Lagoas marginais: berçários naturais para peixes migradores

Marginal lagoons: natural nurseries of migratory fish

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Resumo

Introdução: As lagoas marginais constituem ambiente complexo que potencializa o sucesso reprodutivo das espécies migratórias, fornecendo abrigo e recursos. Objetivo: Nosso estudo teve o objetivo de avaliar o papel dessas lagoas no recrutamento de peixes migradores da bacia do rio São Francisco. Metodologia: Para a realização dos estudos, foram realizadas coletas mensais de peixes, especialmentes exemplares jovens, durante um ano em quatro lagoas marginais do rio Jequitaí: Lagoão (LAG), Renero (REN), Buriti (BUR) e Tamatião (TAMA). Resultados: Foram capturados 1.049 indivíduos pertencentes a sete espécies de peixes migradores: *Brycon orthotaenia*, *Megaleporinus obtusidens*, *Prochilodus argenteus*, *Prochilodus costatus*, *Pseudoplatystoma corruscans*, *Salminus franciscanus* e *Salminus hilarii*. Como resultado foi observado que o comprimento médio dos exemplares capturados foi de 13,6 cm e o peso corporal médio de 80,7 g, evidenciando o predomínio de peixes jovens. A espécie mais representativa em números absolutos foi *L. obtusidens* (41,47%) enquanto *P. costatus* foi a mais representativa (24,57%) na biomassa. *Salminus hilarii* e i apresentaram as menores taxas de aumento do comprimento corporal (1,90 e 2,10, respectivamente). *S. franciscanus* e *M. obtusidens* aumentaram seu comprimento em 4 e 3,6 vezes, respectivamente. Além disso, *S. franciscanus* e *M. obtusidens* aumentaram seu peso em 81,3 e 102,4 vezes, respectivamente. Conclusão: Os dados obtidos nos permite concluir que as lagoas marginais podem funcionar como grandes berçários para o desenvolvimento e recrutamento de peixes migradores, contribuindo assim para a conservação de peixes de importância comercial e ecológica.

Além disso, este estudo reduz a escassez de conhecimento sobre o uso de lagoas marginais por espécies de peixes migradores e destaca a importância desses ambientes.

Palavras-Chave: Lagoas marginais; Berçários naturais; Recrutamento; Peixes migradores; Rio Jequitaí.

Abstract

***Introduction**: Marginal lagoons constitute a complex environment that enhance the reproductive success of migratory species, providing shelter and resources. **Objective:** Our study aimed to evaluate the role of marginal lagoons in the recruitment of migratory fish from the São Francisco river basin. **Methodology:** To carry out the studies, monthly collections of fish were carried out, especially young specimens, for one year in four marginal lagoons along the Jequitaí river: Lagoão (LAG), Renero (REN), Buriti (BUR), and Tamatião (TAMA). **Results:** A total of 1,049 individuals belonging to seven species of migratory fish were caught: Brycon orthotaenia, Megaeporinus obtusidens, Prochilodus argenteus, Prochilodus costatus, Pseudoplatystoma corruscans, Salminus franciscanus, and Salminus hilarii. As a result it was observed that the average length of the captured specimens was 13.6 cm and the average body weight was 80.7 g, thus showing a predominance of young fish. The most representative species in absolute numbers was M. obtusidens (41.47%) while P. costatus was most representative (24.57%) in biomass. Salminus hilarii and P. argenteus had the lowest rates of body length increase (1.90 and 2.10, respectively). S. franciscanus and M. obtusidens increased their length by 4 and 3.6 fold, respectively. Also, S. franciscanus and M. obtusidens increased their weight by 81.3 and 102.4 times respectively. **Conclusion:** The results obtained allow us to conclude that marginal lagoons can function as large nurseries for the development and recruitment of migratory fish, thus contributing to the conservation of fish that are commercially and ecologically important. Furthermore, this study reduces the scarcity of knowledge on the use of marginal lagoons by migratory fish species and highlights the importance of these environments.*

***Keywords**: Marginal lagoons; Natural nurseries; Recruitment; Migratory fish; Jequitaí river.*

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1. Introduction

Fish represent approximately 50% of vertebrates, with approximately 33,200 species[1]. The Neotropical region, which includes South America, has the most diverse freshwater fish fauna in the world. As Brazil has the largest hydrographic network on the planet, it holds the

greatest wealth of freshwater fish species, with around 3,000 species[2].

