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ECOLOGY

Larvae of migratory Characiformes species in an archipelago in the Lower Amazon River

Lucas Silva de Oliveira[1*], Ruineris Almada Cajado[1,2] and Diego Maia Zacardi[1,3]

[1]Laboratório de Ecologia do Ictioplâncton e Pesca em Águas Interiores, Instituto de Ciências e Tecnologia das Águas, Universidade Federal do Oeste do Pará, Rua Vera Paz, s/n, 68040-470, Santarém, Pará, Brazil. [2]Programa de Pós-Graduação em Ecologia Aquática e Pesca, Universidade Federal do Pará, Belém, Pará, Brazil. [3]Programa de Pós-Graduação em Biodiversidade e Conservação, Universidade Federal do Pará, Altamira, Pará, Brazil. *Author for correspondence. E-mail: lucasmdcpa@gmail.com

ABSTRACT. In the Amazon basin, most of the migratory Characiformes species represent an important fishing resource for local people. However, the lack of information about the main areas and periods of reproduction and the importance of certain environments for the maintenance of species may jeopardize the renewal of fish stocks. Thus, the aim was to examine the spatial and seasonal variation in the density of larvae of migratory Characiformes species in an archipelago in the Lower Amazon River and to assess the importance of this environment for the biological recruitment of the studied species. The capture of larvae was carried out in places close to restinga swamps, steep ruts, and inlet areas with a plankton net (300 μm) in monthly sampling from January to December 2013. An analysis of variance was used to verify differences in larval density between seasons and sampling months. A total of 30,997 larvae were captured and showed no significant differences in their distributions between habitats. However, a variation between the phases of the hydrological cycle was evident, in which the highest larval concentrations were observed during the flooding (17.72 larvae.10m^{-3}) and the drought (1.33 larvae.10m^{-3}). The study area has a great capacity to assist in the maintenance and renewal of regional fish stocks, as it is an important retention and nursery site for larvae of Characiformes that drift along the main channel of the Amazon River.

Keywords: Ichthyoplankton; biological recruitment; fish larvae.

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Introduction

Migration is known as a periodical or seasonal synchronous movement process carried out by a large part of a population between two or more environments (Lucas & Baras, 2001; Dingle & Dranke, 2007). Many Neotropical fishes of great commercial interest, such as Characiformes, popularly known as scales fish, perform these migratory movements to reproduce and stand out for being intensively exploited by artisanal, commercial and subsistence fishing activities, providing food and income generation opportunities (Santos-Filho & Batista, 2009; Silvano, Hallwass, Juras, & Lopes, 2016; Corrêa, Rocha, Santos, Vaz, & Zacardi 2018, Duponchelle et al., 2021). Thus, they make fishing vital for the social and economic development of the Amazon (Batista, Isaac, & Viana, 2004; Faria-Júnior & Batista, 2019).

In the Lower Amazon region, overfishing has reduced the volume of production and the size of the species of fish caught (Vaz, Rabelo, Corrêa, & Zacardi, 2017). Besides, the signs of depletion observed in fisheries resulted not only from intense fishing pressure but also due to poor recruitment caused by unfavorable environmental conditions (Souza, Camargo, & Camargo, 2012). Zacardi, Ponte, Chaves, Oliveira, & Cajado (2018) observed that the decrease in larvae abundance of two species of migratory Characiformes was directly correlated with fishing landing. So, spawning stocks are compromised and directly influence the occurrence and abundance of fish larvae and the natural renewal of the fish community (Reynalte-Tataje, Zaniboni-Filho, Bialetzki, & Agostinho, 2012; Zacardi et al., 2018).

Insufficient information on reproduction, nursery, and development areas for the main species of fish caught in the Lower Amazon River are limiting factors for the sustainability of artisanal fishing (Ferreira, Ponte, Silva, & Zacardi, 2016). The ecological knowledge of the early stages of ichthyofauna development clarifies fundamental aspects of the group's life history. Furthermore, it assists to maintain fish stocks, to estimate renewal potential, and to assess the conservation status of species (Cruz, Affonso, & Gomes, 2016), enabling appropriate proposals for management measures.

