MANAGEMENT AND RELATIONSHIP OF ENVIRONMENTAL FACTORS WITH REPRODUCTIVE CHARACTERISTICS OF SILVER CROAKER IN CAGE CULTURE

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ABSTRACT

In the first study of *Plagioscion squamosissimus* in cages culture, different culture structures, as well the reproductive period, fecundity and sexual dimorphism were evaluated. Cages with 2 m depth resulted highest survival. The reproductive peak was in January and February. Females showed three stages of gonads development and males only one. The pelvic and anal fins in sexually mature females showed reddish color. Mature oocytes gonads showed diameters between 0.45 and 0.55 mm. Fertility was estimated at 337.562 ± 333.061 oocytes. A pair of extrinsic muscles in males and absent in females was responsible for producing audible sounds. The dry season and the beginning of the rising water, low conductivity and low pH are potential triggers of gonadal maturation. The results of this study provide information on techniques bases for silver croaker cage culture.

Keywords: Aquaculture; Amazon; *Plagioscion squamosissimus*; reproduction; sonic muscle

MANEJO E RELAÇÃO DE FATORES AMBIENTAIS COM CARACTERÍSTICAS REPRODUTIVAS DA PESCADA-BRANCA CULTIVADA EM TANQUES-REDE

RESUMO

No primeiro estudo do cultivo de *Plagioscion squamosissimus* em tanque-rede, foram avaliadas diferentes estruturas de cultivo, como também o período reprodutivo, fecundidade e dimorfismo sexual. Tanques-rede com profundidade de 2 m foram os que resultaram em maior sobrevivência. O pico reprodutivo foi em janeiro e fevereiro. As fêmeas apresentaram três estágios de desenvolvimento das gônadas e os machos apenas um. As nadadeiras pélvica e anal nas fêmeas sexualmente maduras apresentaram cor avermelhada. Ovócitos em gônadas maduras apresentaram diâmetros entre 0,45 e 0,55 mm. A fertilidade foi estimada em 337,562 ± 333,061 ovócitos. Um par de músculos extrínsecos em machos, ausente nas fêmeas, foi responsável pela produção de sons audíveis. O período da seca e o início da subida da água, baixa condutividade e baixos valores de pH são potenciais desencadeadores de maturação gonadal. Os resultados deste estudo constituem em informações das bases técnicas para o cultivo de pescada-branca em tanque-rede.

Palavras chave: Aquicultura; Amazônia; *Plagioscion squamosissimus*, reprodução; músculo sonoro

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INTRODUCTION

The development of fish farming relies on an active diversification of farmed fish species. Utilizing native species could reduce the environmental impact of fish culture and fit the needs of local markets (FONTAINE *et al*., 2009). Despite the great diversity of fishes in the Amazon basin, regional fish-farming focuses mainly on two species, tambaqui (*Colossoma macropomum*) and matrinxã (*Brycon* sp.). Both species are cultured in ponds and cages.

Cage culture in Brazil has expanded in the last decade in order to combine the sustainable use of the environment with a high stocking rate, in rivers, lakes or dams, which can provide constant renewal of water and high productivity in small areas (GOMES *et al*., 2004).

The silver croaker (*Plagioscion squamosissimus*) is a potential fish-farming candidate as it stand out due to white meat and low-fat (ROCHA *et al*., 1982) and is widely consumed in the Amazon. Since 1935 it has successfully colonized reservoirs. It was introduced to restocking, mainly in Northeast Brazil for acclimatization and extensive farming (CHACON, 1972) and later into several reservoirs in South and Southeastern Brazil (AGOSTINHO and JULIO JR, 1996), where it makes a significant contribution in local fisheries (AGOSTINHO, 1994).

Successful domestication of a new species requires a long-term effort in basic and applied research coupled with information gathered from aquaculture. Certain biotic or abiotic factors, specially feeding behavior as well as food preference, unknown reproduction history, and climate could hinder domestication (LIAO and HUANG, 2000). Silver croaker is a benthic-pelagic carnivore that inhabits lakes and shores of white, clear, black and mixed water rivers and feeds mainly on shrimp and fishes (ALMEIDA *et al*., 1997; GOULDING and FERREIRA, 1984). Furthermore, reproductive biology is well-known for populations in rivers, dams and reservoirs (BRAGA, 1997; LOUBENS, 2003; BIALETZKI *et al*., 2004; FELIX *et al*., 2009; BARBOSA *et al*., 2012).