Most teleosts reproduce seasonally and spawning generally occurs when the environmental conditions are favourable for offspring survival, especially those related to food supply, shelter and space availability[3]. Some fish species migrate to reproduce from the lower parts of rivers to places suitable for spawning[4,5]. After spawning, fertilised eggs are passively transported downstream until they find sites with favourable conditions for their development[6], such as marginal lagoons which are generally found in flood plains[7]. Rivers with deep valleys usually do not have marginal lagoons or flood plains. In this case, larval development may occur in "calm waters" that are dammed by the main river during the flood period, as was observed in the Uruguay River[8].

Flood plains may be described as low relief surfaces formed by river depositions, generally adjacent to river channels[9]. These plains are periodically flooded and are considered important components of river basins since they have ecological functions that are fundamental and exclusive to these environments[10]. Flood plains play important roles in river basins such as flood regulation, maintenance of minimum current levels through the discharge of alluvial aquifers, and storage of sediments. Flood plains themselves function as biodiversity hot spots, providing a range of habitat types, and therefore, they are among the most dynamic and heterogeneous ecosystems, which present complex patterns of variation both in the temporal and spatial scale[9,10]. Nevertheless, deforestation, drainage of areas that flood for agricultural use, together with water damming and pollution directly affect these environments, thus compromising fundamental ecosystem functions for fish communities[11]. Flood plains also accumulate and store nutrients during the season in which rivers have low water levels, releasing these nutrients to river streams during the flood season, thus providing much of the primary production that supports aquatic ecosystems[12].

During flood periods, marginal lagoons have lower water turbidity compared to rivers, thus allowing algae and aquatic vascular plants to have higher photosynthetic rates[13]. Many fish use these plains as refuges during floods[14]. Many fish species precisely time their spawning period to occur during the flood period, so that their offspring can develop in a habitat where food and resources are widely available, thus ensuring greater reproductive success[15].

It is known that keeping connectivity between the floodplain and the main river

is one of the essential components of any restoration plan of these environments to maintain primary production at an adequate level[16], as well as increasing ichthyofauna diversity, reducing mortality rates, maximising the growth rate of native species[17] and helping to keep the genetic diversity of migratory fish[18].

One of the most important points to be considered in studies of ichthyological communities is determining the species that inhabit each of the ecotones and how these environments interact with the life cycle of the fish. However, there are few studies involving the ichthyological communities of marginal lagoons and their role in aquatic ecosystems, or the marginal lagoons themselves[19, 18, 20]. In this sense, flood plains and especially marginal lagoons deserve special attention in the efforts to preserve the ichthyofauna diversity.

Given the above, this study evaluates the ichthyofauna present in the environments of marginal lagoons, analysing whether they can be used by migratory species at some stage of their reproductive process. The species that use these environments were quantitatively and qualitatively evaluated, in what stage of life they remain in the marginal lagoons, what are the growth rates of the alevins and juveniles of each species. Thus, the importance of the marginal lagoons in the conservation of migratory fish species from the Jequitaí River can be evaluated, in order to provide information that will help in the conservation of the native fish fauna of the São Francisco River basin.

2. Materials and Methods

Study Area

The Jequitaí River is a tributary on the right bank of the São Francisco River, and it covers an area of 9,000 km, including a large area of well-delimited flood plains, which makes it ideal for studies ecotones[21]. Despite the Jequitaí River being an important tributary of the São Francisco River, there is a lack of basic information about its ichthyofauna, since no ichthyofauna studies have been carried out in this area.

Experimental fishing was used to study the ichthyofauna communities of the marginal lagoons of the Jequitaí river at previously selected sampling points between November 2013 and December 2014. The sample points of the present study can be seen in Table 1. Aiming for quantitative sampling, fish were captured using sets of 10 m long gill nets with 3, 4, 5, 6, 7, 8, 10, 12, 14, and 16 cm meshes (between opposing knots). The gill nets

were placed late in the afternoon and removed the following morning, remaining in the water column for approximately 12 hours. For the qualitative samplings, thrown fishing nets ("tarrafas de lançar") with 3, 4, 6, 9, and 11 cm meshes, trawls, and sieves were used.

