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Spatial variation in abiotic conditions and fish diversity in coastal lagoons, Southern Brazil

Variação espacial de condições abióticas e diversidade de peixes em lagoas costeiras, Sul do Brasil

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Abstract: Aim: To compare abiotic variables and fish assemblage descriptors (species composition, richness, dominance and diversity) among coastal lagoons of the Tramandaí river system, southern Brazil. **Methods:** Water and fish samples were taken monthly from April 2009 to March 2010 in the littoral zone of six coastal lagoons, three located at the north and three at the south of the Tramandai estuary. Thirteen environmental variables were measured. The fish assemblage samples were sampled with gillnets. We used multivariate analyses to investigate spatial variation in abiotic conditions and fish diversity. **Results:** The samples at northern lagoons (Itapeva, Quadros and Malvas) were related to greater values of the turbidity and biochemical oxygen demand, while the southern lagoons (Fortaleza, Rondinha and Barros) were related to greater values of hardness, total dissolved solids, transparency, conductivity and salinity. The fish assemblages were similar in species composition. The species richness was higher in the southern lagoons when considering the same number of specimens. In the northern lagoons the assemblages were numerically dominated by *Psalidodon* aff. *fasciatus* and *Loricariichthys anus* and less diverse, while in southern lagoons were more equitable and diverse. **Conclusions:** We concluded that the coastal lakes studied differ in the patterns of variation in abiotic parameters and this reflect in the water quality. Fish richness and species composition are similar, a likely result of the common and recent biogeographic origin of these lagoons. Fish assemblages in large and turbid lagoons present more dominance while the fish assemblages in small and clear lagoons are more diverse. These results may be useful for coastal management that prioritizes fish stocks or for proposing models of fish assemblages in subtropical coastal lagoons.

Keywords: Tramandaí river system; gillnets; fishery resources; littoral zone.

Resumo: Objetivo: Comparar variáveis ambientais e descritores das assembleias de peixes (composição de espécies, riqueza, dominância e diversidade) entre lagoas costeiras do sistema do rio Tramandaí, sul do Brasil. **Métodos:** Amostras de água e de peixes foram coletadas mensalmente de Abril de 2009 a Março de 2010 na zona litoral de seis lagoas, três ao norte e três ao sul do estuário de Tramandaí. Treze variáveis ambientais de qualidade da água foram mensuradas. As capturas de peixes foram realizadas por meio de redes de emalhe. Usamos abordagem multivariada para investigar variações espaciais nas variáveis abióticas e diversidade de peixes. **Resultados:** As amostras das lagoas ao norte (Itapeva, Quadros e Malvas) foram relacionadas com maiores valores de turbidez e demanda bioquímica de oxigênio, enquanto as amostras das lagoas ao sul (Fortaleza, Rondinha e Barros) com maiores valores de dureza, sólidos totais dissolvidos, transparência, condutividade elétrica e salinidade. As assembleias de peixes foram similares em composição de espécies entre as lagoas. A riqueza foi superior nas lagoas ao sul quando o mesmo número de exemplares foi considerado. Ao norte, as assembleias mostraram dominância numérica de *Psalidodon* aff. *fasciatus* e *Loricariichthys anus*, e menor diversidade, enquanto ao sul as assembleias foram mais equitativas e diversas. **Conclusões:** Concluímos que as lagoas costeiras estudadas diferem no padrão de variação de parâmetros abióticos, refletindo em diferenças na qualidade da água. A composição e riqueza de espécies são similares e refletem a origem biogeográfica comum e recente das lagoas. As assembleias de peixes em lagoas grandes e turvas apresentam maior dominância enquanto as assembleias de peixes em lagoas pequenas e claras são mais diversificadas. Esses resultados podem ser úteis no manejo costeiro que prioriza os estoques pesqueiros ou na proposição de modelos de assembleias de peixes em lagoas costeiras subtropicais.

Palavras-chave: sistema do rio Tramandaí; redes de emalhe; recursos pesqueiros; zona litorânea.

1. Introduction

Coastal lagoons constitute a common coastal environment, occupying 13% of coastal areas worldwide (Kjerfve, 1994) and the conservation of these habitats depends largely on the assessment of their natural characteristics, especially biodiversity (Kruk et al., 2009). These inland aquatic systems are among the most impacted because human reliance on freshwater leads to a concentration of human activities (Esteves et al., 2008). Many coastal lagoons are experiencing adverse effects from climate change, eutrophication, and pollution, which can lead to biodiversity loss (Esteves et al., 2008; Reid et al., 2019; Albert et al., 2021).

Investigating the dynamics of abiotic factors is central to the understanding of the biological, chemical and physical properties of coastal lagoons (Esteves et al., 2008). The coastal plain in extreme southern Brazil corresponds to a biogeographic transition hot-temperate zone through the influence of the subtropical convergence zone in the southwest Atlantic Ocean (Seeliger et al., 1997). This region presents around a hundred coastal lagoons of recent origin (Tomazelli & Villwock, 2005). The coastal lagoons of the Tramandaí river system (TRS) are in the northern portion of this coastal plain. All lagoons are mesotrophic according to trophic indices determined by transparency, total phosphorus, and chemical oxygen demand (Schäfer, 1988). A decreasing pattern of trophic level and salinity from north to south were verified and related to tidal influence, connection with the sea, distance from the coast, and wind impact (Schwarzbold & Schäfer, 1984; Würdig, 1987). Based on hydrologic and morphometric features, these coastal lagoons system is divided into two subsystems (north and south from the Tramandaí estuary). In the northern subsystem, the lagoons are generally large (~90 km^2) while in the southern subsystem they are medium to small sized (~12 km^2). They also differ concerning the main water input, which occurs through the largest rivers in the northern subsystem (Três Forquilhas and Maquiné) and only through rainfall in the southern subsystem (Malabarba et al., 2013). Southern lagoons are more influenced by saline waters, while northern lagoons are more influenced by the wind action and generally show lower transparency (Würdig, 1987). The environmental variability in the coastal lakes of the TRS, imposed by their variable size, depth, and landscape orientation, makes them an interesting model system to study the roles of biotic and abiotic variables in the formation of patterns in community structure.