Despite its relevance, the existing scientific information on the Amazon fish larvae community and its essential habitats for development is still insufficient, diffuse, and very recent (Zacardi, Bittencourt, & Queiroz, 2020). In this context, this study aims to: investigate the distribution of larvae of migratory Characiformes species of economic interest along with three distinct habitats in an Amazonian archipelago, verify their temporal variation, and provide information on the importance of the islands as retention areas for fish larvae drifting along the main channel of the Lower Amazon River.

Material and methods

Study area

The study was carried out in the lower stretch of the Amazon River in the Marrecas archipelago, comprising the islands of Bom Velho and Marrecas, located between latitudes 2°12'41.86” S and 2°18'52.90” S and longitudes 54°45'42.49” W and 54°43'11.89” W (Figure 1). Marrecas archipelago is located in the main channel of the Amazon River close to Santarém, Pará State, Brazil. This river is classified as a whitewater river, having high dissolved oxygen concentrations, almost neutral pH, and large concentrations of nutrient-rich sediments, making it a highly dynamic and productive river (Junk et al., 2011). Due to the local characteristics of the river's hydrodynamics, erosion processes, transport, and sediment deposition on the archipelago, this environment has annual changes in its structure. These changes generate a mosaic of habitats (i.e., channels, marginal lakes, extensive stands of aquatic macrophytes) that favor success in the life cycle of many regional species (Zacardi, Chaves, Ponte, & Lima, 2017a; Oliveira, Cajado, Santos, Suzuki, & Zacardi, 2020).

Moreover, it is an important fluvial and lake fishing area in the Lower Amazon, with the city of Santarém being the main fish market for landing and marketing fish (Pereira, Silva, & Sousa, 2019). The mean annual fluctuation in the water level is regulated by the local flood pulse, characterized by four moments in the hydrological cycle: flooding (January, February, and March), rising water (April, May, and June), receding water (July, August, and September), and drought (October, November, and December) (Bentes, Oliveira, Zacardi, & Barreto, 2018).