Using knowledge of the adaptation and reproductive biology of *P. squamosissimus,* the aim of this study was generate a breeding stock, in a confined environment and, thus, diversify the regional-fish farming with the initial domestication stages of a new species.

MATERIAL AND METHODS

Study area

The study was conducted in a floating laboratory located in the north entrance of Catalão Lake Community at the confluence of the Negro (black water) and Solimões (white water) rivers (03°08’58’’S e 59°55’02’’W). There are 36 floating houses, and residents focus on wood extraction and commercialization, fishery and tourism (FONSECA and BATISTA, 2010).

Negro River is the main black water tributary and meets the Solimões River, formerly known as the Amazon River. The water characteristics of this area vary seasonally with fluctuating water levels; the water is predominantly black during low waters and white in high waters influenced by white-water of the Solimões River. White-water rivers like the Solimões have a muddy color, an alkaline to neutral pH, and a high sediment load originating from the Andes (KONHAUSER *et al*., 1994; AUCOUR *et al*., 2003). Black water Rivers like Negro are black due to a high concentration of dissolved organic carbon, have lower suspended sediment, and are usually acidic (RICKEY *et al*., 1990).

Capture and storage

In September and October 2007, during dry season, 170 specimens of the silver croaker were captured (with IBAMA authorization) using fiber line and shrimp as bait, gill and cast nets. Specimens were collected near the study area and transported live in 120 L coolers with 60 L of water, containing a maximum of five fish (>20 cm of standard length - SL), to the experimental site. The fish were stocked in a wooden cage measuring 2 x 2 x 1.5 m (E1) with spacing of 1 cm between the boards, for acclimation period of 20 days.

After acclimation, 150 fishes were stocked for two months in three different types of floating structures. A wooden cage, E1, with 50 fishes; and two cages constructed of steel-coated wire with 19 mm mesh opening: E2 (2x2x1.5 m) stocked with 50 fishes and E3 (3x2x2 m), with 50 fishes.

The floating structure was wood (*Hura crepitans*) used by floating-house communities. The resistance of structure and how fish adapted to it were evaluated.

In January 2008, 130 fish were stocked during one year in three cages of 12 m^3 (type E3): Cage 1, with 40 fishes (22-29 cm TL; total length); Cage 2, with 40 fishes (28-33 cm TL); and Cage 3, with 50 fishes (27-30 cm TL).

The fish were fed daily with small pieces of fish (5% of live weight) in the morning and late afternoon.

Croaker survival rate (SR) was calculated according:

$$SR = (NM * 100) * FN^{-1},$$

where: NM = natural mortality, FN = number of live fish plus those removed for analysis (VAZZOLER, 1996).

Reproductive aspects

Ten fish were randomly selected from each cage for monthly weight and length measurements, and one or two fish from each cage were selected to determine sex and gonadal development. A total of 43 fishes, 37 female and 6 male, were dissected, and gonads were stored in 70% alcohol for further study.

Gonads were weighed and evaluated macroscopically. The following stages were characterized: Stage A (immature or virgin), stage B (maturing), stage C (Mature), Stage D (resting). The gonadosomatic index (GSI) was calculated as:

$$GSI = [\text{gonad weight (g)} \times \text{total weight (g)}^{-1}] \times 100.$$

The number of oocytes was estimated gravimetrically from six mature fish (mean 32.2 ± 4.2 cm SL, standard length; and 620.4 ± 251.8 g Wt; total weight). Fertility was estimated by dividing the gonad into anterior, middle and posterior portions, each weighing between 0.1 and 0.2 g. The number of eggs was counted in each section and estimated the total according the equation:

$$N = (n \times Wtg) \times Wt^{-1},$$

where: N = total oocytes, n = number of oocytes in the aliquot, Wtg = total weight of the gonad and Wt = total weight of the fish.