Fishes represent an important component of the biodiversity of coastal lagoons in subtropical regions of South America (Garcia et al., 2006; Artioli et al., 2009; Teixeira de Mello et al., 2009; Kruk et al., 2009; Hartz et al., 2019; Artioli et al., 2022). A constant issue for aquatic ecologists in tropical and subtropical regions is understanding the importance of different factors on fish assemblages structuring (Hutubessy & Mosse 2023; Guimarães et al., 2020; Petry et al., 2016). In 106 coastal lagoons, in the South American Atlantic coast, differences in latitude, morphometry, connectivity, and sampling effort explained the variation in fish species richness (Petry et al., 2016). In these lagoons the differences observed in fish species composition are explained by historic (paleodrainages) and current factors (catchment area, salinity and lagoon area) (Guimarães et al., 2020). In the Uruguayan coast, the fish assemblages were tested for fish species richness between turbid and clear shallow lagoons. Higher species richness was observed in large and turbid lagoons (Kruk et al., 2009). However, a particular environmental scenario points to greater fish richness in large, clear, plant-dominated lagoons (Kruk et al., 2009). The knowledge of functional patterns of fish assemblages may help the development of appropriate policies to prevent eutrophication or support restoration projects (Jeppesen et al., 2005). Comparing these patterns with those from temperate climate may enable predictions on shifts in fish assemblage structure in this region, especially considering the growing evidence of global warming (Jeppesen et al., 2015).

In coastal lagoons of the Tramandaí river system around seventy freshwater fish species have been recorded (Malabarba et al., 2013), which corresponds to 68% of the species described for the whole basin (102 species according to Bertaco et al., 2016). In six coastal lagoons of the TRS, fish assemblages in littoral areas showed high species richness, dominated by small fishes. In contrast, an assemblage with lower species richness comprised by larger fishes was found in inner areas of the littoral zone (Artioli et al., 2022). In the TRS the connectivity is a good predictor for estuarine fish species richness. For freshwater fish species, the lake area is a better predictor for species richness (Guimarães et al., 2014). The lake shape and estuarine connectivity were the best predictors for taxonomic diversity and functional richness of the fish assemblages, although not for their equitability and functional dispersion (Hartz et al., 2019).

In the present paper, we focused on the spatial differences between abiotic conditions and fish assemblage descriptors in six coastal lagoons of the Tramandaí river system. Our objectives were: (1) to compare water quality parameters among lagoons, (2) to compare fish assemblage richness, composition, dominance and diversity patterns among lagoons, and (3) to assess the similarity of fish assemblages among lagoons. Based on previous knowledge, differences in water quality parameters are expected, following a trophic gradient (trophic level at the lakes decreasing from north to south) as described by Schäfer (1988). Likewise, lagoons with larger areas and more connectivity should present greater species richness, while smaller and more isolated lagoons should show the opposite trend (Hartz et al., 2019).

2. Material and Methods

2.1. Study Area

This study considered six coastal lagoons belonging to the Tramandaí River Basin (29°45’; 30°15’S), located in northern coastal plain of Rio Grande do Sul (Figure 1).

These coastal lagoons were formed through marine transgression and regression processes along with wind action over the last 5,000 years (Schwarzbold & Schäfer, 1984; Tomazelli &

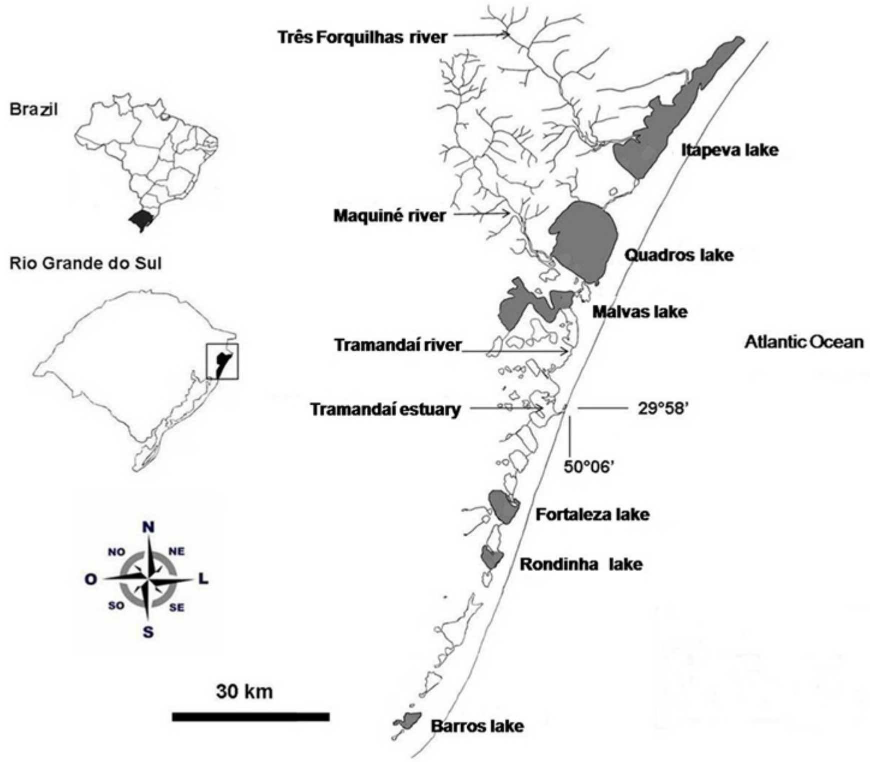

Figure 1. Map illustrating the geographical position of the Tramandaí River Basin and the coastal lagoons.

