The ichthyofauna of drifting macrophyte mats in the Ivinhema River, upper Paraná River basin, Brazil

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We describe the fish assemblages associated with drifting macrophyte mats and consider their possible role as dispersal vectors in the Ivinhema River, a major tributary of the upper Paraná River, Brazil. Fish associated with drifting mats were sampled in the main river channel during January and March 2005, when the wind and/or the increased water level were sufficient to transport macrophyte stands. Fish in the drifting mats were sampled with a floating sieve (4 m long x 2 m wide x 0.6 m high, and 2 mm mesh size). In the laboratory, larvae, juvenile, and adult fish were counted and identified to the lowest possible taxonomic level. In four drifting macrophyte mats we captured 218 individuals belonging to at least 28 species, 17 families, and 6 orders. *Aphyocharax dentatus*, *Serrasalmus* spp., and *Trachelyopterus galeatus* were the most abundant taxa associated with the mats, but species richness ranged from 6 to 24 species per mat. In addition, 85% of the total number of individuals caught was larvae and juveniles. Although preliminary and based on limited samples, this study of drifting macrophyte mats was the first one in the last unregulated stretch of the Paraná River remaining inside Brazilian territory, and alerts us to the potential role of macrophytes mats as dispersers of fish species in the region.

Nesse trabalho as assembleias de peixes associadas a bancos de macrófitas flutuantes à deriva foram descritas. Além disso, foi considerado o possível papel desses bancos como vetores de dispersão no rio Ivinhema, importante tributário do alto rio Paraná, Brasil. Os peixes associados aos bancos à deriva foram amostrados no canal principal desse rio, entre os meses de Janeiro a Março de 2005, quando o vento e/ou o aumento no nível da água foram suficientes para transportar os bancos de macrófitas. Os peixes foram amostrados com uma rede flutuante (4 m de comprimento x 2 m de largura x 0,6 m de altura e 2 mm de tamanho de malha). No laboratório, larvas, jovens e adultos foram contados e identificados ao menor nível taxonômico possível. Nos quatro bancos de macrófitas flutuantes a deriva foram capturados 218 indivíduos pertencentes à pelo menos 28 espécies, 17 famílias e 6 ordens. *Aphyocharax dentatus*, *Serrasalmus* spp. e *Trachelyopterus galeatus* foram os táxons mais abundantes associados aos bancos de macrófitas à deriva, mas a riqueza de espécie variou entre 6 e 24 espécies por banco. Além disso, 85% do total do número de indivíduos capturados foram larvas e juvenis. Embora preliminar e baseado em amostragens limitadas, este estudo, conduzido em bancos de macrófitas flutuantes à deriva, foi o primeiro no último trecho não regulado do rio Paraná em território brasileiro, e alerta para o papel potencial que os bancos de macrófitas têm como dispersores de peixes na região.

Key words: Dispersion, Fish guilds, Floodplain, Free-floating plants, Freshwater fishes.

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Introduction

Floodplains are mosaics of biotopes consisting of rivers, side channels, and lakes where the flood pulse is considered the main force that regulates their functioning and that structures their biotic assemblages (Junk *et al.*, 1989; Agostinho *et al.*, 2004). In the littoral areas of these biotopes, there are dense mats of aquatic macrophytes, which are common components of the waterscape (Thomaz *et al.*, 2004) and contribute to increased habitat heterogeneity (Dibble & Thomaz, 2009; Padial *et al.*, 2009).

Areas covered with macrophytes support high abundances of individuals and species, including fish, due to their role as spawning substrate, refuge against predators, and concentrated food availability (Dibble *et al.*, 1996; Agostinho *et al.*, 2003, 2007; Pelicice *et al.*, 2005). In fact, the presence of macrophytes is essential in the life history of many fish species (Chick & McIvor, 1997), and some species are associated with patches of dense aquatic vegetation during all stages of their life cycles (Winemiller & Jepsen, 1998).