The diameters (mm) of oocytes were measured using an ocular micrometer. Reproductive methods followed VAZZOLER (1996).

Physico-chemical water parameters

Weekly water samples from inside the cages were measured for temperature (°C), with a digital thermometer; dissolved oxygen (mg L^{-1}) (Milwaukee SM600); pH (Hanna HI99104) and conductivity (mS cm^{-1}) in the morning. The water color (black or white) was visually determined and water levels of the Negro river in Manaus were obtained through official data collected by the National Water Agency (ANA, 2008). These values were correlated with reproductive state of silver croaker using Pearson correlation test. Photoperiod does not vary significantly from 12:12 in the tropics.

RESULTS

Capture and storage

Silver croaker captured using fiber line and shrimp as bait showed best result. During the initial adaptation period, 11.7% of 170 confined fishes died. The fish exhibited red marks near the operculum, caused by gillnets; weight loss and fin damage, possibly caused by piranhas (*Serrasalmus* sp.) and candirú (*Cetopsis* sp.), found in the cages.

The three structures tested during tow moth varied in success. Wood structure, E1, was difficult to use during management, transportation and removal of fish. Water renewal was inefficient and probably caused the mortality of 10 (20%) fishes. A positive feature was that it had a low construction cost due to the availability of timber on site. In structure E2 four fishes (8%) died, fish became agitated and had difficulty swimming when water color changed from black to white. Structure E3 was resistant, easy to handle, permitted constant renewal of water and without mortality.

Rarely was observed fish feeding at the surface during the day. The fishes showed greater feeding voracity at the surface in black water. During white water, some fishes had problems with lack of oxygen in the morning and swam at the surface; they rarely came to feed near the surface. There was no occurrence of cannibalism,

and mortality was possibly due to environmental problems. The fishes were calm during management, indicating docility without anesthetic.

The 130 fish stocked in cages of 12 m^3 (type E3) during one year grew from 29.4 to 34.8 cm SL and increased in weight from 536 to 812 g. Growth can be improved with and adequate management and food quality.

Reproductive aspects

Macroscopic analysis of the ovaries and the temporal variation of the GSI indicated that the reproductive period in confinement began in September and October, peaked in January and February and decreased in May. There were no mature fish, Stage C, between June and August (Figure 1).

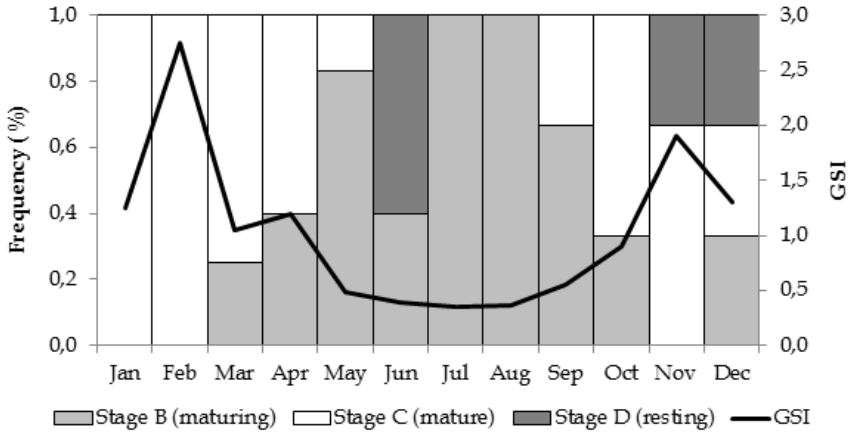

Figure 1. Percentage of mature female silver croaker *Plagioscion squamosissimus* in cages, with spawning in two periods, with the principal peak in January and February. The gonadosomatic index GSI indicates that the month of February is the peak of reproduction, confirming the data from the gonad development.

Ovarian development in captivity separated into three stages (n = 37): stage B (maturing, n = 17), stage C (mature, n = 18) and stage D (resting, n = 8) (Table 1). The resting gonads showed hemorrhagic characteristics, with an atresic appearance, indicatring gonadal regression.