Villwock, 2005). The climate, according to Köppen, is Cfa or subtropical humid (Hasenack & Ferraro, 1989). Winds from northeast and east quadrants are frequent in spring and summer, while winds from south and southwest quadrants are frequent in autumn and winter (Ferraro & Hasenack, 2009). The studied lagoons are: Itapeva (95.16 km^2), Quadros (119 km^2) and Malvas (55.08 km^2) in the northern portion; and Fortaleza (18.54 km^2), Rondinha (8.92 km^2) and Barros (9.2 km^2) in the southern portion. The northern lagoons are larger and have low (<3 m) to intermediary depths (3 to 5 m). The southern lagoons are smaller in size and have lower depths (<3 m) (Schäfer, 1988). The Barros Lagoon is the only isolated, not linked to the fluvial system. It is part of a series of asymmetric lagoons, which tend to be deeper (> 5 m), clearer and have a low trophic level (Schäfer et al., 2009). The lagoons substrate is predominantly composed by sand and its shores are intensely colonized by emergent macrophytes (Prado, 2009). The surrounding areas are occupied by rice fields which are seasonally flooded. Freshwaters and slightly brackish waters can be found in the same lagoon at different times, depending on the recent wind direction and sea level. All lagoons are freshwater, excepting the Tramandaí Lagoon, which contains saline waters (salinity < 30 ppt) (Würdig, 1987).

2.2. Sampling design

Monthly samples were taken from April 2009 to March 2010. Fish were captured with a set of nine gillnets (nylon monofilament; 30 m long; 1.5 m high) of several mesh sizes (15, 20, 25, 30, 35, 40, 50, 60, and 70 mm between adjacent knots), totaling 270 m long and 405 m^2 in area. The gill nets were placed in the afternoon, close to the emergent reed vegetation banks around 30 m from the margin, at depths of up to 3 m. Nets were removed in the next day, with total exposure time of ca. 18 h/month in each lagoon. Captured fish were fixed in 10% formalin and preserved in 70% ethanol. All fish were identified at the species level and counted. Representative specimens were cataloged in the fish collection of Zoology Department at UFRGS. Fish species name and habitat use were updated according to Fricke et al. (2023).

The water temperature (°C), depth (cm), and Secchi transparency (cm) were measured at the time of sampling. Water samples were taken with a Van Dorn bottle at 20 cm deep and ten variables were measured in the laboratory. All measures and water samples were taken immediately after gill nets removal. Conductivity (mS.Cm^{-1}), pH, turbidity (NTU), hardness (mg.L^{-1}), total dissolved solids (mg.L^{-1}), dissolved oxygen (mg.L^{-1}), biochemical oxygen demand $BOD_{5,20°C}$ (mg.L^{-1}), and suspended solids (mg.L^{-1}) were estimated according to APHA (1998). The salinity (‰) was estimated according to Baumgarten et al. (1996), and chlorophyll (μg.L^{-1}) according to Golterman et al. (1978).

2.3. Data analysis

In order to control the effects of temporal correlation, the data matrix was built from average values of each abiotic parameter and lagoon. To assess the relationship between abiotic variables and lagoons, a principal component analysis (PCA) was performed using the variance-covariance matrix. The data were standardized through the equation $(x-\mu)/\partial$, where μ is the sample average and ∂ the standard deviation (Field et al., 1982).

To compare the richness of each lagoon, individual-based rarefaction curves were calculated (Gotelli & Colwell, 2001). To compare composition and dominance, the raw data on the number of individuals (n) per species were standardized as catch per unit effort (CPUE). Each species CPUE is defined as the number of specimens by net area by hour (ind/m^2/h). Then, numerical percentage (NP) was calculed based on each species CPUE using the formula: $NP = (CPUEi/\sum CPUEi)*100$, where CPUEi is the catch per unit effort of specie i, and the frequency of occurrence (FO) using the formula: $FO = (n/N)*100$, where n is the number of samples in which each species was recorded and N the total number of samples. Then the FO of each species was transformed in relative frequency of occurrence (FO%) using the formula: $FO\% = (FOi/\sum FOi)*100$, where FOi is the frequency of occurrence of species i.

To assess the dominance patterns of fish assemblages, the values of numerical percentage (NP) and the frequency of occurrence (FO%) of each species and lagoon were compared to each lagoon average (100/S where S = the total number of species captured in each lagoon), and the species were classified as follows: abundant and frequent (NP ≥ the average NP and FO% ≥ the average FO%); only abundant (NP ≥ the average NP and FO% < the average FO%); only frequent (NP < the average NP and FO% ≥ the average FO%); present (NP < the average NP and FO% < the average FO%). Abundant and frequent species were then considered to be dominant (Artioli et al., 2022).

To compare diversity among lagoons the Shannon-Wiener index was utilized (Magurran, 2004). To assess the similarity of fish assemblages, cluster analysis was performed, and the attributes were calculated by Bray-Curtis coefficient. To control the temporal correlation, the sum of CPUE by species and lagoon was utilized in this analysis. In the similarity analysis, rare species (present in one lagoon only) were excluded. All multivariate analyses were performed using the software PAST version 4.08 (Hammer et al., 2001).

3. Results

3.1. Abiotic factors

Principal component analysis (PCA) showed eight principal components and the first two axes explained 86% for the data variability. Northern lagoons (Itapeva, Quadros and Malvas) were related to greater values of the turbidity and biochemical oxygen demand. Southern lagoons were related with greater values of hardness, total dissolved solids, transparency, conductivity and salinity. The most transparent was the Barros Lagoon (Figure 2).

