An Acad Bras Cienc (2022) 94(1): e20201598 DOI 10.1590/0001-3765202220201598
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ANIMAL SCIENCE

Structure of the ichthyoplankton community in a Neotropical floodplain lake affected by environmental degradation

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Abstract: Many Amazonian fish' reproduction is associated to seasonality and to the conditions of habitat integrity. In a Neotropical floodplain lake of the Amazon region, the temporal structure of ichthyoplankton was investigated and the hypothesis that the density of fish eggs and larvae and the diversity of species vary between two areas with different levels of environmental changes occurred was tested. The sampling occurred monthly between September 2017 and August 2018. Six sampling stations were used, distributed in locations close to and far from the altered area. 195 eggs and 1,785 larvae from nine orders and 27 species were captured. The eggs were from non-migratory fish species and occurred during two moments. The larvae presented different abundance peaks during the sample months and all the initial stages of development occurred. Clupeiformes was the most abundant and Characiformes the species richest. The density of the ichthyoplankton and the diversity of species presented temporal variation. However, only the larval density varied between the areas of the lake. The Lake Juá is a spawning area for resident fish and is a nursery and growth area for larvae of species with different ecological categories and socioeconomic importance during different periods of the year.

Key words: Amazon, fish eggs and larvae, impacted area, Neotropical fishes, spawning, nursery.

INTRODUCTION

The environmental conditions of lakes adjacent to the numerous Amazonian rivers are associated with the seasonal dynamics of the flood pulse that generates temporary changes in their morphometry and in their existing habitats (Melack et al. 2009, Junk et al. 2012, Brito et al. 2017). Variations in water level allow the maintenance of natural patterns of longitudinal and lateral connectivity of water bodies and contribute to the dispersion and viability of fish populations (Osorio et al. 2011, Ortega et al. 2015).

In recent years, these aquatic environments have undergone several alterations of anthropogenic origin, causing severe impacts and interference in the relations of the fauna with the environment (Castello et al. 2013, Arantes et al. 2018, 2019). Thus, they compromise the provision of ecosystem services and generate socioeconomic losses to traditional populations.

The Amazonian ichthyofauna is one of the richest and most diverse biological communities in number of species (Reis et al. 2016, Dagosta & Pinna 2019). This diversity is associated with the large number of aquatic ecosystems, the extent of the basin and/or linked to ecological factors such as habitat complexity, biotopes, physicochemical parameters, among other factors. The existence of these conditions allows them to play a relevant role and directly influence the life history of fish (Leal et al. 2018, Oberdorff et al. 2019, Oliveira et al. 2020a).

Understanding the patterns and variations in the distribution and composition of egg and larvae of fish assemblage leads to insights on aspects that regulate the biological recruitment of species and serves as an effective method in the determination and delimitation of spawning and growth times and areas (Silva et al. 2012, Cajado et al. 2020a). However, studies of this nature in oligotrophic water environments in the Amazon are scarce and are limited to the work of Lima & Araujo-Lima (2004), Zacardi & Ponte (2016) and Cajado et al. (2020a).

In this context, this study aims to evaluate the variation of the structure and diversity of fish eggs and larvae in a Neotropical floodplain lake in the Amazon region through analysis of composition, abundance and occurrence of development stages. Due to the several anthropic processes that occurred in the studied area and the existence of a more preserved and a more altered area, the hypothesis that the density of the ichthyoplankton and the diversity of species differ between the two areas over the sampling months was tested.

MATERIALS AND METHODS

Study area

Lake Juá is located around an Environmental Protection Area (APA of Juá) on the right bank of the Tapajós River (2°25’55” S and 54°46’36” W) near the confluence with the Amazon River, Lower Amazon, Pará, Brazil (Fig. 1). The lake presents seasonal morphological variation due to: the annual flood pulse of the region, the local rainfall peak and the confluence flow of many headwaters and igarapés (streams) in its surroundings. This water body is connected to the Tapajós River through a short winding and perennial channel.