During floods, macrophyte stands, especially those composed mainly of free-floating species, frequently fragment and are carried by water flow and/or wind. Thus, fragments detach from littoral areas of floodplain lakes, often forming floating mats, which drift in the main channel of rivers. These mats transport elements of the aquatic fauna, contributing to the dispersal of fish and other organisms in large rivers and lakes (Oliver & Mckaye, 1982; Sazima & Zamprogno, 1985; Rossi & Parma de Croux, 1992; Henderson & Hamilton, 1995; Horvath & Lamberti, 1997; Schiesari *et al.*, 2003). However, this dispersal mechanism has received limited study in the Neotropical region and elsewhere, despite its potential importance to the maintenance of local and regional biodiversity. In the intensely regulated Paraná River, these mats will generally reach a reservoir downstream, which is the final destination for the accompanying ichthyofauna.

Considering this gap in knowledge, this study sought to describe the ichthyofauna associated with mats of aquatic macrophytes drifting in a South American rivers. Our goal was to evaluate the possible role of these mats as dispersers of the fish assemblage. Specifically, we aimed to identify fish, according to species as well as trophic and reproductive guilds, drifting in the river within the floating macrophyte mats.

The study was conducted in the Ivinhema River, State of Mato Grosso do Sul, Brazil. With a basin of 38,200 km², the Ivinhema River is 310 km long and flows northwest to southeast until it reaches the upper Paraná River floodplain. This floodplain section is 210 km long and extends from the tailrace of Porto Primavera Dam to the upper reaches of Itaipu Reservoir. Within this floodplain section, the Ivinhema River meanders parallel to the main channel of the Paraná River (Fig. 1). From the Curutuba Channel to the Paraná River, the Ivinhema has a sinuosity quotient of 1.26, width: depth ratio of 22:1, and an average slope of 10.8 cm/km. In both sides of the river there are several ephemeral and permanent floodplain lakes with some of the largest ones directly connected to the main channel of the river.

The Paraná River has been heavily impounded over the last 40 years. Multiple dams in the mainstem Paraná River and in its tributaries regulate the seasonal hydrological dynamics of the river. Yet, despite a modified hydrograph, the flood pulse is still the main force acting on the aquatic biota of the floodplain section. In addition, depending on the intensity of the flood pulse, mats of aquatic macrophytes are found drifting in the main channel of the Paraná and tributaries, such as the Baia and Ivinhema Rivers, that join the Paraná within the floodplain section. In these rivers, water level rises in November/January to May/June (Agostinho *et al.*, 2001). During these months, it is common to find mats of floating macrophytes drifting in the main channels. Associated with these mats are fish, aquatic invertebrates, amphibians, and organisms that inhabit the submerged and immersed elements of these mats.

Floating macrophyte mats in the Ivinhema River have diverse attributes. They generally include multiple plant species, both free-floating (mainly) and emergent (occasionally).
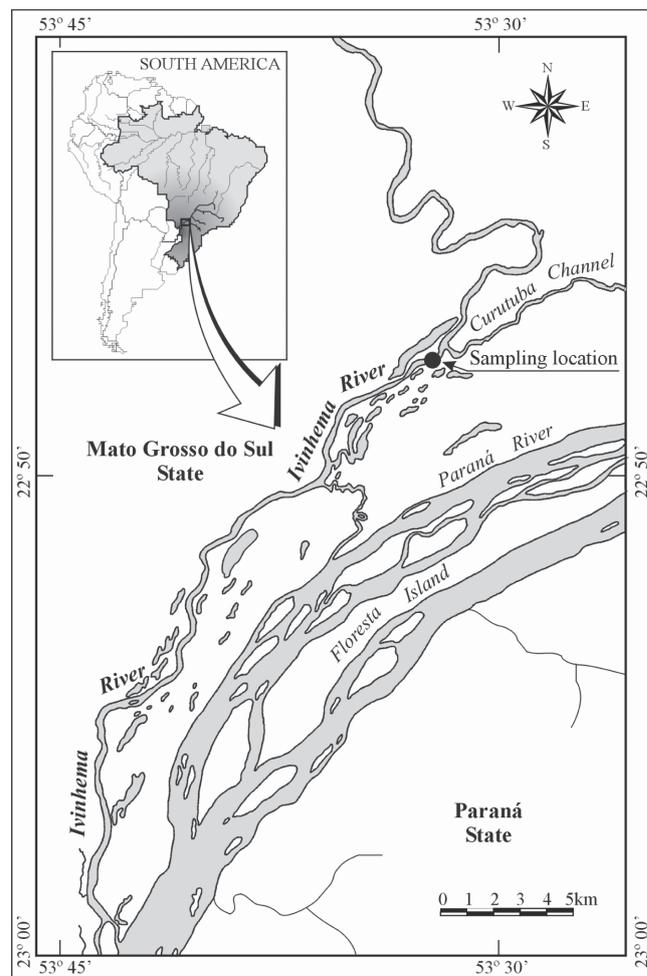