Table 1. Stages of gonadal development of female and male silver croaker *Plagioscion squamosissimus* in cages.

Stages	Macroscopic appearance
B (maturing)	The ovaries showed considerable volume in the abdominal cavity (weighing 3-7 g). It was clear the visualization of oocytes and peripheral blood supply through the membrane. The testes weighted about 2 g. Semen was whitish in color and slightly viscous.
C (Mature)	The females had visible abdominal dilatation, with yellowish ovaries occupying a large part of the coelomic cavity. The oocytes was clear viewing through the membrane with peripheral blood supply and weighed between 10 and 20 g.
D (resting)	The ovaries had a much reduced volume, with a yellowish to red color, stiff and hemorrhagic characteristics.

All six males were maturing with whitish testes that occupied considerable volume within the coelomic cavity. Males released a drop of sperm after abdominal pressure (Table 1).

The estimated number of oocytes was 337,562 ± 333,061 (standard deviation - SD), and weight varied from 24.7 ± 17.5 g (n = 6). Oocyte diameter ranged between 0.15 and 0.55 mm, with two size

groups. 78% of oocytes were mature and had diameters between 0.45 and 0.55 mm.

Silver croaker presented secondary sexual dimorphism, the females showed a reddish tinge on the pelvic and anal fins during the breeding season and a dilation of urogenital pore. Males emitted sound (audible in the air) when held using a pair of sonic muscles that insert on an aponeurosis above the swimbladder and follow the contour of the hypaxial musclature (Figure 2B). Sonic muscles were absent in females (Figure 2A), but females can produce clicking sounds possibly through stridulation of pharyngeal teeth.

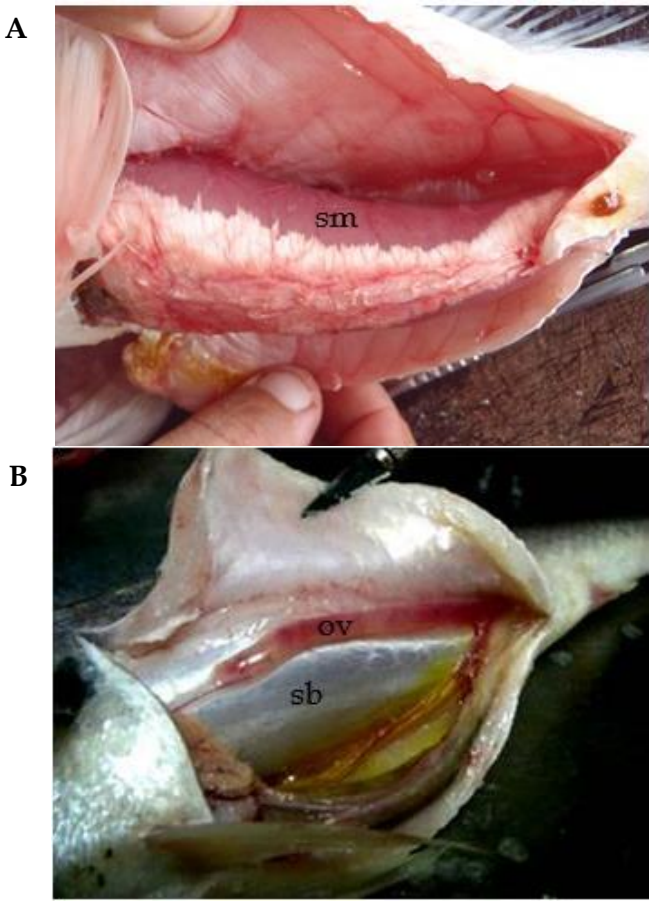

Figure 2. Silver croaker *Plagioscion squamosissimus.* A. The sonic muscle involving swimbladder, testicles and entrails in males. B. Maturing female with absence of sonic muscle. (sm) sonic muscle; (ov) ovary; (sb) swimbladder.