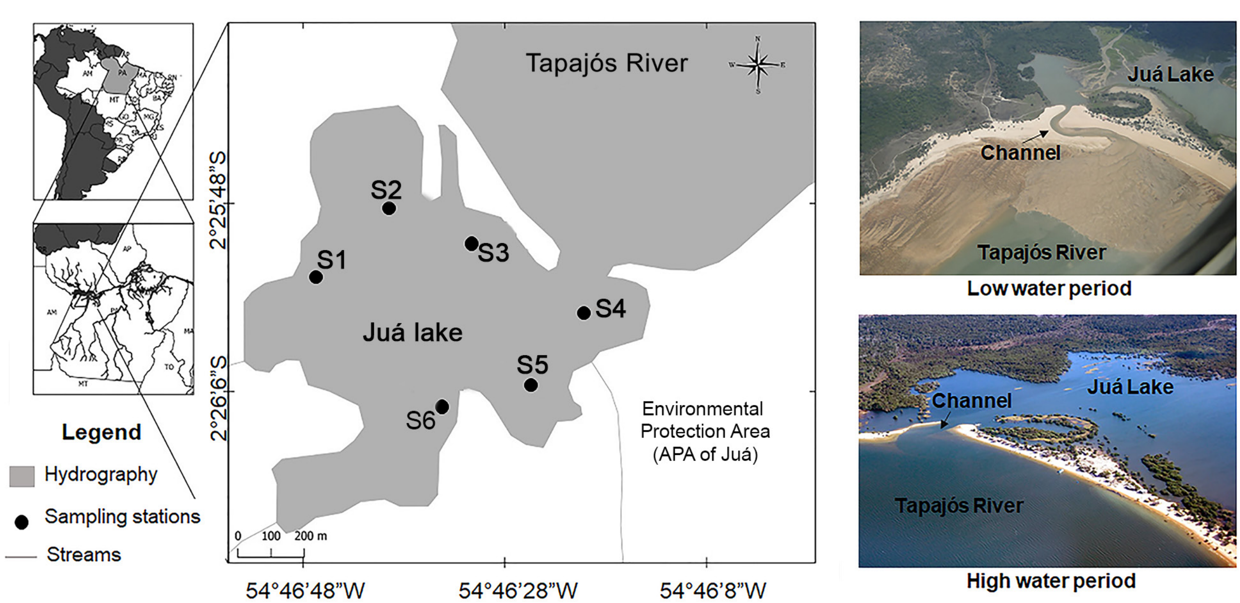

Figure 1. Study area with emphasis on Lake Juá located at the mouth of the Tapajós River and the distribution of sampling points. Photos of Manuel Dutra (low water) and Celso Lobo (high water).

This lake environment is widely used by several fishermen and local residents who survive directly or indirectly from fishing (Rabelo et al. 2017, Corrêa et al. 2018, Serrão et al. 2019). However, Lake Juá is suffering from the effects of anthropogenic intervention that have caused fires, deforestation, silting and erosion of its marginal areas to give way to irregular occupation that houses hundreds of families and a large housing development. These activities have caused several conflicts between residents, fishermen, entrepreneurs and public agencies (Corrêa et al. 2018, Nascimento & Santos 2019, Cardoso et al. 2021).

The local climate is humid tropical, with an average annual temperature of 27.7°C and little variability in humidity and air temperature. The average rainfall is 2,096 mm, with the highest concentrations between December and June (rainy season) and the lowest between July and November (dry season) (Costa et al. 2013).

Sampling

The samples were collected monthly between September 2017 and August 2018 in daytime and nighttime samplings, totaling 144 samples. The license for the collection of biological material was granted by Sistema de Autorização e Informação em Biodiversidade (SISBIO) of Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), authorization number 72,330, issued based on Normative Instruction no. 154/2007 of Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA).

The samplings occurred in six stations properly georeferenced and spatially divided into two areas: *area 1*- "more conserved" (S1, S2 and S3) and *area 2*- "more altered" (S4, S5 and S6). The area considered most conserved on the lake has little landscape alteration in its riparian forest and is widely used as a fishing spot. The area considered most altered, on the other hand, has a large surrounding area deforested, high rates of sedimentation, allochthonous inorganic material from areas deforested by the developments adjacent to the lake, in addition to undergoing an intense silting process.

The ichthyoplankton was captured, on board a local vessel, by horizontal trawling on the subsurface of the water column using plankton net (300 μm mesh) with a coupled flowmeter to obtain the volume of filtered water. The samples were submitted to Eugenol solution (50 mg/L), fixed in 10% formalin solution buffered with calcium carbonate and packed in polyethylene bottles (500 mL). The fluviometric level data were provided by the Capitania Fluvial da Marinha do Brasil in Santarém, state of Pará, Diretoria de Hidrografia e Navegação.

Sample processing

The samples were sorted by separating the larvae from the suspended material and from the total plankton using a stereoscopic microscope. Subsequently, the eggs were quantified and classified according to the reproductive strategy of the species (migratory and non-migratory) and the stages of embryonic development were determined. The larvae were also quantified and identified at the lowest possible taxonomic level by specialized bibliographies, and they were classified as the larval development phase. These classifications were based on Nakatani et al. (2001) and Orsi et al. (2016).

The taxonomic framework was based on Betancur-R et al. (2017) and the reproductive strategy (migratory and non-migratory) of the species based on the information of adult individuals (Barthem & Fabré 2004, Granado-Lorencio et al. 2005, Goulding et al. 2019). Specimens were deposited in the Laboratório de Ecologia do Ictioplâncton e Pesca em Águas

Interiores at the Universidade Federal do Oeste do Pará to constitute a reference collection.

Data analysis

The abundance was standardized for ichthyoplankton density by $10m^{-3}$ of filtered water according to Nakatani et al. (2001). The density data matrix of fish eggs and larvae did not meet the assumptions of normality (Shapiro-Wilk test) and homoscedasticity (Levene test) and therefore only nonparametric analyses were used.

To verify possible significant differences in ichthyoplankton density variation between sampling months, the Kruskal-Wallis test was applied. The Bonferroni post-hoc correction test was used to adjust the alpha values to determine statistical significance. Larval density and abundance of development stages were considered as predictor variables and sampling months as response variable. An analysis of similarities (ANOSIM) was performed to test whether species composition and larval stages significantly differed between the sampling months. When different, similarity percentages (SIMPER) were performed to identify the species responsible for the variation. Before the analyses, the data were transformed into log (x+1) and the similarity matrices based on the Bray-Curtis distance (Clarke 1993).