3.2. Fish assemblages

Fish sampling resulted in a total of 7,881 specimens distributed in 16 families, 27 genera e 37 species (32 freshwater fish species, two freshwater/brackish species, sardine *Platanichthys platana* (Regan 1917) and anchovy *Lycengraulis grossidens* (Agassiz 1829), and three brackish/marine species, sea catfish *Genidens genidens* (Cuvier 1829), *Genidens barbus* (Lacepède 1803) and sea bass *Centropomus parallelus* Poey 1860) (Fricke et al., 2023). Higher richness was observed in the Malvas Lagoon and the higher CPUE was observed in the Quadros Lagoon. The opposite was observed in the Rondinha Lagoon (lowest richness and CPUE) (Table 1).

Psalidodon aff. *fasciatus* (Cuvier, 1819) and *Loricariichthys anus* (Valenciennes 1835) were the most representative species regarding the number of individuals. These species were dominant in all lagoons. Other eight species were considered dominant in at least one lagoon (*Cyphocharax voga* (Hensel 1870), *Oligosarcus robustus* Menezes 1969, *Geophagus iporangensis* (Quoy & Gaimard 1824), *Odontesthes ledae* Malabarba & Dyer 2002, *L. grossidens*, *Oligosarcus jenynsii* (Günther 1864), *Psalidodon eigenmanniorum* (Cope, 1894) and *Astyanax lacustris* (Cope, 1894)). In the northern lagoons three to five species were dominant, while in the southern lagoons five to eight species were dominant. No species was dominant only in northern lagoons, while five species were dominant only in southern lagoons. The king-fish *O. ledae* and the lambari *Astyanax* sp. were present only in southern lagoons, while the king-fishes *Odontesthes bonariensis* (Valenciennes 1835) and *Odontesthes piquava* Malabarba & Dyer 2002 and the sea catfishes *G. genidens* and *G. barbus* only in the northern lagoons. Six species were present in only one lagoon.

The rarefaction curves indicated that species richness is higher in the southern lagoons considering a same sampling effort (number of individuals).

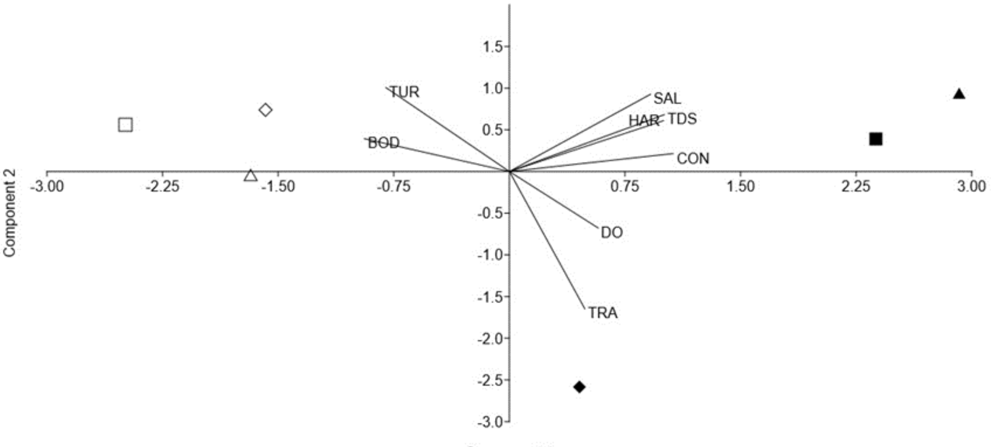

Figure 2. Principal Component Analysis (PCA) of the relationship between abiotic variables (TRA = transparency; HAR = hardness; SAL = salinity; TDS = total dissolved solids; CON = conductivity; DO = dissolved oxygen; TUR = turbidity; BOD = biochemical oxygen demand) and the lagoons (Itapeva = diamond; Quadros = triangle; Malvas = square; Fortaleza = filled square; Rondinha = filled triangle; Barros = filled diamond).

Table 1. Comparative list of numerical capture per unit effort (sum of the CPUE) and the relative importance (based on the CPUE% and FO%), where: (black) abundant and frequent, (brown) only abundant, (dark grey) only frequent, (light grey) present species and (colorless) absent species, caught in the coastal lagoons at Tramandai river system (Ita = Itapeva, Qua = Quadros, Mal = Malvas, For = Fortaleza, Ron = Rondinha, Bar = Barros) between 2009 and 2010.