Physico-chemical water parameters

The yearly variation in water characteristics at our cage site changed with water level. The water color was predominantly black in August to November, white in December, returned to black in January to February. The oscillations of the water level in 2008, showed a variation of 10.19 m. The reproductive peak occurred during rising water levels (Figure 3A) during the predominance of black water, influenced by the Negro River. Black water had low levels of conductivity (between 17.8 and 42.8 μS cm^{-1}) and pH (between 4.6 and 5.2) (Figure 3B and 3C respectively), and both variables correlated with sexual maturation (Pearson coefficient of 0.79 and 0.82 respectively, $P<0.01$). The correlations between other parameters were not statistically significant (e.g. dissolved oxygen, Figure 4 E), although there was a positive correlation between temperature and mature females. Temperatures between 30.4 and 31.7°C (Figure 3D) may also favor the maturation process.

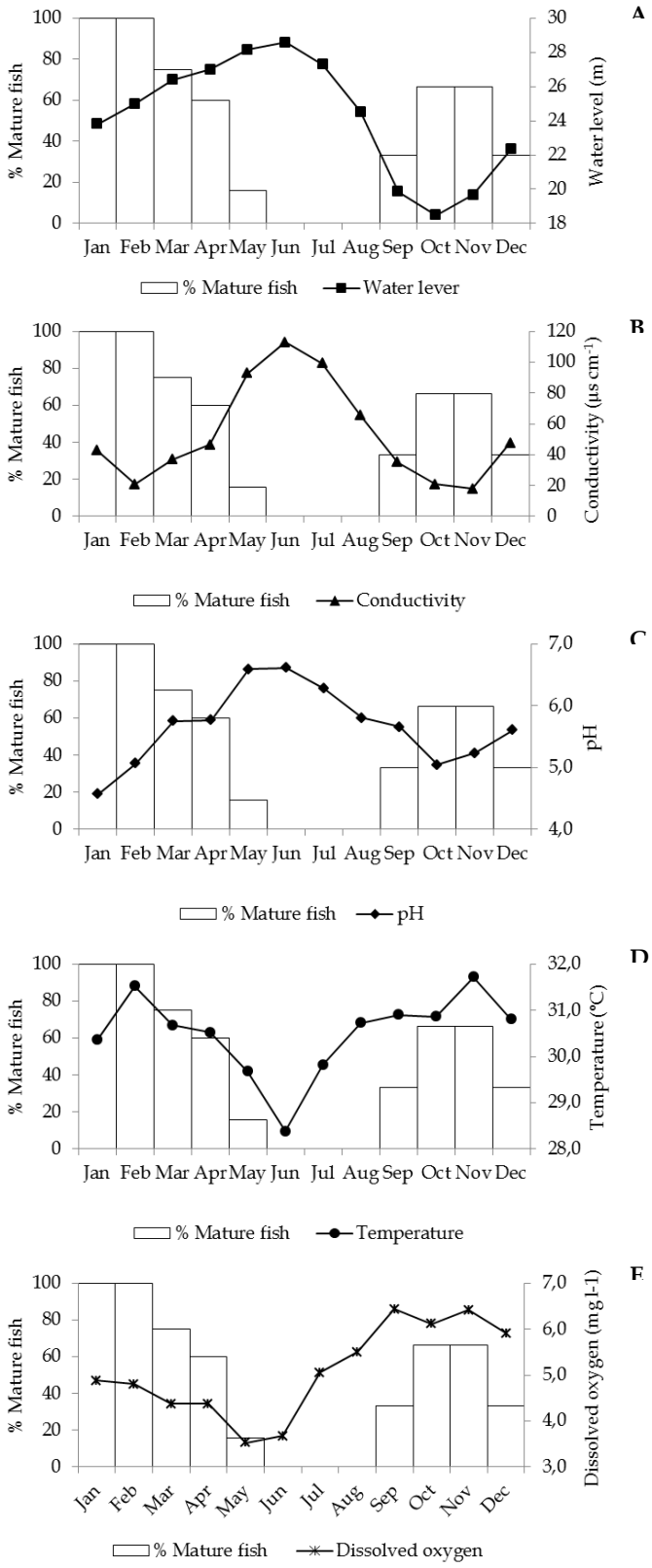

Figure 3. Relationship of physical-chemical water parameters with the reproductive period of silver croaker *Plagioscion squamosissimus*. A) Water level (m); B) Conductivity (mS cm^{-1}); C) pH; D) Temperature (°C); E) Dissolved oxygen (mg L^{-1}).