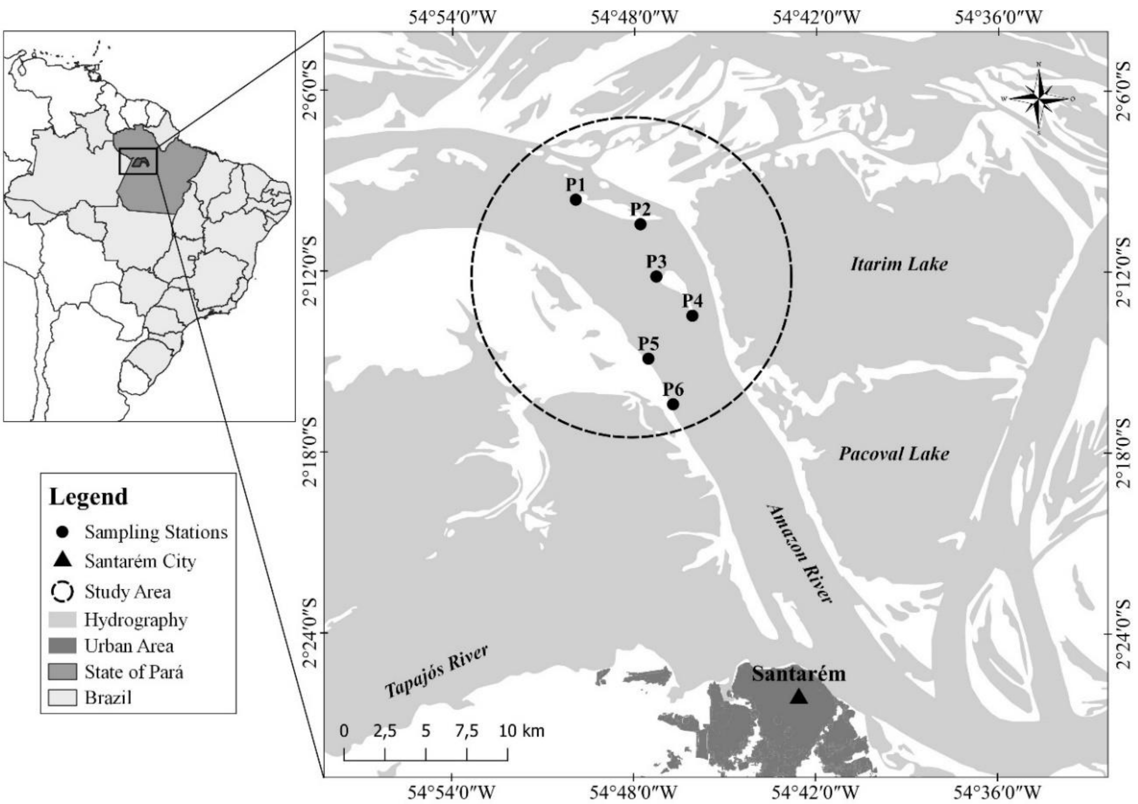

Figure 1. Location of the study area highlighting sampling stations in the Marrecas archipelago, Santarém, Pará State, Brazil.

Sampling and analysis of biological material

Sampling was carried out in the Marrecas archipelago and the marginal region of the Amazon River in monthly collections from January to December 2013 in areas close to three different habitats. Six sampling stations were defined, two in each habitat. The sampling stations P2 and P6 were defined in areas of restinga swamps that have undergrowth, mostly composed of herbaceous plants, with an intense sandy deposition band along the river and with low current (Figure 2A). The sampling stations P1 and P3 represented areas of steep ruts that are sites characterized by intense erosive processes of marginal soil and sediment transport caused by strong currents, forming cliffs and embankments (Figure 2B). The sampling stations P4 and P5 were located in inlets areas that are semi-lotic environments with a curvature pattern resulting from processes of river dynamics, geological and hydrological factors, with strong marginal erosion and land depletion (Figure 2C).

Figure 2. Habitats sampled around the Marrecas archipelago, Santarém, Pará State, Brazil. A. Restinga swamps areas; B. Steep ruts areas and C. Inlets areas.

Horizontal trawls were carried out on the subsurface of the water column for approximately five minutes in daytime and nighttime, between 5 and 15 meters from the marginal region. For the samplings, a conical-cylindrical plankton net with a 60 cm circular diameter and 300 μm mesh with a coupled mechanical flowmeter was used to measure the volume of filtered water. Samples totaled 12 per month and 144 throughout the study.

The collected material was euthanized with benzocaine (250 mg L-1) and then preserved in a 10% formalin solution buffered with calcium carbonate and packed in polyethylene flasks. Sampling was carried out with authorization issued by the Sistema de Autorização e Informação em Biodiversidade (Biodiversity Authorization and Information System) (SISBIO nº. 43128), provided by the Instituto Chico Mendes de Conservação da Biodiversidade (Chico Mendes Institute for Biodiversity Conservation) - ICMBio. The fluviometric level data were provided by the Capitania Fluvial da Marinha do Brasil (Fluvial Captaincy of the Brazilian Navy) in Santarém, Pará State, Diretoria de Hidrografia e Navegação (Hydrography and Navigation Directorate).

In the laboratory, samples were sorted separating Characiformes larvae from the detritus and total plankton with a stereoscopic microscope. Then, the larvae were quantified and identified at lowest possible taxonomic level based on morphological, meristic, and morphometric characteristics described by Araújo-Lima (1985), Araújo-Lima & Donald (1988), Araújo-Lima (1991), Araújo-Lima, Kirovsky, & Marca (1993), Nakatani et al. (2001), and Mateussi, Oliveira, & Pavanelli (2018).