Species	Ita	Qua	Mal	For	Ron	Bar
Psalidodon aff. *fasciatus* (Cuvier, 1819)	34.37	47.80	42.19	7.43	8.21	5.74
Loricariichthys anus (Valenciennes 1835)	16.64	50.05	21.66	5.57	2.17	3.73
Cyphocharax voga (Hensel 1870)	2.01	8.05	22.32	5.15	3.46	2.29
Oligosarcus robustus Menezes 1969	6.97	4.30	7.24	1.72	1.91	2.02
Geophagus iporangensis (Quoy&Gaimard 1824)	1.21	3.03	2.62	1.48	1.09	4.62
Odontesthes ledae Malabarba & Dyer 2002*				1.27	9.10	3.25
Lycengraulis grossidens (Agassiz 1829)	0.35	3.37	4.41	0.59	0.35	2.58
Deuterodon luetkenii (Boulenger 1887)		0.49	0.81	6.65	0.81	0.50
Oligosarcus jenynsii (Günther 1864)	0.86	1.40	0.63	1.32	0.66	1.52
Hoplias malabaricus (Bloch 1794)	0.35	0.43	1.10	0.44	0.75	1.54
Psalidodon eigenmanniorum (Cope, 1894)	0.04	0.97	0.05	0.37	0.39	2.34
Astyanax lacustris (Cope, 1894)	0.41	0.42	0.46	0.24	0.04	2.03
Rineloricaria quadrensis Reis 1983*	0.33	1.17	0.62	0.43	0.66	0.18
Trachelyopterus lucenai Bertoletti, Pezzi da Silva & Pereira 1995	0.52	0.49	2.22		0.05	0.07
Gymnogeophagus lacustris Reis &Malabarba 1988*	0.24		0.59	0.04		2.28
Odontesthes bonariensis (Valenciennes 1835)		2.57	0.25			
Crenicichla maculata Kullander & Lucena 2006	0.20	0.37	0.51	0.28	0.39	0.96
Charax stenopterus (Cope, 1894)	1.32		0.35	0.23	0.18	0.18
Astyanax sp.				0.04		1.78
Gymnogeophagus gymnogenys (Hensel 1870)		0.12	0.15	0.04	0.09	1.31
Platanichthys platana (Regan 1917)		0.33	0.79		0.04	0.06
Pimelodella australis Eigenmann 1917	0.04	0.76	0.05	0.04	0.08	0.19
Odontesthes piquava Malabarba& Dyer 2002*	0.08	0.55	0.22			
Genidens genidens (Cuvier 1829)		0.12	0.48			
Rhamdia aff. *quelen* (Quoy & Gaimard 1824)	0.09	0.12	0.11	0.08		
Centropomus parallelus Poey 1860			0.36	0.04		
Hoplosternum littorale (Hancock 1828)	0.04		0.29			0.06
Corydoras paleatus (Jenyns, 1842)		0.24				0.13
Hypostomus spiniger Valenciennes 1836			0.12			0.07
Australoheros acaroides (Jenyns 1842)			0.10			0.07
Hyphessobrycon togoi Miquelarena & López 2006				0.12		
Genidens barbus (Lacepède 1803)		0.06	0.06			
Acestrorhynchus pantaneiro Menezes 1992					0.04	
Crenicichla lepidota Heckel, 1840	0.04					
Gymnotus aff. *carapo* Linnaeus, 1758	0.04					
Hisonotus leucofrenatus (Miranda Ribeiro 1908)	0.04					
Cyphocharax saladensis (Meinken 1933)				0.04		
Total of CPUE	66.21	127.18	110.75	33.60	30.48	39.52
Total of Species	22	23	28	23	20	25

Endemic species (*).

These curves indicated stability of Malvas and Quadros lagoons and richness increment for the others lagoons (Figure 3). Shannon diversity index was higher in southern lagoons than the northern lagoons. The highest value was observed in Barros Lagoon and the lowest in Itapeva Lagoon (Figure 4). Cluster analysis indicated two groups with northern and southern lagoons with low similarity between them (Figure 5).

4. Discussion

Our results showed that northern lagoons are more turbid with higher BOD when compared to the southern lagoons, which are saltier,

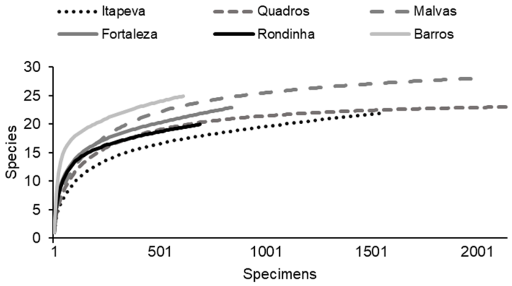

Figure 3. Rarefaction curves of species from lagoons in relation to the number of individuals estimated from 1000 randomizations on the order of samplings.

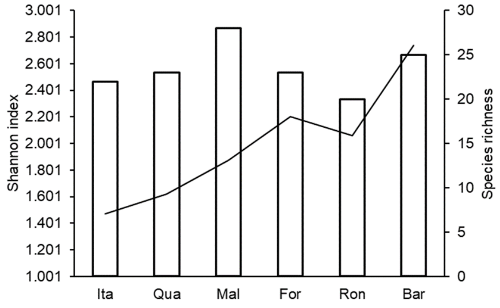

Figure 4. Shannon index (line) and species richness (bars) of fish assemblages from each lagoon (Itapeva = Ita; Quadros = Qua; Malvas = Mal; Fortaleza = For; Rondinha = Ron; Barros = Bar).

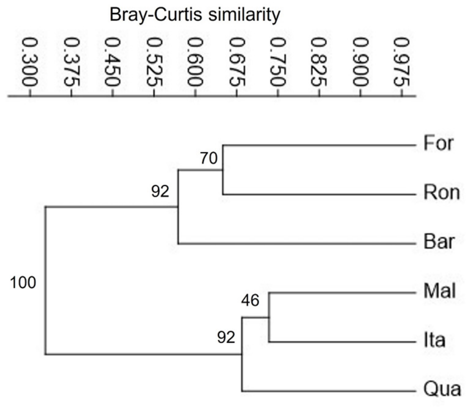

Figure 5. Cluster plot derived from a Bray-Curtis similarity matrix constructed from the CPUE of the fishes caught in each lagoon samples. Itapeva = Ita; Quadros = Qua; Malvas = Mal; Fortaleza = For; Rondinha = Ron; Barros = Bar).

with higher water hardness, conductivity and transparency. The fish assemblages at northern and southern lagoons presented low similarity regarding composition and numeric abundance of species. Fish assemblages from large turbid lagoons presented higher richness but lower diversity while the fish assemblage from smaller, clearer lagoons presented lower richness and higher diversity. The results support the existence of an ecological gradient from north to south in the trophic structure of coastal lagoons of the Tramandaí river system (Schäfer, 1988), pointing to differences in water quality and ecosystem functioning.