DISCUSSION

Silver croaker specimens caught with hook and line caused minor damages and low mortality rate. Cages with depths of 2 m are suitable due to benthopelagic habit of this species. The constant renewal of water also allowed a similar environment that the species found in nature.

Caged specimens were fed with pieces of fish smaller than 3 cm^3, and quickly accepted this type of food, demonstrate the simplicity of feed conditioning. Another Amazonian carnivorous fish like pirarucu (*Arapaima gigas)* is easily conditioned after a feeding period with pieces of fish.

The reproductive period of *P. squamosissimus* is similar to most tropical freshwater fish (GODINHO *et al*., 2010); the mature gonads are found at the time of rise of the river level. According to LOWE-MCCONNELL (1999) the flood period provides a greater supply of shelter and food for the fry. Silver croakers kept in cages have a prolonged spawning period, beginning gonadal development in October and November (dry season), and a main peak in January and February, during rising of water. LEITE *et al*. (2006) found a higher abundance of protolarval of silver croaker in Catalão Lake in January, supporting the data obtained in this study. Similarly, two spawning peaks were also observed in the Pereira de Miranda reservoir (SANTOS *et al*., 2003).

Ovarian characteristics were similar to those found by FELIX *et al*. (2009). In addition it was observed atretic ovaries implying that the silver croaker can not complete the reproductive process in captivity. *Mugil cephalus*, usually complete the vitelogênesis but not final maturation and spawning in captivity (YOUSEFIAN *et al*., 2009). The only stage found in males (stage B, maturing) probably indicates dysfunctional spermiation in captivity; this also was observed in males *Umbrina cirrosa* bred in captivity in the Mediterranean (MYLONAS *et al*., 2004), males of *Seriola dumerili* produce viable sperm in small quantities compared to individuals in the natural environment (GÁNDARA and GARCIA-GOMEZ, 2004).

The mature oocytes from the captive silver croaker were between 0.45 and 0.55 mm in diameter. According to VAZZOLER (1996) the diameter of mature oocytes in the same species was 0.52 mm, and the oocyte development was synchronic with two size groups.

Sciaenid fishes, with common names such as croakers and drums, produce advertisement calls during the reproductive season (CONNAUGHTON and TAYLOR, 1995; LAGARDÈRE and MARIANI, 2006; LUCZKOVICH *et al*., 2008; MOK *et al*., 2009; PICCIULIN *et al*., 2012; MILES *et al*., 2012). The sounds are produced by contraction of a pair of sonic muscles typically present in males or occasionally in both sexes (CHAO, 1978). These muscles act as a secondary sexual characteristic in *Cynoscion regalis* (CONNAUGHTON *et al*., 1997). In silver croaker the sonic muscle is only present in males; this also occurs in marine species like *Leiostomus xanthurus* and *C. regalis*, the development of sonic muscle is synchronous with growth of gonads in both species (HILL *et al*., 1987), and probably this also occurs in our species.

Higher temperature and lower pH are likely triggers of gonadal maturation of silver croaker in southern Brazil (BIALETZKI *et al*., 2004). The dry season and the beginning of rising water together with low conductivity and low pH, would be important factors to trigger the onset of gonadal maturation of silver croaker in the Amazon basin.

CONCLUSIONS

This work showed for first time the successful of capture, management and culture of *P. squamosissimus* in 2 m deep cages and feeding with pieces of fish. The information about gonadal development could be used for artificial breeding programs, and sound production of silver croaker is useful to distinguish males from females, facilitating the sexual proportion desired. The results of the study constitutes a technical basis for white croaker cage culture, which can be put in practice for rural areas in the Amazon, but more studies are needed to evaluate the potential of this species for Amazon fish farming.

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