For the analysis, the larvae of migratory Characiformes species with relative abundance greater than 0.05% in each habitat were selected: Leporinus sp., Schizodon fasciatus Spix & Agassiz, 1829, Potamorhina altamazonica (Cope, 1878) , Psectrogaster amazonica (Eigenmann & Eigenmann, 1889), Anodus elongatus Agassiz, 1829, Hemiodus sp., Prochilodus nigricans (Spix & Agassiz, 1829), Semaprochilodus insignis (Jardine & Schomburgk, 1841), Semaprochilodus taeniurus (Humboldt & Valenciennes, 1821), Mylossoma albiscopum (Cope, 1872), Mylossoma aureum (Spix & Agassiz, 1829), and Triportheus auritus (Valenciennes, 1850).

Data analysis

The abundance of larvae was standardized for a volume of 10 m^3 of filtered water (Nakatani et al., 2001). The larval density data were log-transformed (log (x +1)) because data did not meet the assumptions of normality (Shapiro-Wilk test) and homoscedasticity (Levene test). An analysis of variance (one-way ANOVA) was used to verify possible significant differences in the spatial (steep ruts, restinga swamps and inlets) and seasonal (flooding, rising water, receding water, and drought) variations of the larval density. Tukey test was used to identify the differences when a significant difference was detected. The different habitats and sampling periods were considered as response variables and the larval density as a predictor variable. The analyses were performed using the R Statistic 3.4.4 software (R Development Core Team, 2020).

Results and discussion

A total of 30,997 larvae of 12 species were captured. Mylossoma albiscopum sensu Mateussi et al. (2018) (31.74%), Mylossoma aureum (29.39%) – 'pacus' – and Schizodon fasciatus (18.74%) – 'aracu' were the most representative in the sampling area. All species were recorded in the three habitats, however, the inlets areas contributed with the highest values of larvae density when compared to the areas close to restinga swamps and steep ruts (Table 1). Larval densities along habitats did not show significant differences (ANOVA; $p > 0.05$) (Figure 3), demonstrating that the distribution of the Characiformes larvae is homogeneous. This distribution may be a result of the proximity between sampling stations. In this way, the geomorphological and landscape configurations present on the margins of the Marrecas archipelago does not directly influence species density during their early stages of development.

Table 1. Total abundance (A), relative abundance (RA), and mean density of migratory Characiformes larvae captured from January to December 2013 in three different habitats present in the Marrecas archipelago, Lower Amazon River, Pará State, Brazil.

Species	A	RA (%)	Habitats		
			Steep ruts	Inlets	Restinga swamps
Leporinus sp.	1343	4.33	6.72	4.33	2.11
Schizodon fasciatus Spix & Agassiz, 1829	5809	18.74	8.54	24.55	15.58
Potamorhina altamazonica (Cope, 1878)	1040	3.36	1.40	5.90	2.46
Psectrogaster amazonica (Eigenmann & Eigenmann, 1889)	2000	6.45	3.97	8.39	5.12
Anodus elongatus Agassiz, 1829	852	2.75	2.37	1.07	5.16
Hemiodus sp.	742	2.39	1.39	0.50	12.32
Prochilodus nigricans Spix & Agassiz, 1829	58	0.19	0.04	0.07	0.29
Semaprochilodus insignis (Jardine & Schomburgk, 1841)	50	0.16	0.19	0.08	0.30
Semaprochilodus taeniurus (Humboldt & Valenciennes, 1821)	38	0.12	0.07	0.07	0.06
Mylossoma albiscopum (Cope, 1872)	9838	31.74	30.71	55.02	32.84
Mylossoma aureum (Spix & Agassiz, 1829)	9110	29.39	30.24	51.91	29.00
Triportheus auritus (Valenciennes, 1850)	117	0.38	0.52	1.39	0.18
Total	30997	100	86.16	153.28	105.42

During the early life cycle, fish larvae are passively transported by the hydrodynamic system of the currents, going downstream from rivers until they find environments which are favorable to growth and development, such as floodplain lakes (Gogola, Sanches, Gubiani, & Silva, 2013; Ponte, Oliveira, & Zacardi, 2019; Zacardi et al., 2020). When the larvae find the Marrecas archipelago in the main channel of the Amazon River, they are retained in the environment and maximize their chances of survival since this place has ideal conditions for growth and escape from predators (Oliveira et al., 2020). Among these conditions that favor the development of larvae are the presence of aquatic vegetation, lower sediment concentrations and high biological productivity, ensuring food and protection for the larvae (Cajado, Oliveira, Suzuki, & Zacardi, 2020; Oliveira et al., 2020). Thus, the archipelago acts as a place of concentration and colonization of fish larvae, favoring the success in recruiting and renewing the fish stocks in the region.