A nested two-way permutational multivariate analysis of variance (two-way PERMANOVA nested design) was performed to verify differences in the density of eggs and fish larvae and the diversity of species as a function of the sampled areas (conserved and altered) and the months of sampling. PERMANOVA was performed based on the Hellinger distance matrix with 999 permutations (Anderson 2001). Species diversity was based on the Shannon-Wiener index (Magurran 2013). The statistical tests were performed in the software R Studio version 4.0.1, Vegan package (Oksanen et al. 2019) with the significance level of $p < 0.05$.

RESULTS

A total of 195 eggs and 1,785 fish larvae were collected. All eggs belonged to non-migratory species and were obtained only in two months of sampling. The larvae presented heterogeneous distribution but were recorded in all sampling stations and were taxonomically grouped into nine orders, 18 families and 27 species (Table I). Of all captured species, 48.15% (n= 13) have economic importance for the Amazon region. Most are sedentary and do not perform reproductive migrations (63%; n= 17). Clupeiformes (five species) was the most abundant order (54%), followed by Gobiiformes (one species) (23%) and Characiformes (13 species) (17%), which together made up more than 90% of the total captured larvae, making these groups the most representative in the study area (Fig. 2).

The eggs were obtained only in two sampling months: April, which is characterized as the end of the Tapajós River flood period, with the capture of *Loricariichthys acutus* carrying eggs in the final phase of development; and December, with the contribution of pelagic eggs of non-guarding species (Fig. 3). The temporal distribution of egg density varied significantly over the sampling months (KW-H= 27.718; p= 0.0036), April differed from the other months (Dunn's test; $p < 0.05$).

Larval density also varied significantly over the months (KW-H= 36.647; p= 0.0001), with a clear seasonality pattern. This difference is the result of the variations observed between October and April (Dunn's Test; p = 0.0014), October and November (Dunn's test; p = 0.0004),

Table I. **Taxonomic composition, total abundance and monthly variation of the density of ichthyoplankton collected in Lake Juá, during samplings from September 2017 to August 2018, at the mouth of the Tapajós River, state of Pará, Brazil. EI: economic importance. (♦) Marketed in regional marts and fairs. (◊) Ecological importance in the ecosystem. TN: total number. RS: reproductive strategy. M: migratory species. NM: non-migratory species. *Yolk-sac stage individual.**

ORDER/ FAMILY/ SPECIES	TN	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	EI	RS
CHARACIFORMES	153*	0.16	-	0.03	0.02	-	-	-	-	-	-	-	21.61		
Anostomidae	-														
Rhytiodus microlepis Kner, 1858	2	-	-	-	-	-	-	-	-	-	-	-	0.23	♦	M
Characidae	3	0.03	-	-	-	-	-	-	-	-	-	0.03	0.02		
Hyphessobrycon cf. *pulchripinnis* Ahl, 1937	2	-	0.01	-	-	-	-	-	-	-	-	-	0.08	◊	NM
Moenkhausia sp.	5	-	0.02	-	-	-	-	-	-	-	-	-	0.38	◊	NM
Curimatidae	-														
Psectrogaster amazonica Eigenmann & Eigenmann, 1889	51	0.18	0.19	-	-	-	-	-	-	-	-	0.09	4.77	♦	M
Erythrinidae	-														
Hoplias malabaricus (Bloch, 1794)	4	-	-	-	-	-	-	-	-	-	-	-	0.32	♦	NM
Hemiodontidae	-														
Anodus elongatus Agassiz, 1829	1	-	0.01	-	-	-	-	-	-	-	-	-	-	♦	M
Hemiodus cf. *immaculatus* Kner, 1858	22	0.31	0.03	-	-	-	-	-	-	0.17	-	-	0.28	♦	M
Hemiodus cf. *unimaculatus* (Bloch, 1794)	49	0.19	-	-	0.02	-	-	0.48	3.23	0.32	-	0.06	0.31	♦	M
Hemiodus cf. *microlepis* Kner, 1858	2	-	-	-	-	-	-	-	-	-	-	-	0.23	♦	M
Hemiodus sp.	3	0.02	0.01	-	0.02	-	-	-	-	-	-	-	-	♦	M
Iguanodectidae															
Iguanodectes spilurus (Gunther, 1864)	1	-	-	-	-	-	-	-	-	-	-	-	0.15	◊	NM
Serrasalmidae	-														

Table I. Continuation.

