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Original Article

Altitudinal distribution and body condition of migratory fish juveniles *Megaleporinus obtusidens* (Valenciennes) and *Salminus brasiliensis* (Cuvier) in the main channel of the Uruguay River, Southern Brazil

Distribuição altitudinal e condição corpórea de juvenis dos peixes migradores *Megaleporinus obtusidens* (Valenciennes, 1837) e *Salminus brasiliensis* (Cuvier, 1816) no canal principal do rio Uruguai, sul do Brasil

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Abstract

In this study, we analyzed the altitudinal distribution and body condition of the juvenile migratory fish *Megaleporinus obtusidens* and *Salminus brasiliensis* in the Uruguay River, a South American subtropical river. We used the presence/absence data and condition factor (K) of juveniles as indicators to try to characterize some recruitment patterns of migratory fish in the main channel of the Uruguay River. Gillnet sampling was conducted during two reproductive years, 2015–2016 and 2016–2017 (November and March of each reproductive year), in three Uruguay River stretches at different levels of altitude. The nets remained in the water for 10–12 hours per night or day for 10 days during each field trip (NOV-15, MAR-16, NOV-16, and MAR-17). The abundance of *M. obtusidens* juveniles were similar between the two reproductive years, whereas *S. brasiliensis* capture was higher during the 2015–2016 reproductive year. The probability of finding *M. obtusidens* juveniles in the Uruguay River was negatively correlated ($p < 0.05$) with the altitudinal gradient of the sampling points, as shown by the GLM model. For *S. brasiliensis*, the logit model indicated a non-significant probabilistic relationship ($p > 0.05$) between the presence of juveniles of this fish species and the altitude gradient. Regarding the body condition of juveniles, the water quality of the sampling points did not affect the juvenile condition factor for either species; however, a positive relationship ($p < 0.05$) was found with the water level for both species, even with an adjusted R^2 of 0.13 for *M. obtusidens* and 0.48 to *S. brasiliensis*. Altitude gradient and water level were factors that may affect the juvenile distribution and body condition of these species, respectively, in the Uruguay River. Therefore, this information can be used in hydropower generation policies to conserve migratory fish populations in the Uruguay River Basin.

Keywords: condition factor, fish conservation, floodplains, nurseries, recruitment.

Resumo

Neste estudo, analisamos a distribuição altitudinal e condição corpórea de juvenis dos peixes migradores *Megaleporinus obtusidens* e *Salminus brasiliensis* no rio Uruguai, um rio subtropical sul-americano. Nós utilizamos os dados de presença/ausência e o fator de condição dos juvenis como indicadores, para tentar caracterizar alguns padrões de recrutamento de peixes migradores no canal principal do rio Uruguai. A amostragem com rede de espera foi realizada durante dois anos reprodutivos, 2015-2016 e 2016-2017 (novembro e março de cada ano reprodutivo), em três trechos do rio Uruguai em diferentes níveis de altitude. As redes permaneceram na água por 10–12 horas a noite ou dia, por 10 dias durante cada saída de campo (NOV-15, MAR-16, NOV-16 e MAR-17). A abundância de juvenis de *M. obtusidens* foi semelhante entre os dois anos reprodutivos, enquanto a captura de *S. brasiliensis* foi maior durante o ano reprodutivo 2015-2016. A probabilidade de encontrar juvenis de *M. obtusidens* no rio Uruguai foi negativamente correlacionada ($p < 0,05$) com o gradiente altitudinal dos pontos amostrais, conforme demonstrado pelo modelo GLM. Para *S. brasiliensis*, o modelo logit apresentou relação probabilística não-significativa ($p > 0,05$) entre a presença de juvenis desta espécie de peixe e o gradiente de altitude. Com relação à condição corpórea dos juvenis, a qualidade da água dos pontos amostrais não influenciou o fator de condição dos juvenis para nenhuma das espécies; no entanto, uma relação positiva ($p < 0,05$) foi encontrada com o nível da água para ambas as espécies, com um R^2 ajustado de 0,13 para *M. obtusidens* e 0,48 para *S. brasiliensis*. O gradiente de altitude e o nível da água foram fatores significativos que podem afetar a distribuição de juvenis e a condição corpórea destas espécies, respectivamente, no rio Uruguai. Portanto, estas informações podem ser utilizadas em políticas de geração de energia hidrelétrica para conservar as populações de peixes migradores na bacia do rio Uruguai.

Palavras-chave: fator de condição, conservação de peixes, planícies de inundação, berçários, recrutamento.