TABLE 1: Marginal lagoons sampled and coordinates of the collection sites.

Spots	Description	UTM Coordinates
REN	Renero lagoon, a mid-size lagoon, located on the right bank of the Jequitaí River. In its maximum volume, it has an approximate area of 2 hectares and an average depth of 98 cm.	23K 541630.58 m E 8103708.23 m S
LAG	Lagoão, large size marginal lagoon, located on the right bank of the Jequitaí River. In its maximum volume, it has an approximate area of 41 hectares and an average depth of 148 cm.	23K 542585.64 m E 8104433.66 m S
BUR	Buriti lagoon, a large size lagoon, located on the right bank of the Jequitaí River. In its maximum volume, it has an approximate area of 48 hectares and an average depth of 125 cm.	23K 545877.74 m E 8103154.49 m S
TAMA	Tamatião lagoon, a large size marginal lagoon, located on the left bank of the Jequitaí River. In its maximum volume, it has an approximate area of 52 hectares and an average depth of 98 cm.	23K 569814.00 m E 8092132.00 m S

Fish captured alive were killed with a lethal dose of Eugenol prior to their manipulation and preservation in 10% formaldehyde solution. The handling of the specimens followed the guidelines of the CONCEA for killing animals[22] and the collection of fish was authorised by the State Forestry Institute of Minas Gerais (license No. 148/2013) and the CEUA PUC Minas protocol No 009-2014. Only a fraction of the fish caught in the quantitative samplings was collected,

between 3 to 10 specimens per sampling, the remaining ones were returned alive to the body of water in which they were captured.

Data analysis

The relative abundance of fishing with gillnets was determined by the catch per unit effort (CPUE), defined as the sum of the number (CPUEn) or biomass (CPUEb, in g) of fish / 100 m^2 of nets employed / 12 hours. This procedure allowed for quantitative comparisons between species, mesh sizes and collection sites, obtained as follows:

$$\text{CPUEn} = \sum_{i=1}^{n} N / E \times 100$$

and

$$\text{CPUEb} = \sum_{i=1}^{n} B / E \times 0{,}1$$

CPUEn = number of fish per unit of effort from 100 m^2;

CPUEb = biomass of fish (g) per unit of effort from 100 m^2;

N = number of fish caught for a given mesh size;

n = mesh sizes employed (3, 4, 5, 6, 7, 8, 10, 12, 14 and 16 cm);

B = biomass (g) of fish caught for a given mesh size;

E = fishing effort for a given mesh size (net area used) during the exposure time.

To compare abundance variations between the sampling points, an ANOVA test (Instat 3.0) together with the Tukey *a posteriori* test was performed considering CPUEb. The same was done with CPUEn; however, the Kruskal Wallis test was used as the data were f the non-normal data when submitted to the Shapiro Wilk test.

For the species that were recorded fingerlings and juvenile fish, weight and body length gains were evaluated through the construction of graphs with the evolution of fish size over the thirteen months of fish sampling.

From the total length of the fish collected, graphs were drawn based on length classes of the migratory fish species, in order to verify if there was a pattern in relation to this variable (length) over time (campaigns). For each migratory species, a graph was drawn based on the number of individuals collected per campaign, which generated the ideal number of classes. Finally, in order to obtain the

class interval, the difference between the largest and the smallest individual divided by the ideal number of classes, calculated previously, was calculated.

3. Results

A total of 1,049 specimens belonging to seven large migratory fish species of high economic and ecological value, including four endemic species to the São Francisco River basin, were captured at the four sampling sites (Table 2).

TABLE 2: List of species caught in the four lagoons, according to Fishbase[23].

SPECIES	COMMON NAME
ORDEM CHARACIFORMES	
Família Prochilodontidae	
Prochilodus argenteus	Curimatã-pacu
Prochilodus costatus	Curimatã-pioa
Família Anostomidae	
Megaleporinus obtusidens	Piau-verdadeiro
Família Bryconidae	
Salminus franciscanus	Dourado
Salminus hilarii	Tabarana
Brycon orthotaenia	Matrinxã
ORDEM SILURIFORMES	
Família Pimelodidae	
Pseudoplatystoma corruscans	Surubim

Size and abundance

Considering all specimens captured, the most representative species in absolute numbers was *Megaleporinus obtusidens* (41.47%), whereas the species with greatest the total biomass captured was *Prochilodus costatus* (24.57%). The largest specimen was a Surubim (*Pseudoplatystoma corruscans*) with total length of 79 cm and body weight of 4,400 g, which was captured in Lagoão in October 2014. The average total length of the captured specimens was 13.6 cm and the average body weight was 80.7 g,

showing the predominance of young fish. The total biomass of fish captured during the samplings was 84,622.6 g (Table 3).