Mylossoma aureum (Spix & Agassiz, 1829)	2	-	-	-	-	-	-	0.13	-	-	-	-	-	♦	M
Serrasalmus sp. (Cuvier, 1818)	3	0.02	-	0.03	0.02	-	-	-	-	-	-	-	-	♦	NM
CICHLIFORMES	-														-
Cichlidae	1	-	-	-	-	-	-	-	-	-	1.72	-	-	-	
Crenicichla sp.	1	-	-	-	-	-	-	-	-	-	-	-	0.08	◊	NM
CLUPEIFORMES	67	-	-	-	-	-	-	-	-	0.59	-	-	6.00		
Engraulidae	497	0.43	1.16	1.51	0.24	4.30	1.81	3.64	2.59	0.84	1.72	0.15	16.38	◊	
Anchoviella guianensis (Eigenmann, 1912)	15	-	0.12	0.03	-	-	-	-	-	-	13.23	-	0.62	◊	NM
Anchoviella jamesi (Jordan & Seale, 1926)	263	31.69	0.48	0.72	0.01	-	0.16	-	-	0.81	188.61	-	8.07	◊	NM
Anchoviella juruansanga Loeb, 2012	113	-	1.23	0.69	0.07	0.38	0.31	0.82	0.24	0.17	-	0.22	-	◊	NM
Pristigasteridae	-														
Pellona flavipinnis (Valenciennes, 1837)	4	-	-	-	-	-	-	-	-	0.20	-	-	-	♦	M
Pellona castelnaeana Valenciennes, 1847	2	-	0.01	-	-	-	-	-	-	0.06	-	-	-	♦	M
GOBIIFORMES	-														
Eleotridae	-														
Microphilypnus tapajosensis Caires, 2013	414	4.35	1.45	0.65	0.36	1.54	0.92	1.07	1.01	35.1	-	0.16	5.40	◊	NM
GYMNOTIFORMES	-														
Sternopygidae	-													-	
Sternopygus cf. *macrurus* (Bloch & Schneider, 1801)	2	-	0.02	-	-	-	-	-	-	-	-	-	-	◊	NM
Eigenmannia sp.	1	-	-	-	0.04	-	-	-	-	-	-	-	-	◊	NM
PERCIFORMES	-														
Sciaenidae	-														

Table I. Continuation.

Plagioscion squamosissimus (Heckel, 1840)	2	-	-	-	-	0.11	-	-	-	-	-	-	-	♦	NM
PLEURONECTIFORMES	-														
Achiridae															
Hypoclinemus mentalis (Günther, 1862)	43	-	-	-	-	1.33	0.47	0.40	0.21	0.17	-	-	-	◊	NM
SILURIFORMES	1	-	-	0.02	-	-	-	-	-	-	-	-	-		
Auchenipteridae	-														
Trachelyopterus cf. *coriaceus* Valenciennes, 1840	2	-	0.05	-	-	-	-	-	-	-	-	-	-	◊	NM
Doradidae	5	-	0.09	-	0.02	-	-	-	-	-	-	-	-		
Trichomycteridae	-														
Paracanthopoma sp.	2	-	-	-	0.02	-	0.04	-	-	-	-	-	-	◊	NM
TETRAODONTIFORMES	-														
Tetraodontidae	-														
Colomesus asellus (Müller & Troschel, 1849)	6	-	0.03	-	-	0.42	0.04	-	-	-	-	-	-	◊	NM
Unidentified larvae	41	0.44	0.13	0.02	-	0.55	0.04	0.61	1.16	-	1.95	-	-		
Total (larvae)	1.785	263	243	139	57	110	65	74	52	68	81	18	615		
Eggs of non-migratory species (non-guarding species)	38	-	-	-	-	-	-	-	-	-	-	-	3.11		NM
Eggs of non-migratory species (guarding species)	157	-	-	-	3.10	-	-	-	-	-	-	-	-		NM
Total (eggs)	195	-	-	-	157	-	-	-	-	-	-	-	38		

November and January (Dunn's Test; p = 0.0094) and November and May (Dunn's Test; p = 0.0186).

The species composition also differed between months (ANOSIM; Global R= 0.468; p < 0.0001). A high dissimilarity was recorded (SIMPER; > 60%) with high contribution of Pleuronectiformes (*Hypoclinemus mentalis*) during May, from Gobiiformes (*Microphilypnus tapajosensis*) in September, individuals of the order Clupeiformes (species of the genus *Anchoviella*) in October and by the Characiformes (*Hemiodus immaculatus*, *Hemiodus unimaculatus* and *Psectrogaster amazonica*) during December (Fig. 3).

Through PERMANOVA it was possible to verify significant differences in spatial, temporal effects and the interaction of the two factors only for the larval community (Table II), indicating a variation of fish larvae between the two areas studied between the sampling months (Fig. 4b). The highest egg densities in the most conserved region of the lake (Fig. 4a) indicate that this site is a spawning area for non-migratory species. The diversity of species did not vary significantly