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1. Introduction

The successful recruitment of most South American migratory fish primarily results from egg and larval dispersion in the currents and vortices of rivers (Godinho and Kynard, 2009) combined with the probability of finding nursery habitats in river floodplains (Suzuki et al., 2009; Oliveira et al., 2015). In addition, interannual variations in the duration and delay of floods strongly influence fish recruitment (Agostinho et al., 2004). Generally, migratory fish recruitment is positively related to greater river flow and water levels, higher rainfall and air temperatures (Carolsfeld et al., 2003; Humphries et al., 2020).

In Central Amazonia, located close to the equator, migratory fish recruitment is driven by the flood amplitude of large rivers, such as the Amazon, Solimões, and Madeira (Mérona and Gascuel, 1993). Similar effects have been observed in the Paraná and São Francisco Rivers, which are located at higher southern latitudes (Agostinho et al., 2004; Pompeu and Godinho, 2006). However, there are Neotropical rivers that have limited floodplain areas (Silva et al., 2020; Pachla et al., 2022), and therefore, the recruitment patterns in these rivers need to be better clarified. These fluvial ecosystems do not seem to fully support the concept of "floodplain recruitment" (King et al., 2003), widely spread in South America and in other rivers around the world.

The Uruguay River, which originates in southern Brazil, is considered one of these rivers (Zaniboni-Filho and Schulz, 2003). This river is situated in subtropical latitudes where flood regimes do not follow a remarkable sine curve, as is the case for most large South American river systems (Di Persia et al., 1986), and for example, the spawning period of some migratory fish species in this river appears to be longer than that in other South American rivers (Zaniboni-Filho et al., 2017). In addition, habitats such as pools, rapids and the confluence with tributaries seem to be of great importance in the spawning and recruitment processes of migratory fish in this river ecosystem (Ávila-Simas et al., 2014; Luz-Soares et al., 2022). Thus, non-hydrological attributes could influence the recruitment patterns of migratory fish in the Uruguay River, such as the altitude gradient (Alves and Fontoura, 2009; Barradas et al., 2012) and the water quality of aquatic habitats (Chittaro et al., 2009).

Altitude is a very important factor in the ecology of rivers, especially in the River Continuum Concept (Vannote et al., 1980), in which the input of allochthonous energy is more intense in headwater regions, while the production autochthonous has greater intensity in the lowest and most senile regions of a lotic ecosystem. So, hypothetically, in these more senile regions, young migratory fish are able to find environments with greater food availability and more complex environments for refuge from predators (Sedell et al., 1989).

On the other hand, water quality is a term that summarizes the physicochemical characteristics of a given water body or at some point in a water body, whether natural or artificial (Bhateria and Jain, 2016). Due to an osmoregulatory system still in formation, fish larvae and juveniles tend to be more susceptible to water quality conditions in natural and artificial aquatic environments than adult fish (Varsamos et al., 2005). For example, juvenile fish abide anoxic environments in the Amazon floodplains as a way to avoid the presence of predatory fish (Anjos et al., 2008). The water quality of a given habitat can also influence the health and nutritional status of fish, with direct consequences on the growth and weight/length relationships of this group of animals (Sadauskas-Henrique et al., 2011).

Another complex issue regarding the recruitment of migratory fish in the Uruguay River concerns the occurrence of migratory species that also occur in large rivers with vast floodplain areas, such as the Paraná River, the Paraguay River and the São Francisco River (Carolsfeld et al., 2003). Among these fish species are *Megaleporinus obtusidens* (Valenciennes), the piava, and *Salminus brasiliensis* (Cuvier), the dourado. These species are targets of commercial and sport fishing in the Uruguay River (Schork et al., 2012), and face considerable fishing pressure in the Uruguay River Basin, with the dourado assigned a vulnerable status on the Red List of Endangered Species for the Rio Grande do Sul state (Marques et al., 2002). They also face other environmental pressures in this river basin, such as habitat degradation; interruption of migratory routes (upstream and downstream) by hydroelectric dams; and heavy pollution from agricultural, livestock, urban, and industrial activities (Reynalte-Tataje et al., 2012; Lopes and Zaniboni-Filho, 2019; Cataldo et al., 2020).

So, understanding the autoecological processes, particularly the recruitment process of these fish species is of fundamental importance for proposing management measures for these fishery resources (Gomes & Agostinho, 1997). In particular, in a context of the implementation of new hydroelectric projects and the important social role of fishing on these fish species in the Uruguay River Basin (Zaniboni-Filho and Schulz, 2003; Schork et al., 2013; Biassi et al., 2017; Mounic-Silva et al., 2019).