TABLE 3: Number of captured specimens (Nº) minimum (min) and maximum (max) ranges of total length (TL) and body weight (BW) with the respective means (standard deviation) of the seven species captured.

SPECIES	Nº	Min. TL	Max. TL	Med. TL	Min. BW	Max. BW	Med. BW	Total BW	% Nº	% BW
B. orthotaenia	6	24	37,7	27,2	169	641,0	280,2	1681,0	0,57	1,99
L. obtusidens	435	5,5	26	11,2	1,3	222,0	22,8	9931,3	41,47	11,74
P. argenteus	194	6,8	47,5	12,2	5,4	1800,0	89,9	17440,6	18,49	20,61
P. costatus	211	7	44	15	6,9	1166,0	98,5	20788,5	20,11	24,57
P. corruscans	8	29,1	79	59,7	222,1	4400,0	2340,8	18726,1	0,76	22,13
S. franciscanus	87	11,9	48	17,8	12,6	1325,0	128,3	11165,8	8,29	13,19
S. hilarii	108	11,5	28,5	15,6	12	308,0	45,3	4889,2	10,30	5,78

Amongst the seven species studied, only *B. orthotaenia* did not recruit new individuals in the studied lagoons in the Jequitaí River. Among the fish that were successful in recruiting new individuals, *S. hilarii* and *P. argenteus* had the lowest body length increase rates (1.9 and 2.1 fold), while *S. franciscanus* and *L. obtusidens* increased their length in 4 and 3.6 fold respectively. In relation to body weight gain, the "Dourado" and "Piau-verdadeiro" also presented the best values increasing their weight by 81.3 and 102.4 times, respectively. (FIGURE 1).

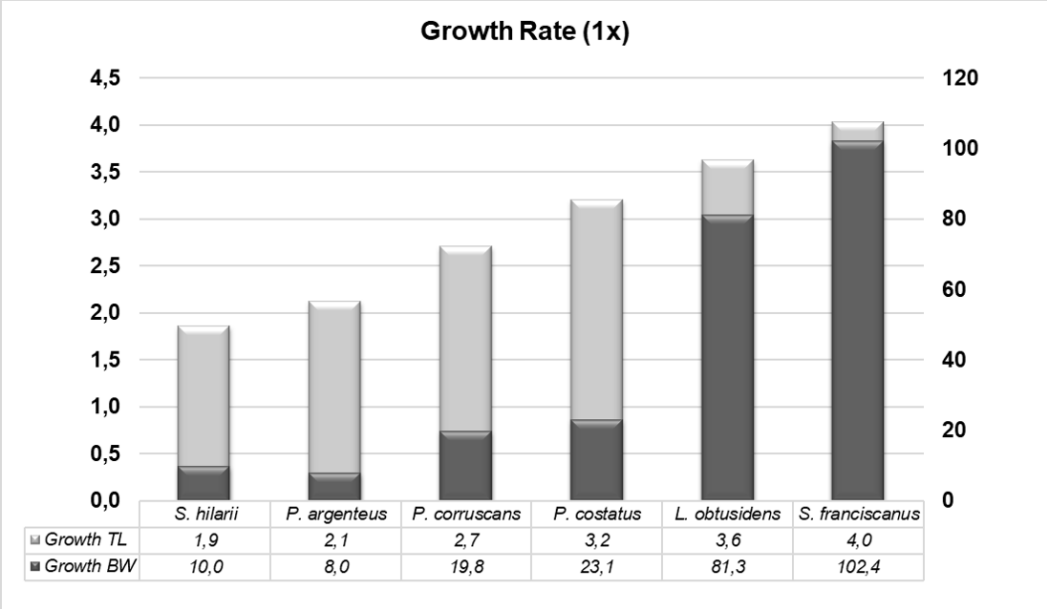

FIGURE 1: Graphical representation of weight and body length gain of the seven species of migratory fishes studied in the Jequitaí River basin, Minas Gerais, Brazil.