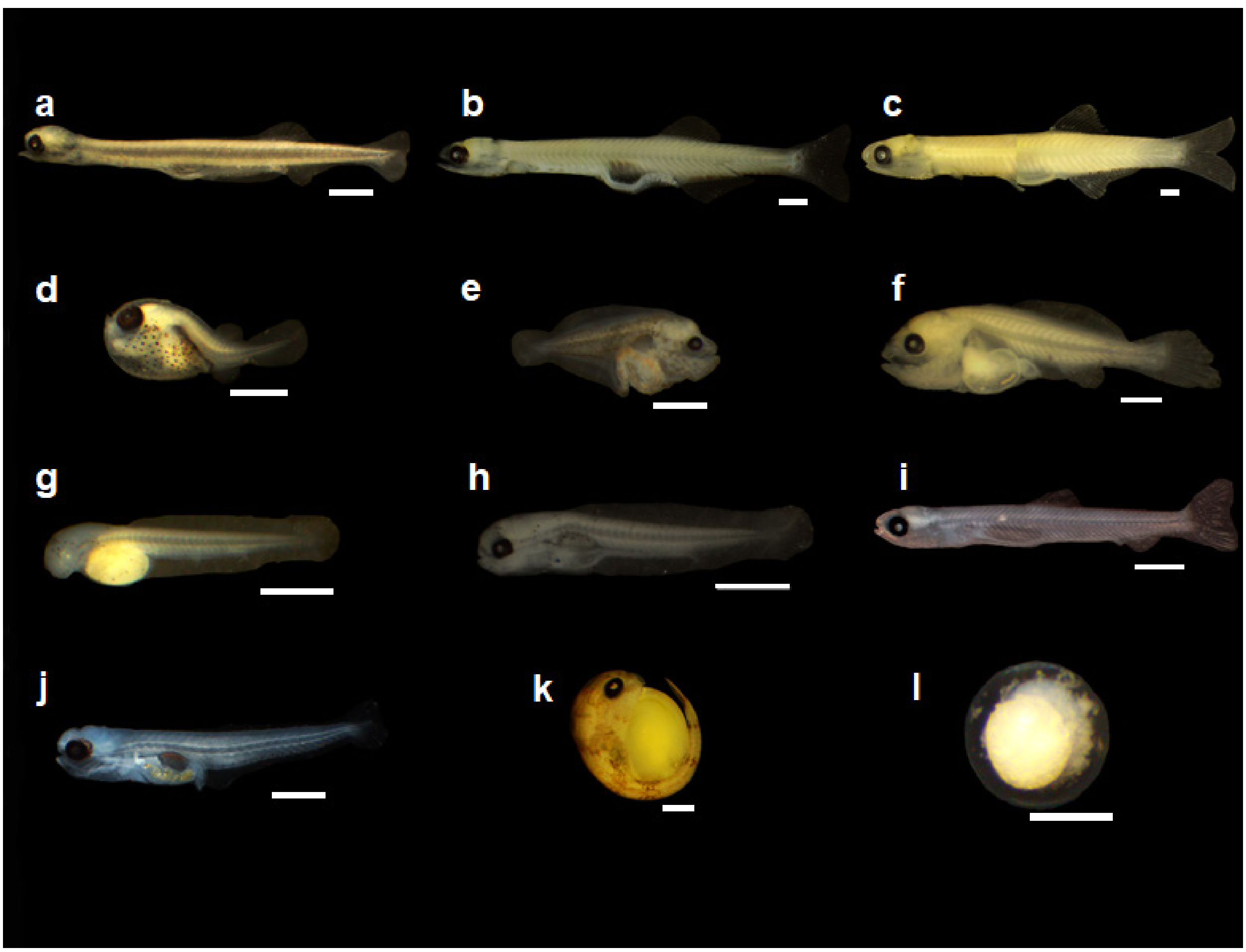

Figure 2. **Images of some ichthyoplankton organisms collected during samplings from September 2017 to August 2018 at Lake Juá, at the mouth of the Tapajós River, state of Pará, Brazil. a) Engraulidae; b) *Anchoviella juruassanga*; c) *Anchoviella jamesi*; d) *Colomesus asellus*; e) *Hypoclinemus mentalis*; f) *Plagioscion squamosissimus*; g) Characiformes yolk-sac stage; h) *Psectrogaster amazonica*; i) *Hemiodus immaculatus*; j) *Microphilypnus tapajosensis*; k) egg with visualization of the embryo of *Loricariichthys acutus* in the final stage (guarding species) and l) pelagic egg in the initial cleavage of non-guarding specie. Bars = 1 mm.**

between the two areas studied, presenting only temporal variation (Table II) (Fig. 4c).

Only eggs in two stages of embryonic development were captured, with significant difference of density between the sampling month for those in initial cleavage (KW-H= 10.50; p= 0.005). Eggs in the final embryo stage corresponded to 80.5% of the total catch, while those in the initial cleavage represented only 19.5% (Fig. 5a). All larval stages of development were captured and significant variations in their abundances were verified throughout the sampling months (ANOSIM; Global R= 0.303; p= 0.001). Most larvae were in preflexion stage (49%) and the lowest captures were from individuals in the yolk-sac stage (9.27%) (Fig. 5b).

DISCUSSION

The ichthyoplankton community of the lake was composed mostly of individuals of non-migratory species and presented variation in composition and density over the sampling months. The absence of eggs from species that perform reproductive migration was already expected, since the reproduction of this group is associated with nutrient-rich rivers (e.g., Amazon/Solimões River) that favor the development of pelagic and semi-dense eggs through the dynamics of its currents (Lopes & Zaniboni-Filho 2019, Zacardi et al. 2020a, Cajado et al. 2020b). In Neotropical lentic environments, the reproduction of ichthyofauna is more favorable for species that have parental care strategies throughout their life histories (Nakatani et al. 2001, Orsi 2010, Garcia et al. 2018).