Therefore, we studied some ecological factors that could influence the juvenile stages of these fish species. We analyzed the distribution of the presence/absence of juvenile fish in an altitude gradient (non-hydrological variable) and their body condition according to the water quality of sampling points (non-hydrological variable) and river water level (hydrological variable) on the sampling dates, in order to try to characterize some recruitment patterns of piava and dourado in the main channel of the Uruguay River.

2. Materials and Methods

2.1. Study area

The Uruguay River begins at the confluence of the Canoas and Pelotas Rivers. Its initial section, the upper stretch, flows east-west towards the Yucumã Falls (Zaniboni-Filho and Schulz, 2003), bordering the Brazilian states of Rio Grande do Sul and Santa Catarina in a valley without floodplains for around 400 km. Three hydroelectric power plants are installed in this section: Machadinho, Itá, and Foz do Chapecó. In its middle section, the river flows north-south for approximately 800 km, separating Brazil from Argentina, and Argentina from Uruguay. This section begins at Yucumã Falls and extends to the Salto Grande Dam between Argentina and Uruguay. The longitudinal profile slope decreases in this section, which provides the formation of floodplain habitats with marginal lagoons, wetlands, and marshes (Quirós and Cuch, 1989).

Three stretches (T1, T2, and T3) in the upper and middle sections of the Uruguay River (Figure 1) were sampled. T1 was located in the upper Uruguay River, between the mouths of the Chapecó and Macaco Branco rivers (approximately 130 km), immediately downstream of the Foz do Chapecó dam. T2 was situated between the mouths of the Buricá and Ijuí Rivers (approximately 180 km), and T3 was situated between the mouths of the Icamaquã and Ibicuí Rivers (approximately 45 km), located in the middle Uruguay River. The three sampling stretches in the main channel of the Uruguay River, illustrated with drainage density gradients ($km.km^{-2}$) which indicates areas prone to flooding (INPE, 2021), are shown in Figure 1.

2.2. Samplings and water quality parameters

Juveniles of *M. obtusidens* and *S. brasiliensis* were sampled during field trips in November 2015, March 2016, November 2016, and March 2017. Sampling was performed for ten days over two successive reproductive periods (2015–2016 and 2016–2017). These months were selected based on the peak reproductive period of the migratory species in the Uruguay River, which generally occurs between October and November (Zaniboni-Filho and Schulz, 2003). Therefore, field expeditions were conducted at the beginning and end of the reproductive season, considering: 1) the possibility of early spawning in the reproductive season (November field trips) and 2) the timely growth of eggs to larvae and juveniles (March field trips).

T1, T2, and T3 were sampled using the same fishing effort over four field trips. Juvenile migratory fish were captured at four randomly selected sampling points in each stretch, totaling 12 samples for each of the four field trips and 48 samples throughout the study period. Specifically, the marginal areas of the main channel of the Uruguay River, comprising shrub vegetation, aquatic macrophytes, and other types of marginal vegetation, were sampled, taking a minimum spacing of 10 km between sampling points. The geographical coordinates of each sampling point were obtained using a Garmin Montana® 610 GPS. The samplings were licensed by the Brazilian Ministry of the Environment (SISBIO licenses 47332-1 and 47332-2).

Sampling was performed using two sets of gill nets: one placed at the bottom (B) and the other at the surface (S) of the water column. Each set was 60 m long and composed of 20 m joints from three mesh openings (1.5, 2.0, and 2.5 cm; opposite nodes). Gill nets were installed at dusk for night sampling and at dawn for daytime sampling and remained in the water for ten hours. Sampling was carried out during day and night periods due to greater or lesser fish activity in relation to daily variation in sunlight. Captured juveniles were euthanized using a 20% clove oil overdose and fixed in 10% formalin.