In coastal lagoons, geomorphologic factors include inlet and outlet configuration, lagoon size and orientation with respect to existing wind direction, bottom topography and depth, and are related to water, salt and heat dynamics. Inlet dimensions control the exchange of water, including dissolved and suspended material. Wind effects will be enhanced in larger lagoons and will be determinant in gas exchange and water mixing (Esteves et al., 2008). In Itapeva Lagoon, the wind has a decisive effect on their physiological/nutritional status and the phytoplankton community. Under the influence of wind from the northeast quadrant, nutrients and phytoplankton are resuspended continuously in the water column (Cardoso et al., 2003; Cardoso & Motta-Marques, 2004). Resuspended material by wind action may be a dominant cause of turbidity in large shallow lagoons (revised in Esteves et al., 2008). Morphometric features such as the perimeter to volume ratio and shallowness also provide favorable conditions for the development of a large littoral region (Kjerfve, 1994), where many macrophyte species segregate along the littoral-zone slope, providing a substantial source of organic matter to the system and substrate for attached organisms (Esteves et al., 2008). Northern lagoons have extensive marginal areas colonized by emergent weeds. They receive water supply from the main rivers (Três Forquilhas and Maquiné), which favor the accumulation of organic matter. This phenomenon must increase microbial decomposition rates, resulting in higher biochemical oxygen demand. Our results follow results found by Würdig (1987), who described the association between conductivity and hardness with salinity (Würdig, 1987). On the other hand, results confirm that Barros Lagoon is part of a distinct lagoon set (Schäfer et al., 2009), probably because its deeper waters are less influenced by the water movement from wind action, and therefore, present clearer waters.

Our results were similar to those observed for lagoons at Taim Ecological Reserve, Lagoa dos Patos system (Garcia et al., 2006; Artioli et al., 2009), also dominated by the characids *P.* aff. *fasciatus*, *P. eigenmanniorum*, *O. jenynsii* and *O. robustus* and the curimatid *C. voga*. In contrast, the loricariid *L. anus* and the cichlid *G. iporangensis* were only frequent, while the anchovy *L. grossidens* was absent in these lagoons (Garcia et al., 2006; Artioli et al., 2009). Moreover, fish assemblages from coastal lagoons at TRS had more species richness (S) when compared to the species richness observed in the Taim Ecological Reserve: Flores Lagoon (11.3 km^2, S = 19), Nicola (2.58 km^2, S = 19), Jacaré (1.45 km^2, S = 23) (Garcia et al., 2006) and Mangueira (802 km^2, S = 33) (Artioli et al., 2009). The differences in species composition between northern and southern lagoons may reflect the effect of system connectivity patterns. A study in TRS indicate higher estuarine connectivity in Itapeva, Quadros, and Malvas lagoons, resulting in higher marine/estuarine species richness (Guimarães, et al., 2014). However, the "sea bass" *C. parallelus* was reported in the Fortaleza Lagoon (Schifino et al., 2004), and the "mullet" *Mugil liza* in the Custódias Lagoon (near Fortaleza Lagoon) (Fialho, 1998). These records for marine species in the southern lagoons indicate that species richness and composition may be distinct than the observed. On the other hand, as in our results, there is no record of sea catfishes *G. genidens* and *G. barbus* in the southern lagoons studied. Among the freshwater species with restrict capture, only the king-fishes have distinct distribution patterns (*O. piquava* and *O. bonariensis* at northern and *O. ledae* at southern), result of the recent evolution process (Malabarba & Dyer 2002). Although there is no connection with the river system, the presence of endemic species in Barros Lagoon confirm the common origin of lagoons, as mentioned in Malabarba et al. (2013). Such result suggests that the same biogeographical processes and ecological filters (such as those related to dispersion and vicariance), which select local species from a group of regional species, act in all lagoons (Jackson & Harvey, 1989; Jackson et al., 2001). Our results are partially similar to those from coastal lakes in Uruguay, where fish species richness increased with lakes area and water turbidity (Kruk et al., 2009). In opposition to the environmental scenario proposed by Kruk et al. (2009) to shallow subtropical lakes (i.e., predicts higher species richness in large, clear, plant-dominated lakes), our results indicate that small, clear and isolated lagoons may hold as many fish species as large, turbid and connected lagoons, a pattern also observed for other groups of organisms (Scheffer et al., 2006). Such hypothesis could be tested with a sampling design including more lagoons of this type.

Our results showed that all lagoons may hold a similar number of species. Nevertheless, large, turbid and with higher DBO lagoons may hold a larger number of individuals than smaller, saltier and clearer lagoons. The northern lagoons environmental conditions, however, led to a higher dominance of littoral zone fish assemblages and lower diversity. In contrast, the southern lagoons environmental conditions led to less dominance and higher diversity. Despite these clear patterns in a wide spatial scale, our results are not conclusive about differences between northern and southern fish assemblages because many lagoons at the north and south of the Tramandaí estuary were not sampled.

Finally, we conclude that northern and southern lagoons studied at Tramandaí river system differ in the pattern of variation of abiotic variables, reflecting differences in water quality. Fish species richness and composition are similar and reflect the recent and common biogeographical origin of the lagoons. In the larger and turbid lagoons, the fish assemblages are less equitable than the smaller and more transparent lagoons, which are more diverse. These results may be useful for studies of coastal management prioritizing fish stocks in the Tramandaí River Basin and proposing models of fish species assemblages in subtropical coastal lagoons.

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References

Albert, J.S., Destouni, G., Duke-Sylvester, S.M., Magurran, A.E., Oberdorff, T., Reis, R.E., Winemiller, K.O., & Ripple, W.J., 2021. Scientists' warning to humanity on the freshwater biodiversity crisis. Ambio 50(1), 85-94. PMid:32040746. http://doi.org/10.1007/s13280-020-01318-8.

American Public Health Association - APHA, 1998. Standard methods for the examination of water and wastewater. Washington: APHA.