The higher numerical capture of Clupeiformes may be related to the ecological and biological aspects of this group. Clupeiformes species present great trophic and reproductive flexibility and may complete their life cycles in several environments (Bloom & Egan 2018, Egan et al. 2018). However, following the composition patterns of Amazonian fish described by Dagosta

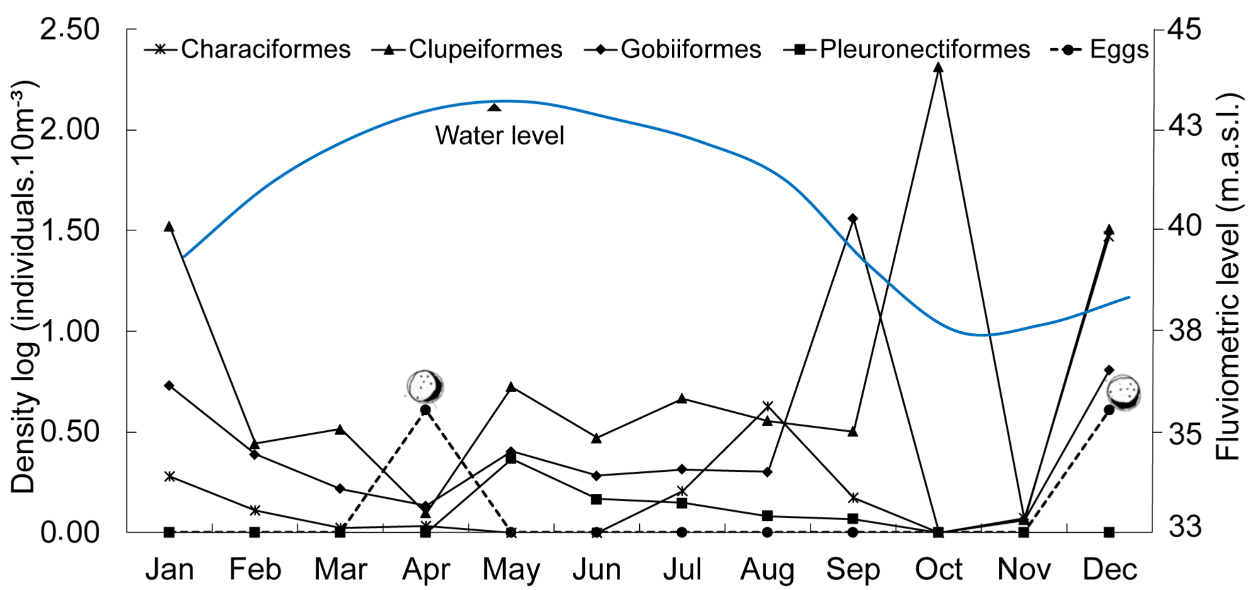

Figure 3. Variation of the density (log transformed) of orders with relative abundance above 2% over the sampling period in Lake Juá and variation of the water level of the Tapajós River, state of Pará, Brazil. m.a.s.l = meters above sea level.

& Pinna (2019), the order Characiformes was more diverse and represented mostly by small and medium-sized species.

Among the Clupeiformes, the Engraulidae was the most abundant along with the species of the genus *Anchoviella*. This group acquired several specific (morphological and ecological) adaptive advantages along its radiation in the South American basins (Nynatten et al. 2015, Bloom & Lovejoy 2017). This allowed them to use new niches and succeed in colonizing the aquatic freshwater of the Amazon. Another abundant order was the Gobiiformes represented solely by *Microphilypnus tapajosensis*. It is considered a forage species, small-sized and without economic importance, but of great importance for the aquatic trophic chain (Caires 2013, Oliveira et al. 2020b). This information allows us to highlight the relevance of Lake Juá as a nursery area for these two groups.

Lake Juá is widely used for the capture of several fish species, especially the "jaraquis" *Semaprochilodus insignis* (Jardine 1841) and *Semaprochilodus taeniurus* (Valenciennes 1821), which constitute an important food item of the Amazon population (Corrêa et al. 2018), but larvae of these species were not recorded. According to Zacardi et al. (2017b) the *Semaprochilodus* use the lowland areas along the trough of white-water rivers as breeding sites and nurseries. However, larvae from other groups with relative socioeconomic importance were found in the lake (species of the genus *Hemiodus* "charutinhos", *Psectrogaster amazonica* "branquinhas", *Plagioscion squamosissimus* "pescada-branca" and *Pellona castelnaeana* and *P. flavipinnis* "apapás"), as well as by adult individuals (Corrêa et al. 2018). This condition demonstrates the ability of this lake environment to assist in the maintenance of fishery stocks.

In the Amazon region, many fish species usually spawn during the first months of the year, due to heavy rains and increased water level in the main rivers (Ponte et al. 2017, Zacardi et al. 2017a, b). However, the reproduction of other species can occur at different times (Chaves et al. 2019, Ponte et al. 2019, Serrão et al. 2019), as observed in this study. For example, Clupeiformes larvae, mainly from Engraulidae, which presented their highest abundances

Table II. Summary of the two-way PERMANOVA on the spatial and temporal effects on the density of fish eggs and larvae and on the diversity of species in Lake Juá at the mouth of the Tapajós River, state of Pará, Brazil. Values in bold represent a significant difference. df: degree of freedom. Pseudo-F: pseudo-F statistics. R^2: R squared.

Community	Variables	df	Pseudo-F	R^2	p-value
Eggs	Temporal	11	1.093	0.165	**0.027**
	Spatial	1	2.136	0.029	0.138
	Temporal *vs* Spatial	11	0.977	0.147	0.532
Larvae	Temporal	11	11.896	0.427	**0.001**
	Spatial	1	7.959	0.026	**0.002**
	Temporal *vs* Spatial	11	10.874	0.390	**0.001**
Diversity	Temporal	11	2.499	0.312	**0.019**
	Spatial	1	2.304	0.026	0.151
	Temporal *vs* Spatial	11	0.940	0.117	0.518

during October – drought and lower water level, confirming the reproduction pattern of the group (Ponte et al. 2019).