At each sampling point, the following water quality variables were measured: dissolved oxygen (DO) ($mg L^{-1}$),

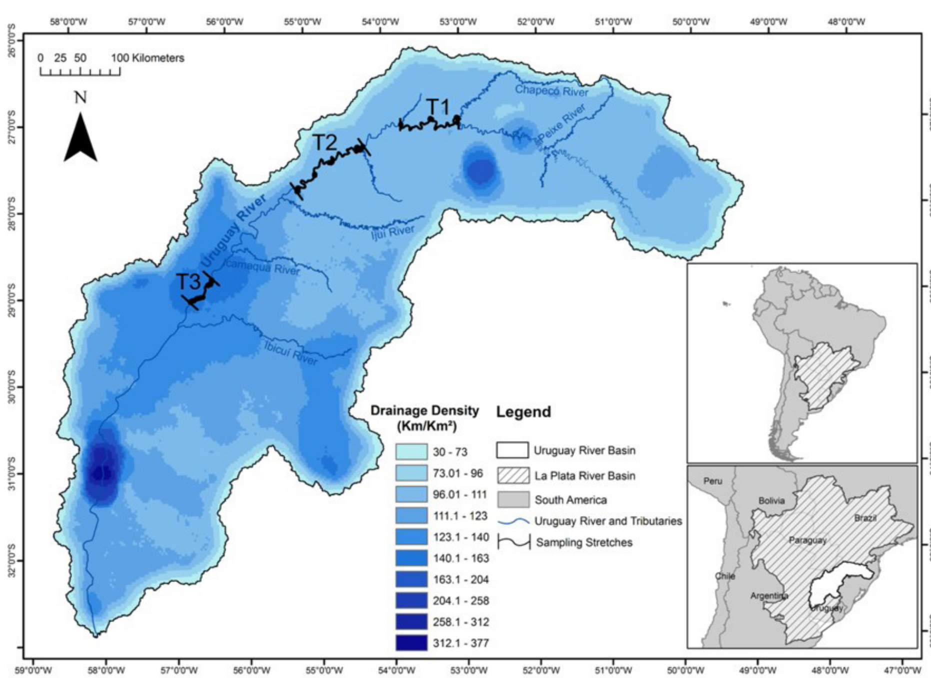

Figure 1. Study area, location of the sampling stretches (T1 - T2 - T3) in the Uruguay River with the respective drainage density gradients ($km.km^{-2}$).

electrical conductivity (µS cm^{-1}), pH, and temperature (°C). All the variables were measured using a YSI® Professional Plus multiparameter probe. In addition, the air temperature (°C) was measured using a mercury thermometer, and water transparency (cm) was measured using a Secchi disc.

2.3. Juvenile migratory fish identification and measurement

The captured juveniles were identified according to the literature (Nakatani et al., 2001; Zaniboni-Filho et al., 2004) and based on the taxonomic identification keys used by the Laboratory of Biology and Aquaculture of Freshwater Fish (LAPAD) at the Federal University of Santa Catarina (UFSC). Subsamples (species vouchers) were separated and deposited in the ichthyological collection of the Museum of Zoology at the State University of Londrina (UEL), Brazil.

The total weight (TW) and length (TL) of the juveniles were measured. Individuals who completed the larval stage (complete flexion of the notochord with formation of all fins) and were smaller than L_{50} (the size at which 50% of the individuals were sexually mature) were considered juveniles (Trippel and Harvey, 1991). In this study, the L_{50} values of the target species were 25.0 cm for *M. obtusidens* (Agostinho et al., 2003) and 51.0 cm for *S. brasiliensis* (Agostinho et al., 2003).

2.4. Altitude and water level

The altitude for each sampling point was determined using the ArcMap program ARCGIS®. The procedure is based on plotting GPS-marked field coordinates in altimetric images derived from the Shuttle Radar Topographic Mission (SRTM). Descriptive graphics of the altitude profile of the Uruguay River were produced together the indication of the average slopes ($m.km^{-1}$), in order to compare the nature of the altitude variation between the three sampling stretches, as well as their average slopes.

Hydrological measurements of water level were obtained from the Hydrological Data Platform HidroWeb of the National Water Agency (ANA) of the Brazilian Government (ANA, 2021). For each stretch, data were obtained from hydrological stations located in the municipalities of Iraí (codes 74100000 and 02753019), Porto Lucena (74800000 and 02755001), and Itaqui (75900000 and 02956005) in the Rio Grande do Sul state (Brazil), for T1, T2, and T3, respectively, considering the sampling dates of this respective study.

2.5. Data analysis

To study some of the recruitment patterns of *M. obtusidens* and *S. brasiliensis,* the following response variables were considered:1) the presence/absence of juvenile migratory fish at each sampling point, and 2) the body condition of the juvenile fish, based on its condition factors (Le Cren, 1951), estimated from the weight-length relationship for each individual captured at each sampling point. The condition factors of migratory fish juveniles were analyzed from subsamples of *M. obtusidens* and *S. brasiliensis*, to enable condition factor analysis with individuals belonging to the same length class, with minimum and maximum total length (TL) limits to the standard error of the TL. The following formula was used (Vazzoler, 1996): $K = Wt/Lt^{\theta}$, where K is the condition factor, Wt is the total weight (g), Lt is the total length (cm), and θ is the allometric index obtained from the linear logarithmic relationship between the weight and length of each target fish species. Owing to environmental differences (mainly the flow and water level of the Uruguay River) between the 2015-2016 and 2016-2017 reproductive years, allometry indices were calculated for each period.

