chaves & Vendel, 1997; Peres-Rios, 2001).

Overall, the histological characteristics of the ovaries of the species under study are similar to other sciaenid species (Valentim, 1998; Santos, 2006). During the spent/spawned stage, *P. magdalenae* presents postovulatory and atretic follicle as observed in *P. squamosissimus* (Valentim, 1998). In this study four gonadal stages were used according to the proposed by Vazoller (1996) and different from the classification adopted by Valentim (1998), who uses a seven-stage classification. This fact is due to a lack of standardization in the description of the ovarian development stages, which difficult the interpretation of the reproductive process in different species.

The Marajo Bay is one of the most important fishing areas of artisanal fishing in the Amazon Estuary and represents an important feeding and breeding area of commercially important species (Barthem, 1985; Isaac & Barthem, 1995). The presence of *P. magdalenae* individuals in all gonadal development stages indicates that the species complete their entire life cycle in the study area, which reinforces the importance of the area as breeding and nursery grounds, since immature individuals were also frequently observed.

Given that *P. magdalenae* is a commercially important species without any regulation and considering that the bay of Marajo is one of the most important fishing areas of the Amazon Estuary, regulation and conservation measures should be considered. The prolonged spawning cycle does not favor the implementation of a closed season for the species since protecting only a little portion of the spawning stock does not guarantee the maintenance of the population. Others management measures as controlling the minimum landing size, considering the size of first sexual maturity, is a reasonable measure to be implemented by controlling the mesh nets used, and also putting into practice an environmental education project with the fishing community, in order to promote greater awareness of this species. Protected areas and/or periods should also be taken into consideration in the case of the bay of Marajo.

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