The high occurrence of fish larvae, independently of conformations and landscape structures, configures the importance of the Marrecas archipelago as a nursery area. This importance is related to the presence of a mosaic of water bodies in the studied area, such as lakes and channels that connect with the fluvial system at least once a year. The connection between the island's internal areas and the Amazon River generates a complex environment composed of flooded forests that offer a series of successional habitats for the ichthyofauna and allows greater interaction and gene flow between species. Thus, the diversity of aquatic habitats within the island promotes intense dispersion and reproductive and ontogenetic movements of individuals, enabling the successful biological recruitment of species.

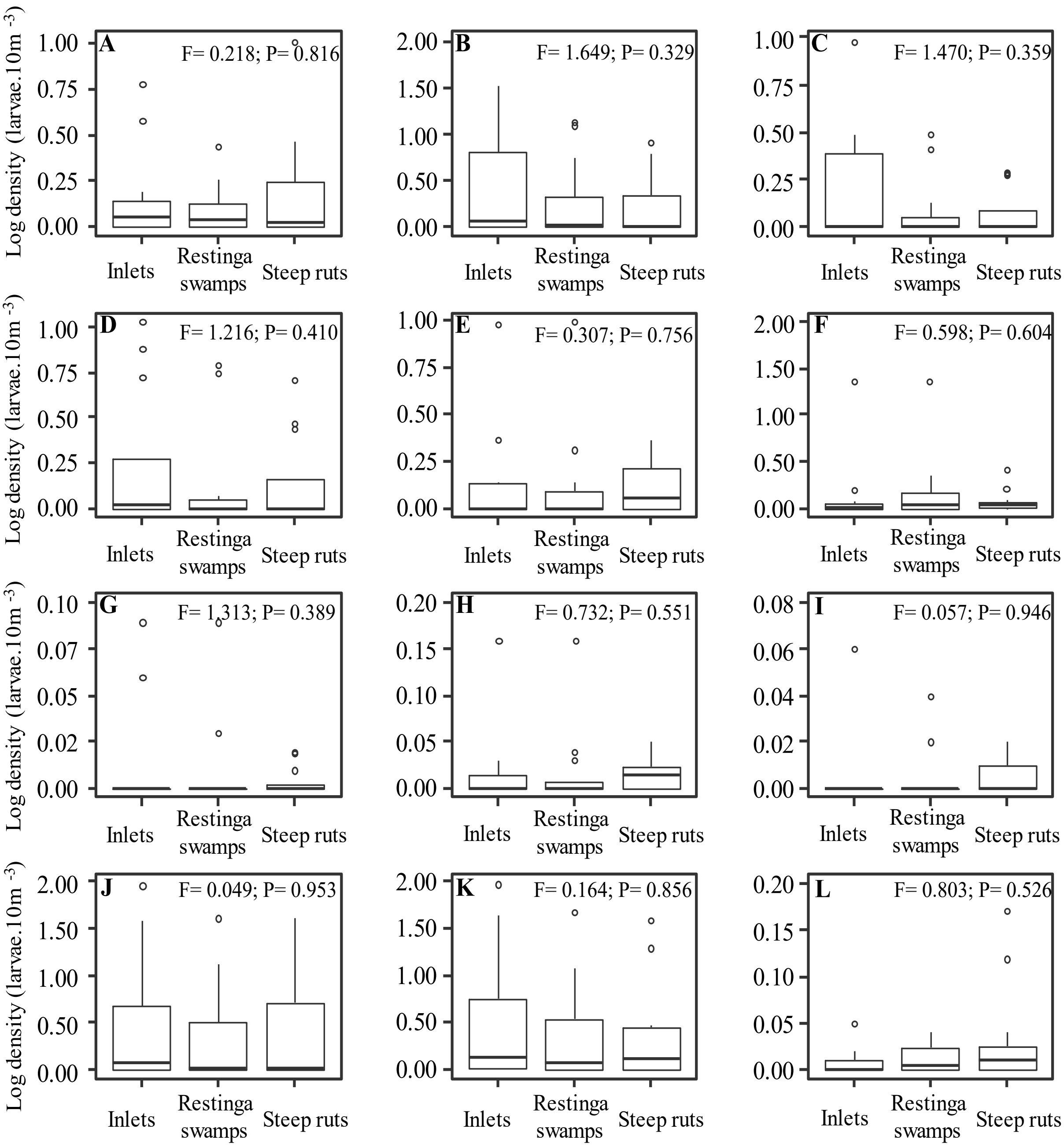

Figure 3. Density of larvae of migratory Characiformes species along the different habitats presents on the Marrecas archipelago in the Lower Amazon River, Santarém, Pará State, Brazil. A. *Leporinus* sp.; B. *Schizodon fasciatus*; C. *Potamorhina altamazonica*; D. *Psectrogaster amazonica*; E. *Anodus elongatus*; F. *Hemiodus* sp.; G. *Prochilodus nigricans*; H. *Semaprochilodus insignis*; I. *Semaprochilodus taeniurus*; J. *Mylossoma albiscopum*; K. *Mylossoma aureum*; L. *Triportheus auritus*. *F and P refer to ANOVA statistical results.