Using a generalized linear model (GLM), the presence/absence data of juveniles were modeled as a variable explained by a logit distribution (Zuur et al., 2009), with the sampling point altitude used as a primary predictor. In addition, a multiple linear model (LM) was applied to the condition factors as the response variable. For these multiple LM, temperature (°C), dissolved oxygen concentration (mg L^{-1}), electrical conductivity (µS cm^{-1}), pH, and transparency (cm) of water of the sampling points were used as environmental predictors. Finally, the body condition data of the migratory fish juveniles regarding the water level of the Uruguay River were analyzed using a linear model, applied considering the water level on the sampling day in the sampling stretch (T1, T2, or T3) as an environmental predictor. Preference was given to separate regression analyzes between the predictor variables "water quality" and "river water level", due to the distinct nature of these predictors.

The GLMs and the LMs were submitted to a statistical assumptions analysis to verify the overdispersion of the models' data. The null and residual deviations associated with degrees of freedom were used, in addition to graphical analyses of Cook's distance, leverage, and null and residual deviations (Zuur et al., 2009).

3. Results

Migratory juveniles of *M. obtusidens* and *S. brasiliensis* were captured over two successive reproductive years (2015–2016 and 2016–2017, respectively). The abundance of *M. obtusidens* juveniles captured was similar between the two reproductive periods (Table 1); however, for *S. brasiliensis,* the number captured in the reproductive year 2015-2016 was higher than 2016-2017 (Table 1).

A GLM relating juvenile abundance to altitude was validated in the assumption analyses, mainly in the study of null and residual deviance (Table 2). The probability of finding *M. obtusidens* juveniles in the Uruguay River was negatively correlated with the altitude of the sampling points ($p < 0.05$), as shown in Figure 2, emphasizing T3 as an important stretch for the presence of juvenile of *M. obtusidens* and, in this way, contrasting with stretches T1 and T2. For *S. brasiliensis,* the logit model indicated non-significant probabilistic relationship between the presence of juveniles and altitude gradients ($p > 0.05$). Therefore, for this fish species, the stretches T1, T2 and T3 do not seem to present differences in the presence/absence of juveniles.

The variation in altitudes demonstrated that T1 is a stretch with a steeper slope than the other two sampling stretches. T1 presented a slope rate of 0.43 $m.km^{-1}$, while

Table 1. Summarized matrix of mean values of the environmental predictors (water quality and water level) and abundance of juveniles each sampling stretch (T1, T2, and T3) in the Uruguay River and field trips (Nov. 2015, Mar. 2016, Nov. 2016, and Mar. 2017).

RY	Month (Season)	S	WL (cm)	WT § (°C)	pH §	DO § (mg L^{-1})	EC § (µS cm^{-1})	WTr § (cm)	A † (m)	***Mo***	***Sb***
2015/2016	November (Spring)	T1	426	22.6	7.46	8.92	61.0	58	207	0	0
		T2	320	23.7	6.58	8.73	50.2	35	119	0	0
		T3	580	24.3	6.85	6.40	55.2	39	53	1	0
	March (Summer)	T1	218	24.2	8.03	6.66	50.3	72	212	0	0
		T2	151	26.9	8.27	6.76	52.4	62	106	0	1
		T3	348	26.3	7.09	5.85	53.8	53	51	17	11
	Total									*18*	*12*
2016/2017	November (Spring)	T1	262	25.3	10.6	6.65	57.6	107	207	0	1
		T2	122	25.4	8.27	7.08	55.8	84	102	0	0
		T3	276	25.8	7.24	5.80	57.5	62	48	5	0
	March (Summer)	T1	144	25.6	7.39	6.69	67.1	51	208	0	1
		T2	198	26.2	7.19	4.32	64.0	37	101	0	0
		T3	472	27.9	6.77	4.74	65.1	55	51	14	0
	Total									*19*	*2*

RY = Reproductive year; S = Stretch of river; WL = Water level; WT = Water Temperature; pH = Hydrogenionic potential; DO = Dissolved Oxygen concentration; EC = Electrical conductivity; WTr = Water transparency; A = Altitude; *Mo* = *Megaleporinus obtusidens* juveniles'abundance; *Sb* = *Salminus brasiliensis* juveniles' abundance. §Average of 10 sampling points for stretch/field trip; †Average of 10 sampling points for stretch/field trip. Values were taken from the ArcMap program – ArcGIS®.