Artioli, L.G.S., Lampert, V.R., & Fialho, C.B., 2022. Comparing beach seine and gillnet sampling methods in fish assemblages from Southern Brazilian shallow coastal lakes. Biotemas 35(2), 1-15. http://doi.org/10.5007/2175-7925.2021.e84470.

Artioli, L.G.S., Vieira, J.P., Garcia, A.M., & Bemvenuti, M.A., 2009. Distribuição, dominância e estrutura de tamanhos da assembleia de peixes da lagoa Mangueira, sul do Brasil. Iheringia Ser. Zool. 99(4), 409-418. http://doi.org/10.1590/S0073-47212009000400011.

Baumgarten, M.G.Z., Rocha, J.M.B., & Niencheski, L.F.H., 1996. Manual de Análises em Oceanografia Química. Rio Grande: Editora da FURG.

Bertaco, V.A., Ferrer, J., Carvalho, F.R., & Malabarba, L.R., 2016. Inventory of the freshwater fishes from a densely collected area in South America: a case study of the current knowledge of Neotropical fish diversity. Zootaxa 4138(3), 401-440. PMid:27470773. http://doi.org/10.11646/zootaxa.4138.3.1.

Cardoso, L.S., & Motta-Marques, D., 2004. The Influence of hydrodynamics on the spatial and temporal variation of phytoplankton pigments in a large, sub-tropical coastal lake (Brazil). Braz. Arch. Biol. Technol. 97(4), 587-600. http://doi.org/10.1590/S1516-89132004000400013.

Cardoso, L.S., Silveira, A.L.L., & Motta-Marques, D., 2003. A ação do vento como gestor da hidrodinâmica na lagoa Itapeva (Litoral Norte do Rio Grande do Sul-Brasil). Rev. Bras. Recur. Hidricos 8, 5-15.

Esteves, F.A., Caliman, A., Santangelo, J.M., Guariento, R.D., Farjalla, V.F., & Bozelli, R.L., 2008. Neotropical coastal lagoons: an appraisal of their biodiversity, functioning, threats and conservation management. Braz. J. Biol. 68(4, Suppl.), 967-981. PMid:19197469. http://doi.org/10.1590/S1519-69842008000500006.

Ferraro, L.W., & Hasenack, H., 2009. Clima. In: Würdig, N.L., & Freitas, S.M.F., eds. Ecossistemas e biodiversidade do litoral norte do RS. Porto Alegre: Nova Prova, 26-31.

Fialho, C.B., 1998. Estudo da Ictiofauna da Lagoa das Custódias, Tramandaí, Rio Grande do Sul, Brasil [Doctoral dissertation in Ecology and Natural Resource]. São Carlos, Universidade Federal de São Carlos.

Field, J.G., Clarke, K.R., & Warwick, R.M.A., 1982. Practical strategy for analysing multispecies distribution patterns. Mar. Ecol. Prog. Ser. 8, 37-52. http://doi.org/10.3354/meps008037.

Fricke, R., Eschmeyer, W.N., & Van der Laan, R., eds., 2023. Eschmeyer's catalog of fishes: genera, species, references (Online). Retrieved in 2022, November 14, from http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp

Garcia, A.M., Vieira, J.P., Bemvenuti, M.A., Motta-Marques, D.M.L., Burns, M., Moresco, A., & Condini, V., 2006. Checklist comparison and dominance patterns of the fauna at Taim Wetland, South Brazil. Neotrop. Ichthyol. 4(e2), 261-268. http://doi.org/10.1590/S1679-62252006000200012.

Golterman, H.L., Clymo, R.S., & Ohnstad, M.A.M., 1978. Methods for physical and chemical analysis of fresh water. Oxford: Blackwell Scientific Publications, 213 pp.

Gotelli, N.J., & Colwell, R.K., 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol. Lett. 4(4), 379-391. http://doi.org/10.1046/j.1461-0248.2001.00230.x.

Guimarães, T.F.R., Hartz, S.M., & Becker, F., 2014. Lake connectivity and fish species richness in southern Brazilian coastal lakes. Hydrobiologia 740(1), 207-217. http://doi.org/10.1007/s10750-014-1954-x.

Guimarães, T.F.R., Petry, A.C., Hartz, S.M., & Becker, F.G., 2020. Influence of past and current factors on the beta diversity of coastal lagoon fish communities in South America. J. Biogeogr. 48(3), 639-649. http://doi.org/10.1111/jbi.14029.

Hammer, Ø., Harper, D.A.T., & Ryan, P.D., 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol. Electronica (Online), 4(1), 1-9. Retrieved in 2022, November 14, from http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Hartz, S.M., Rocha, E.A., Brum, F.T., Luza, A.L., Guimarães, T.F.R., & Becker, F.G., 2019. Influences of the area, shape and connectivity of coastal lakes on the taxonomic and functional diversity of fish communities in Southern Brazil. Zoologia 36, 1-12. http://doi.org/10.3897/zoologia.36.e23539.

Hasenack, H., & Ferraro, L., 1989. Considerações sobre o clima da região de Tramandaí, RS. Pesquisas 22, 53-70.

Hutubessy, B.G., & Mosse, J.W., 2023. Identifying fish assemblages in tropical lagoon ecosystem: First record from Luang Island, South-west Maluku Indonesia. Aquac. Fish. 8(2), 221-226. http://doi.org/10.1016/j.aaf.2021.09.004.

Jackson, D.A., & Harvey, H.H., 1989. Biogeographic associations in fish assemblages: local versus regional processes. Ecology 70(5), 1472-1484. http://doi.org/10.2307/1938206.

Jackson, D.A., Peres-Neto, P.R., & Olden, J.D., 2001. What controls who is where in freshwater fish communities – the roles of biotic, abiotic, and spatial factors. Can. J. Fish. Aquat. Sci. 58(1), 157-170. http://doi.org/10.1139/f00-239.