Length classes

The frequency distribution by length class (Figure 2) of the captured fish showed that migratory species presented specimens in the alevin and juvenile forms, and the number of fish in larger length classes tended to decrease (Figure 2).

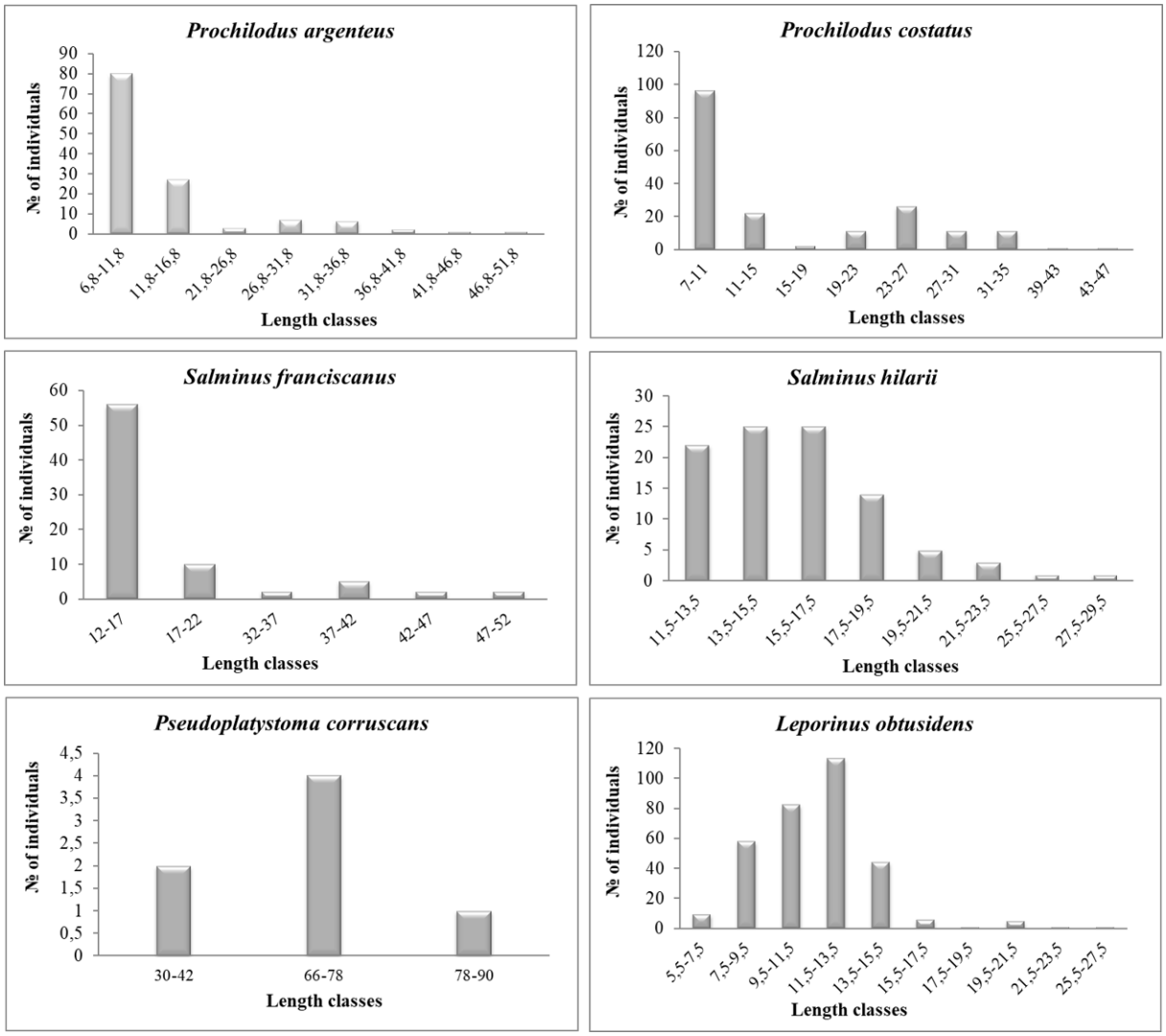

FIGURE 2: Length classes of six species of migratory fishes that showed recruitment in the Jequitaí River basin, Minas Gerais, Brazil.