Table 2. Summary for GLM binomial (link = logit) applied to presence/absence data of *Megaleporinus obtusidens* and *Salminus brasiliensis* juveniles related to the sampling points altitude (m).

Fish species	Estimate	Std. error	*P* value	Null Deviance/ GL	Residual Deviance/GL
Megaleporinus obtusidens	-0.0663	0.0254	0.009*	51.674/47	28.193/46
Salminus brasiliensis	-0.0036	0.0064	0.572	39.880/47	39.547/46

* statistical significance ($p < 0.05$).

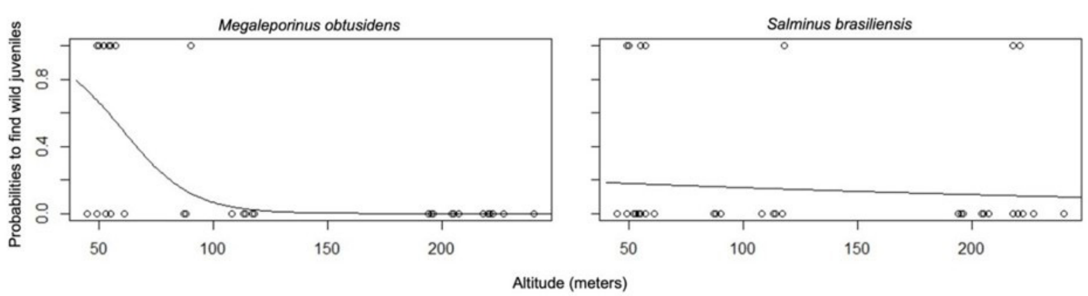

Figure 2. Probabilities to find fish juveniles of *Megaleporinus obtusidens* and *Salminus brasiliensis* in an altitude gradient (m) of the main channel of the Uruguay River.

sections T2 and T3 presented a slope rate of 0.17 $m.km^{-1}$ and 0.08 $m.km^{-1}$, respectively (Figure 3).

In captured individuals, the total length ranged between 10.0 and 19.8 cm for *M. obtusidens* and from 12.8 to 24.3 cm for *S. brasiliensis*. Table 3 summarizes the total length and weight data of *M. obtusidens* (n = 30) and *S. brasiliensis* (n = 11) from the subsamples used to assess the condition factors of the juveniles.

In the multiple linear models between the condition factors of juveniles and water quality parameters, no

Table 3. Reproductive year (RY), total length (TL; mean ± standard error), weight (W; mean ± standard error), and allometric index (θ) of the juvenile subsamples of *Megaleporinus obtusidens* and *Salminus brasiliensis* used to calculate the condition factor.

Species	RY	TL (cm)	W (g)	θ
Megaleporinus obtusidens	2015-2016	13.6 (± 2.4)	54.1 (± 28.5)	2.78
	2016-2017	15.8 (± 3.4)	95.7 (± 49.8)	2.96
Salminus brasiliensis	2015-2016	21.5 (± 1.5)	194.1 (± 43.5)	3.10
	2016-2017	16.8 (± 2.4)	83.2 (± 35.2)	3.56