The density of Characiformes larvae showed a significant difference in relation to the phases of the hydrological cycle (ANOVA; $F = 147.30$; $p < 0.001$), being observed through the Tukey test differences between almost all phases ($p < 0.004$), except between rising water and receding water (Tukey; $p = 0.947$) (Figure 4).The mean density of the larvae along the phases of the hydrological cycle was: 17.72 larvae 10 m^{-3} in the flooding, 0.13 larvae 10 m^{-3} in the rising water, 0.04 larvae 10 m^{-3} in the receding water, and 1.33 larvae 10 m^{-3} in the drought.

The high density of larvae drifting during the flooding phase - the beginning of the rainy season in the region - was already expected since this moment is characterized as the reproduction and spawning season for migratory Characiformes species in the Amazon basin (Araújo-Lima & Oliveira, 1998; Zacardi et al., 2020). In the Amazon River system, the hydrological cycle influences all ecological processes, and the seasonal flood pulse is a process that induces the reproduction of many fishes (Goulding et al., 2019; Ponte et al., 2019). Therefore, these hydrological dynamics are pivotal for the survival of the offspring and maintenance of fishing resources.

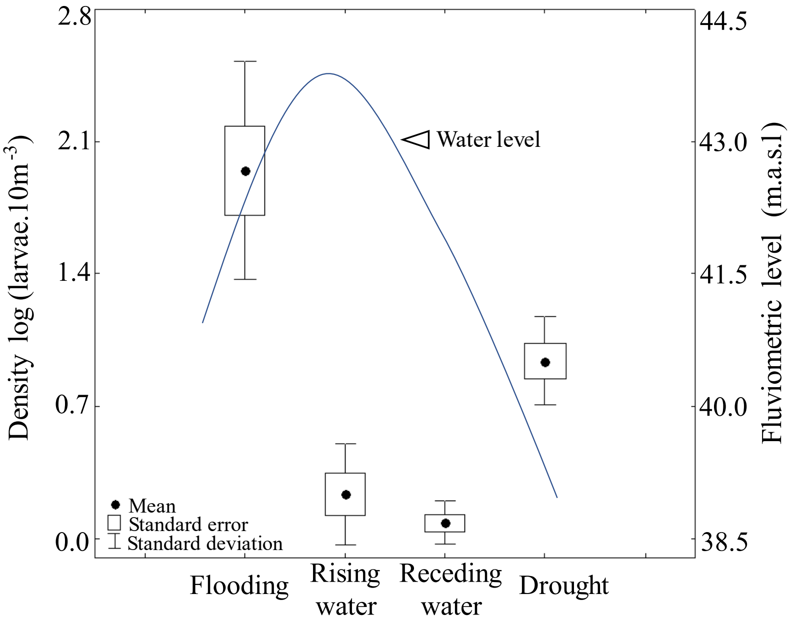

Figure 4. Seasonal distribution of the mean density of migratory Characiformes larvae captured from January to December 2013 along the phases of the hydrological cycle in the Lower Amazon River, Santarém, Pará State, Brazil. m.a.s.l= meters above sea level.