Fish growth depends on the genotype-environment interaction and factors such as environmental quality and food availability, factors that together will regulate fish growth over time. Thus, some species may have different growth curves over time. Species with a carnivorous / piscivorous feeding habit showed more linear growth rates *P. corruscans*, *S. hilarii* and *S. franciscanus*, presenting higher coefficient of determination than the other species (Table 4).

TABLE 4: Coefficient of determination (r^2).

Species	r^2
P. corruscans	0.97
S. hilarii	0.91
S. franciscanus	0.84
P. costatus	0.60
M. obtusidens	0.17
P. argenteus	0.02

In addition to the new individuals from recruitment at each flood cycle, adult individuals of migratory species from previous cycles, which may have been retained in the lagoons after the flood period, as observed in our study, also use the marginal lagoons.

Catches per unit of effort (CPUE)

The analysis of the catches per unit of effort by species, CPUEn, showed a greater concentration of *P. costatus* and *L. obtusidens* (0.8 / 100m²), while the other species presented a catch rate of 0.4 / 100m². Regarding biomass, *S. franciscanus* and *P. costatus* presented higher values (120g / 100 m²), even when compared to *L. obtusidens* (40g / 100m²).

In relation to the differences between CPUEn and the sampling sites, the LAG lagoon presented the highest concentration (87.3 / 100m²), followed by BUR (54.4 / 100m²) and REN (40.3 / 100m²), being significantly different in all three lagoons Lagoão also presented the highest values for CPUEb (LAG = 5,910g / 100m², REN = 3,482.7g / 100m² and BUR = 3,145.4g / 100m²), in this case, only LAG presented values significantly different from the other two lagoons.

The smaller meshes (3, 4 and 5) were numerically the most representative, showing that most migratory fish in the studied lagoons are small size. In relation to the biomass, the medium meshes (6, 7 and 8), as well as the small ones, were more representative.

4. Discussion

Marginal lagoons are heterogeneous environments with unique ecological functions. These lagoons are of great importance for the maintenance of fish stocks and ichthyofauna diversity of the watersheds where they are located, since they can serve as large natural nurseries[24,

[25]. The richness and diversity of a marginal lagoon are directly related to the capacity of species found there to coexist and to persist in these environments. For this to occur, it is necessary to have a balance between new colonisations, mortality, and evasion, which are natural processes that occur in these ecotones[26, 27]. The lagoons selected in this study were completely dry after the drought of the previous year, and only flooded after receiving water during the 2013/2014 rainy season. Thus, the biomass, richness, and diversity recorded in the first campaign of each lagoon were carried to them by the flooding of the Jequitaí River, meaning the selected lagoons became areas of study with a high confidence degree.

In the present study, 1,049 specimens belonging to seven species of migratory fish were captured. In both groups (migratory and sedentary), a large number of specimens with sizes corresponding to fish in the alevin and juvenile forms were recorded. These results corroborate those that can been found in the literature, e.g. floodplain ecosystems are considered high biodiversity environments and generally surpass even terrestrial environments[28, 29]. In this sense, environments formed by rivers with floodplains may present high biodiversity indices, therefore being priority areas in environmental preservation actions.

Due to the fact that TAMA lagoon is located more upstream and in a considerably higher area than the level of the Jequitaí River channel than the other three lagoons studied, it did not receive water from the 2013/2014 floods, resulting in low catch rates of specimens belonging to migratory species, especially young individuals. This result is also relevant to the knowledge of natural nurseries of freshwater migratory fish, showing that not all potential fish recruitment areas in a watershed receive water in the same periods and consequently function as nurseries.

Despite the fact that they are close to each other and receive water from flooding of the Jequitaí River simultaneously, the three lagoons studied are isolated from each other and present distinct physiographic characteristics such as depth, volume, and water depth, which were reflected in some analyses carried out in this study. LAG presented higher CPUEn and CPUEb values in relation to the other monitored lagoons, one of the hypotheses for this result would be that its fish had higher survival and development rates over the studied

period. This result is probably related to the fact that the LAG lagoon has the largest floodable area and water volume of the three lagoons studied. A study[30] carried out in three marginal lagoons of the Upper Paraná River to analyse the trophic characterisation of these environments and found that although the lagoons are relatively close to each other (1km), they are submitted to different levels of influence of the Paraná River, thus presenting distinct physiography and diverse ichthyofauna compositions. Our study found a similar pattern to this assertion, since by analysing the size class graphs it is possible to observe the variations between the three sample sites, which are also located at a relatively small distance from one another.