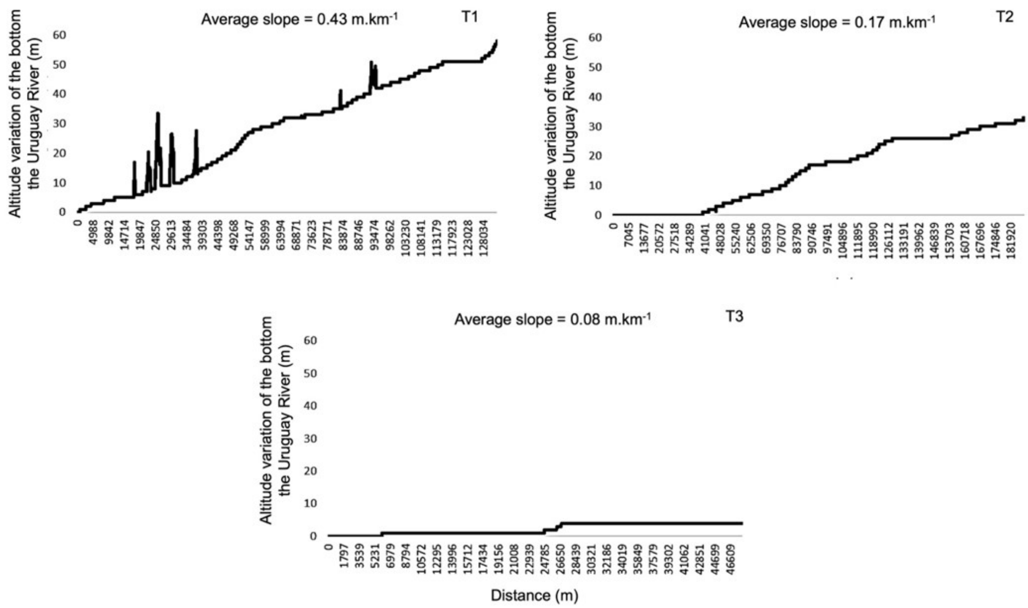

Figure 3. Altitude variation of the bottom (m) and the indication of the average slopes ($m.km^{-1}$) of the three sampling stretches of the Uruguay River.

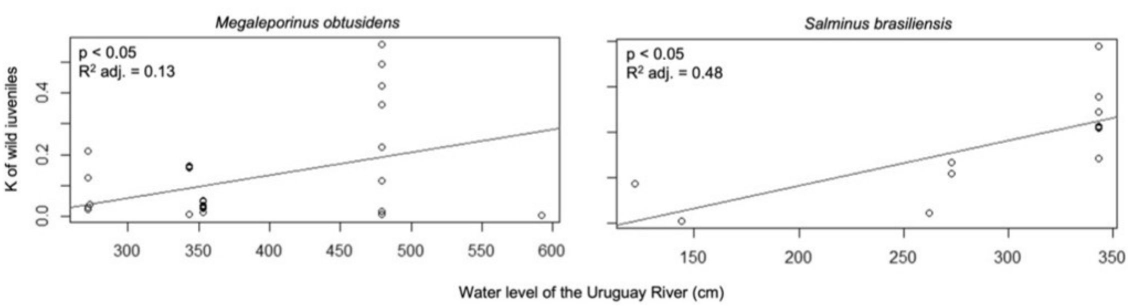

Figure 4. Linear model plot relating the condition factor (K) of juveniles of *Megaleporinus obtusidens* and *Salminus brasiliensis* to the Uruguay River water level (cm).

significant relationship was observed ($p > 0.05$) for any parameter, with a general adjusted $R^2 = 0.2379$ for *M. obtusidens* and $R^2 = 0.3219$ for *S. brasiliensis*. In contrast, the relationship of the condition factor of juveniles with the Uruguay River water level, given by a linear model, was statistically significant for both fish species ($p < 0.05$), with adjusted-R^2 of 0.13 and 0.48 for *M. obtusidens* and *S. brasiliensis*, respectively (Figure 4). In contrast, the linear model applied to *S. brasiliensis* seems to fit the data better, demonstrating that the water level of the Uruguay River seems to considerably influence the condition factor of juveniles for this fish species.

4. Discussion

Extensive floodplains in South American river systems provide the necessary environmental support for the early life stages of the majority of potamodromous Neotropical migratory fish (Lowe-McConnell, 1987). In addition, some floodplains serve as nursery habitats and are vital for conserving of these fish populations (Leite et al., 2002; Agostinho et al., 2003; Godinho and Kynard, 2009; Barletta et al., 2010). But the Uruguay River have limited floodplain areas (Pachla et al., 2022), mainly in the upper part of the basin. Furthermore, most of the basin's hydroelectric projects are located in its upper portion, which brings even more challenging to the recruitment process for migratory fish in this region of the Uruguay River (Zaniboni-Filho and Schulz, 2003; Ávila-Simas et al., 2014).

On the other hand, the middle Uruguay River is a stretch-free section without hydroelectric dams. It supports an apparent effect of altitude gradient on the early life stages of migratory fish populations, i.e., newly hatched larvae and those at early stages of development were mainly found in stretches below the Yucumã Falls (Mounic-Silva et al., 2019). In the present study, juveniles were found in the lower regions, represented by T3. In T3, there is a large-complex area of the floodplain on the right bank of the middle Uruguay River known as Argentine Mesopotamia (Quirós and Cuch, 1989; Brea and Zucol, 2011), in contrast to T1 and T2, which are regions of the Uruguay River still in the form of a valley, with a high presence of rapids (Zaniboni-Filho and Schulz, 2003). Thus, T1 and T2 hypothetically function as larval dispersal regions, whereas T3 is in a floodplain region with a higher drainage density than T1 and T2 and, consequently, acts as a nursery habitat for the early life stages of migratory fish. Thus, altitude appears to be a robust predictor of the spatial distribution of juvenile migratory fish in the middle of the Uruguay River, mainly for *M. obtusidens*.