Jeppesen, E., Brucet, S., Naselli-Flores, L., Papastergiadou, E., Stefanidis, K., Nõges, T., Nõges, P., Attayde, J.L., Zohary, T., Coppens, J., Bucak, T., Menezes, R.F., Freitas, F.R.S., Kernan, M., Søndergaard, M., &

Bekliogu, M., 2015. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. Hydrobiologia 750(1), 201-227. http://doi.org/10.1007/s10750-014-2169-x.

Jeppesen, E., Søndergaard, M., Mazzeo, N., Meerhoff, M., Branco, C., Huszar, V., & Scasso, F., 2005. Lake restoration and biomanipulation in temperate lakes: relevance for subtropical and tropical lakes. In: Reddy, M.V., ed. Tropical eutrophic lakes. Their restoration and management. Enfield: Science Publishers, 331-359, Chap 11.

Kjerfve, B., 1994. Coastal lagoons, In: Kjerfve, B., ed. Coastal lagoon processes. Amsterdam: Elsevier Science Publishers, 1-8. http://doi.org/10.1016/S0422-9894(08)70006-0.

Kruk, C., Rodriguez-Gallego, L., Meerhoff, M., Quintans, F., Lacerot, G., Mazzeo, N., Scasso, F., Paggi, J.C., Peeters, E.T.H.M., & Scheffer, M., 2009. Determinants of biodiversity in subtropical shallow lakes (Atlantic coast, Uruguay). Freshw. Biol. 54(12), 2628-2641. http://doi.org/10.1111/j.1365-2427.2009.02274.x.

Magurran, A.E., 2004. Measuring biological diversity. Hoboken: Blackwell.

Malabarba, L.R., & Dyer, B.S., 2002. Description of three new species of the genus *Odontesthes* from the rio Tramandaí drainage, Brazil (Atheriniformes: atherinopsidae). Ichthyol. Explor. Freshwat. 13(e3), 257-272.

Malabarba, L.R., Carvalho-Neto, P., Bertaco, V. A., Carvalho, T.P., dos Santos, J.F., & Artioli, L.G.S., 2013. Guia de identificação dos peixes da bacia do rio Tramandaí. Porto Alegre: Via Sapiens.

Petry, A.C., Guimarães, T.F.R., Vasconcellos, F.M., Hartz, S.M., Becker, F.G., Rosa, R.S., Goyenola, G., Caramaschi, E.P., Díaz de Astarloa, J.M., Sarmento-Soares, L.M., Vieira, J.P., Garcia, A.M., Teixeira de Mello, F., de Melo, F.A.G., Meerhoff, M., Attayde, J.L., Menezes, R.F., Mazzeo, N., & Di Dario, F., 2016. Fish composition and species richness in eastern South American coastal lagoons: additional support for the freshwater ecoregions of the world. J. Fish Biol. 89(1), 280-314. PMid:27401481. http://doi.org/10.1111/jfb.13011.

Prado, J.F., 2009. Vegetação de ambientes aquáticos do litoral norte do estado do Rio Grande do Sul. In: Würdig, N.L., & Freitas, S.M.F., eds. Ecossistemas e biodiversidade do litoral norte do RS. Porto Alegre: Nova Prova, 76-89.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D., & Cooke, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol. Rev. Camb. Philos. Soc. 94(3), 849-873. PMid:30467930. http://doi.org/10.1111/brv.12480.

Schäfer, A., 1988. Tipificação ecológica das lagoas costeiras do Rio Grande do Sul, Brasil. Acta Limnol. Bras. 2, 29-55.

Schäfer, A., Lanzer, R., & Streher, A.S., 2009. Características ecológicas das lagoas costeiras. In: Schäfer, A. E., Lanzer, R. M., & Pereira, R., eds. Atlas socioambiental: municípios de Mostardas, Tavares, São José do Norte e Santa Vitória do Palmar. Caxias do Sul: Educs, 142-157.

Scheffer, M.G., Geest, J., Zimmer, K., Jeppesen, E., Søndergaard, M., Butler, M.G., Hanson, M.A., Declerck, S., & de Meester, L., 2006. Small habitat size and isolation can promote species richness: second-order effects on biodiversity in shallow lakes and ponds. Oikos 112(1), 227-231. http://doi.org/10.1111/j.0030-1299.2006.14145.x.

Schifino, L.C., Fialho, C.B., & Verani, J.R., 2004. Fish community composition, seasonality and abundance in Fortaleza Lagoon, Cidreira. Braz. Arch. Biol. Technol. 47(5), 755-763. http://doi.org/10.1590/S1516-89132004000500011.

Schwarzbold, A., & Schäfer, A., 1984. Gênese e morfologia das lagoas costeiras do Rio Grande do Sul – Brasil. Amazoniana 9, 87-104.

Seeliger, U., Odebrecht, C., & Castello, J.P., 1997. Subtropical convergence environments: the coast and sea in the southwestern Atlantic. Berlin: Springer.

Teixeira-de-Mello, F., Meerhoff, M., Pekcan-Hekim, Z., & Jeppesen, E., 2009. Substantial differences in littoral fish community structure and dynamics in subtropical and temperate shallow lakes. Freshw. Biol. 54(6), 1202-1215. http://doi.org/10.1111/j.1365-2427.2009.02167.x.

Tomazelli, L.J., & Villwock, J.A., 2005. Mapeamento geológico de planícies costeiras: o exemplo da Costa do Rio Grande do Sul. Gravel 3, 109-115.

Würdig, N.L., 1987. Alguns dados físicos e químicos do sistema lagunar de Tramandaí, RS. Pesquisas 20, 49-74.

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