This variation in the species reproduction is closely related to the environmental conditions that: favor the development of offspring, synchrony with the reproductive activity of adults and evolution results of strategies in the life history of the species (Smith & Wootton 2016, Zacardi & Ponte 2016). Moreover, it corroborates the information that both in lentic and lotic water bodies, fish species present positive responses to environmental stimuli (Sanches et al. 2020).

Lake Juá has a history of disturbances arising from anthropogenic activities in its adjacent forest area that have modified the landscape and some of its limnological parameters. Among the

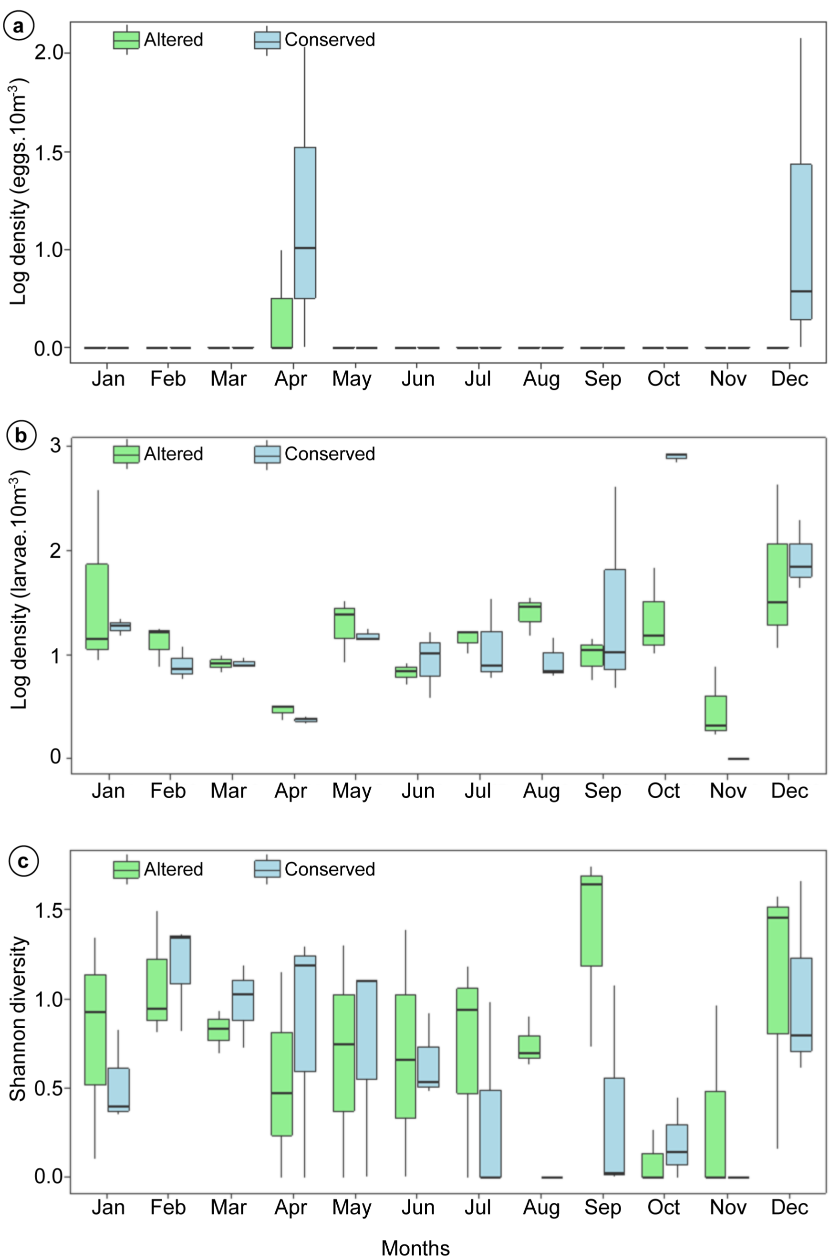

Figure 4. Variation in the density (log transformed) of a) eggs; b) fish larvae and c) species diversity between the altered and conserved areas of Lake Juá over the months of sampling, state of Pará, Brazil.

consequences of anthropogenic disturbances in the lake (i.e., deforestation of the area adjacent to the lake) are increased concentrations of inorganic matter, particulate matter, and high turbidity (Cardoso et al. 2021). The morphological and biogeochemical conditions of freshwater ecosystems are directly related to the presence of native vegetation in their surroundings and that deforestation has been one of the main causes of increased sediment exports to aquatic environments and soil erosion (Neill et al. 2001, Castello et al. 2013). Furthermore, changes in land cover, impacts of dam constructions and other degrading activities are reported as one of the responsible for the reduction of ecosystem services provided by aquatic environments (Castello & Macedo 2016).

The temporal variation in the diversity of fish larvae was already expected, since the occurrence of certain species of the ichthyofauna is influenced by the complexity of the habitat and seasonality (Pinheiro et al. 2016, Oliveira et al. 2020a). The capture of eggs and fish larvae and the absence of significant differences in species diversity along the spatial scale in Lake Juá is an indication that this environment demonstrates a resilience capacity even with past environmental impacts having changed some lake conditions (Corrêa et al. 2018, Cardoso et al. 2021). This capacity may be related to the direct connectivity of the lake with the main river and the confluence of igarapés (streams), which allow greater flow in the exchange of water and ecological interactions of the species between the adjacent aquatic systems throughout all months of the year.