The Marrecas archipelago is characterized as an essential habitat for fish due to presenting favorable environmental conditions for feeding, reproduction, spawning, and development for fish larvae of different groups (Ferreira et al., 2016; Chaves, Carvalho, Ponte, Ferreira, & Zacardi, 2017; Chaves, Oliveira, Cajado, Ponte, & Zacardi, 2019; Ponte, Silva, & Zacardi, 2017; Zacardi et al., 2017a; Zacardi et al., 2017b). In this sense, the results indicate that the presence of the Marrecas archipelago positively influences the ichthyoplankton community in its surroundings. The archipelago in all its extension and present habitats provides favorable places for the development and survival of the early stages of migratory Characiformes that use the Lower Amazon River as a reproductive site over the hydrological cycle (Figure 5).

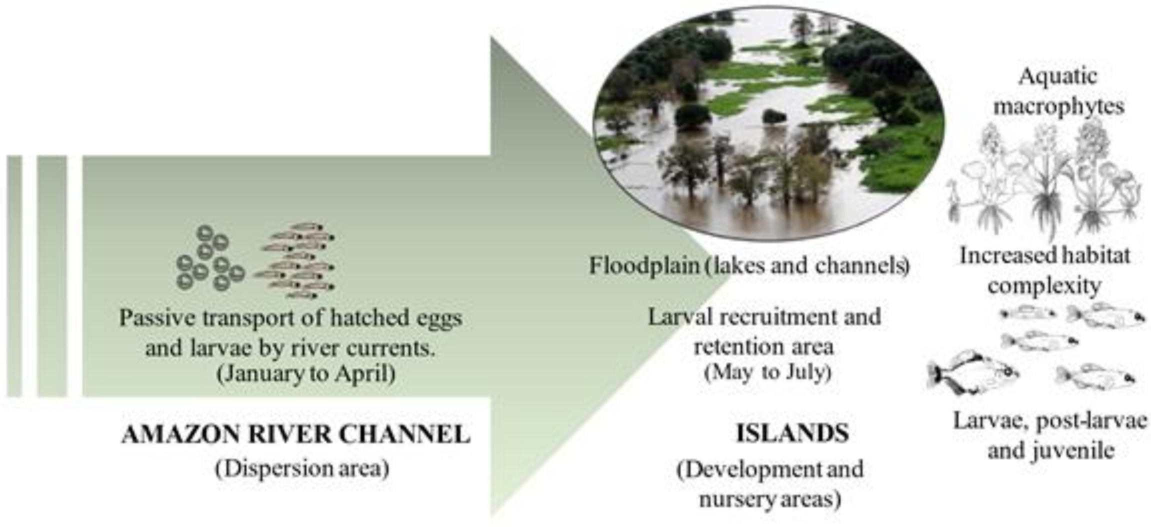

Figure 5. Conceptual model showing the process of dispersion and retention larvae of migratory Characiformes species in the Marrecas archipelago in the Lower Amazon River, Santarém, Pará State, based on Zacardi et al., 2017b, Cajado et al., 2020 and Oliveira et al., 2020.

Conclusion

Marrecas archipelago is a retention area for larvae of migratory Characiformes species of great commercial importance. The larvae densities varied over the phases of the hydrological cycle, with the peak observed during the flooding period of the Amazon River. The Marrecas archipelago has great importance for the sustainability of the natural stocks of migratory Characiformes species, assisting in the maintenance and renewal of these resources. For this reason, we believe that the information obtained in this study can contribute to future decisions on management and conservation measures and minimize actions that may cause the decline of these fish species.

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