The populations of the three lagoons, which presented adequate conditions for the development and recruitment of new individuals, allowed the seven migratory species analysed in this study to show significant growth throughout the sampling period. The development of the fish, together with the fact that these environments remained isolated throughout the study period, proves that the marginal lagoons can function as natural nurseries for the mass production of fish, thus becoming natural stocks for native species, including species that suffer from fishing overexploitation, such as the so called “Dourado”, “Surubim”, and “Curimatãs”. The importance of marginal lagoons has also been demonstrated in temperate water fish, such as salmon, where fish found in marginal lagoons presented growth rates much higher than those observed in the main channel of the adjacent river[29].

In general, the abundance of individuals belonging to the smaller size classes was higher than those belonging to the larger size classes, the expected pattern for this type of environment. This population composition pattern usually occurs due to the high biomass indices associated with the flood period, which over time generates restricts the available dissolved oxygen, and consequently, results in an environment with environmental characteristics that are very different from those found during flooding, making establishment difficult for the

fish communities that developed in these places. Since these environments most often only have a connection to the riverbed during periods of flooding (as is the case of the studied lagoons), they become natural fish nurseries, and predation becomes easier, especially as the volume of water decreases with the arrival of the dry season. Besides piscivorous fish such as Piranhas, Dourado, and Surubim, the predation of fish in marginal lagoons by aquatic birds, reptiles, and aquatic mammals is also quite common. In addition, over-fishing is a major factor responsible for the high mortality rates of large migratory fish due to their commercial value, which may explain the pattern observed in our results[27]. Therefore, a lower number of individuals in the larger length classes over the study period is expected.

Analysis of the ichthyofauna composition showed that *L. obtusidens* was the most representative species in the four sampling sites. This species is classified by many authors as being broad-spectrum omnivorous, which, from a nutritional point of view, is advantageous. This fact probably helped the establishment and abundance of this species in the four lagoons[31, 32].

According literature[28], floodplains should be understood as conservatories of regional biodiversity and as fundamental units of river ecosystems. The evidence provided by this study supports the hypothesis and stresses the importance of these ecotones for fish communities. In view of the facts stated above, the importance of the three marginal lagoons, in relation to the participation in the recruitment of seven migratory fish species from the Jequitaí River basin, is evident, since specimens were found at different stages of their life cycle. Therefore, preserving these environments is extremely important so that there is no loss in the diversity and abundance of these fish, which are more vulnerable to changes in the environment because they are migratory species[33, 27].

The continuous and quick development of aquaculture and the consequent deposition of sediments in important tributaries of the middle part of the São Francisco River basin[34]

may directly affect the conservation of marginal lagoons. In this same sense, a scientific study[27] observed a gradual decrease in fish diversity and abundance in lagoons that do not flood annually, due to the river flow control caused by the Três Marias hydroelectric plant. Another work[35] also extinction processes with an approximately 70% reduction of native fish fauna in a lagoon in the São Francisco River basin. Considering the presence of marginal lagoons (natural nurseries) in the São Francisco and high Paraná basins[36], national conservation policies should include marginal lagoon environments as priority areas for the conservation of ichthyofauna communities and genetic variability of fish, especially migratory species.

4. Conclusion

Data from the present study showed that at least seven large migratory fish species native to the São Francisco River basin use the marginal lagoons adjacent to the Jequitaí River in their life cycle. Even more so, these peculiar environments can function as large nurseries for the development and recruitment of migratory fish, thus contributing to the conservation of fish diversity that is of great ecological and commercial importance. Furthermore, it reduces the lack of knowledge about the use of marginal lagoons by migratory fish species. As this studies shows that marginal lagoons act as fish nurseries in the São Francisco River basin, biodiversity conservation policies should include the floodplains and marginal lagoons in the priority areas for the maintenance of migratory fish stocks.

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