Since the lake has a direct connection with the main river (Tapajós River) and several streams, the presence of larvae within this environment can have three origins: coming from reproductive activities in the Tapajós River, resulting from the reproduction of small species in adjacent streams or from the gene flow that occurred within the lake itself. This allows us to infer that not only the lake is essential in the maintenance of the regional ichthyofauna,

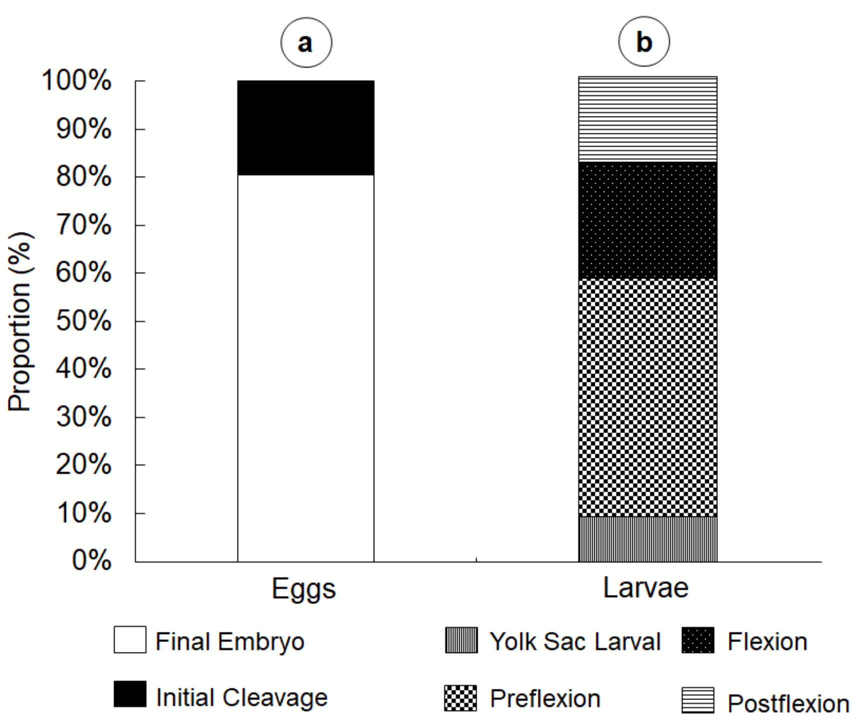

Figure 5. Variation of the capture proportion of development stages of a) fish eggs and b) larvae in Lake Juá, state of Pará, Brazil.

but all the habitats that surround the lake environment, such as the streams, connecting channels and the main river are pivotal. In this sense, future studies should also focus on the role of these adjacent habitats in the occurrence and distribution of fish eggs and larvae.

The capture of eggs in the early and final development stages of non-migratory species emphasizes the premise of the use of this environment as a breeding site for resident fish species (i.e., which have their entire life cycle in the lake). The capture of larvae in early stages (yolk-sac and preflexion) and final development (flexion and postflexion) demonstrates that the lake helps in the renewal of the local ichthyofauna stocks and acts as nursery, growth and development area for the species.

Thus, maintaining the integrity and conservation of these environments that help the renewal of fishery stocks is essential because the improvement of environmental quality generates favorable conditions for the maintenance of fish communities, in addition to ensuring food security for local traditional populations (Pinaya et al. 2016, Begossi et al. 2019, Ponte et al. 2019, Zacardi et al. 2020b). After all, when ensuring the protection of habitats used during the early stages of fish life, the survival of offspring is maximized and the chances of success in the recruitment of populations are increased (Costa et al. 2016, Zacardi et al. 2017a).

In this case, it is essential to implement actions that minimize the environmental changes occurred in Lake Juá and that these measures are designed and implemented according to a participatory and shared management as an integrative tool among users (fishers, residents and tourists), environmentalists and public agencies. Consequently, the lake will continue to maintain its resilience, its ecological and socioeconomic importance. Furthermore, future studies should focus on the relationship of ichthyoplankton with the lake's environmental parameters and the influence of adjacent environments (streams and main river) on the input of eggs and fish larvae in the lake system. The results serve as a subsidy to public policies and to establish sustainable and efficient management actions with repercussions on regional fishing.

Acknowledgments

The authors would like to thank the collaborators of the Laboratório de Ecologia do Ictioplâncton e Pesca em Águas Interiores (LEIPAI) of the Universidade Federal do Oeste do Pará (UFOPA) for their assistance in the field. They also thank the Conselho Nacional de Desenvolvimento Cientifíco e Tecnológico (CNPq) for the financial resources of this research.

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How to cite

DE OLIVEIRA LS, CAJADO RA, DOS SANTOS LRB & ZACARDI DM. 2022. Structure of the ichthyoplankton community in a Neotropical floodplain lake affected by environmental degradation. An Acad Bras Cienc 94: e20201598. DOI 10.1590/0001-3765202220201598.

Manuscript received on October 5, 2020; accepted for publication on April 21, 2021

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DMZ, LRBS, LSO and RAC were responsible for the sample design, collections, counting and identification of the ichthyoplankton. LSO and RAC produced the statistical analysis. LSO produced the results and discussion. DMZ reviewed all text of the manuscript.