These results fit well with the models generated by other studies in the Uruguay River Basin, in which the authors found that the altitudinal gradient strongly influenced the patterns of occurrence of migratory fish, including the two species studied. These authors also demonstrated significant negative relationships between the presence of migratory fish and altitude in the river basins of the Jacuí (Alves and Fontoura, 2009) and Uruguay (Barradas et al., 2012), analyzing data mainly obtained through interviews with fishermen. Therefore, the juvenile data presented here corroborate the models generated with *ex-situ* data, especially those of Barradas et al. (2012).

Water level is an important and influential environmental factor in LMs constructed for the condition factor of juvenile fish. Gomes and Agostinho (1997) found a positive relationship between the water level of the Paraná River and the nutritional status of juveniles of *Prochilodus scrofa* (Steindachner, 1881), and the subsequent fishing recruitment of this fish species. According to the Flood Pulse Concept (Junk et al., 1989), severe floods and high-water levels expand floodplains, increasing the possibility of exploiting habitats for the entire aquatic community and enhancing *in situ* biological productivity. Thus, highlighting the possible effects of hydrological attributes, like the river water level, on the body condition of migratory fish juveniles in the Uruguay River, mainly for *S. brasiliensis*, the dourado. However, for the dourado, the floodplain recruitment pattern (King et al., 2003), which is widely accepted for most Neotropical migratory Characiformes, needs to be further examined, especially in the identification of recruitment habitats used by dourado fish populations. Further investigation needs to be conducted for this fish species, since it is widely accepted in the scientific literature that dourado uses also current habitats and rapids already in the juvenile stage, due to its high swimming potential in this phase of your life history (Carolsfeld et al., 2003).

M. obtusidens and *S. brasiliensis* showed differences in the recruitment patterns analyzed in this study. Piava is an omnivorous species that feeds on seeds, insects, and mollusks (Agostinho et al., 2003). Therefore, its juveniles' occurrence restricted to the lower regions of the middle Uruguay River appears to follow the availability of autochthonous food resources. However, for the piscivorous *S. brasiliensis*, altitude did not have a remarkable influence on juvenile abundance because the species is well adapted to regions of greater flow and currents in the Uruguay River (Zaniboni-Filho and Schulz, 2003).

Water quality did not appear to influence the body condition of the juveniles studied, as expected. For *Prochilodus lineatus* (Valenciennes, 1837), an iliophage Neotropical migratory fish, which also occurs in the Uruguay River Basin, the condition factor of individuals of this species was negatively influenced by the deterioration of water quality in the Tietê and Peixe rivers, belonging to the Paraná River basin (Urbanski et al., 2023). But the temporal scale of the water quality data (dissolved oxygen, water temperature, pH, conductivity, and others) seems incidental and momentary in lotic ecosystems, where water currents are at a much higher speed than lentic floodplain environments (Matthews, 1998). And perhaps, without adjusting the temporal scale of the juveniles' body condition data, which operates in days and/or months (Tribuzy-Neto et al., 2017). Therefore, this temporal mismatch between predictor variable and response variable is one of the plausible reasons for the null effect of water quality data on the body conditions of the juveniles of *M. obtusidens* and *S. brasiliensis*.

Finally, the Uruguay River has a cascade effect in its upper part caused by 3 dams already built (Machadinho, Itá, and Foz do Chapecó). Furthermore, approximately 300 km below the last sampling point, the Uruguay River is dammed by the Salto Grande hydroelectric power plant, which has a severe negative impact on the recruitment of migratory fish populations in the Uruguay River (Cataldo et al., 2020). Therefore, future economic development plans that could compromise the environmental functions of the free stretch of the middle portion of the Uruguay River, such as hydroelectric dams, should consider the pivotal ecological roles of nurseries for migratory fish, particularly the T3 region and, the also fundamental ecological role of T1 and T2 as possible fish spawning areas (Mounic-Silva et al., 2019). This environmental scenario bringing to light the importance of conserving the river connectivity between the three stretches studied for the maintenance of the life cycle of migratory fish species in the Uruguay River.

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