Fig. 1. Map of the floodplain section of the upper Paraná River included in this study, identifying the Ivinhema River and the approximate location where the drifting macrophyte mats were intercepted.

They originate from fragmented stands of macrophytes formed either in the river during low flow or adjacent floodplain lakes. These mats vary in size, and during intense floods could range up to 1 ha or larger, although they commonly average less than 0.02 ha. Depth of the roots provide additional spatial heterogeneity and depth can range up to about 1 m, but for average size mats depth is generally less than 0.3 m. Small mats often do not drift far because they are easily anchored and disrupted. However, large mats may travel long distances, depending on current velocity, and can reach the Itaipu Reservoir, located 110 km downstream of the Ivinhema River. Macrophyte mats usually begin drifting in the wet season when water level and velocity increases, although drifting may also be associated with strong wind conditions.

Macrophyte mats were sampled as they drifted in the Ivinhema River in January and March of 2005, between 14:00 and 18:00 h. Sampling was conducted with three boats pulled adjacent to the mat. A floating sieve (4 m long, 2 m wide, 0.6 m high, and mesh of 2 mm stretch/bar measure throughout) was pushed under the floating mat and allowed to surface and accommodate all or part of the mat. Once the sieve was in place, aquatic plants were identified to species level and removed from the sieve. The fish remaining in the sieve were captured, anesthetized in clove oil and stored in plastic bags partially filled with 4% formalin buffered with calcium bicarbonate.

At a laboratory, fish were identified to the lowest possible taxonomic level. Juveniles and adults were identified based on Graça & Pavanelli (2007) and larval fish based on Nakatani *et al.* (2001). Voucher specimens are deposited in the collection of the Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura of Universidade Estadual de Maringá (UEM). After identification species were classified into trophic (Hahn *et al.*, 2004) and reproductive (Suzuki *et al.*, 2004) guilds, according to earlier studies conducted in this section of the Paraná River system.

We sampled four macrophyte mats drifting in the Ivinhema River, with average area of 3.9 m^2 (Table 1). Three of the mats could be completely engulfed by the sampler; a third mat was bigger but only an area the size of the sampler was assessed. Poor local infrastructure along with strong currents during floods limited our ability to sample more mats. Additionally, sampling mats larger than the sieve sampler were avoided because disconnecting the sieve from the mat would take

about 1 h, which created a hazardous situation because the boats drifted freely with the mat, often in strong currents. Macrophytes identified in the mats included *Eichhornia azurea*, *E. crassipes*, *Hydrocotyle ranunculoides*, *Polygonum* spp., *Limnobium laevigatum*, *Pistia stratiotes*, *Ricciocarpus natans*, *Salvinia auriculata*, *S. herzogii*, and *S. minima*. The predominant macrophytes in two of the mats sampled were *Eichhornia crassipes* and in the other two mats were *Polygonum* spp. and *Salvinia herzogii*.

In all, we captured 218 fish representing 6 orders, 17 families, and at least 28 species (Table 2). Some species have undefined taxonomic status. Additionally, we were not able to identify some individuals to species level (*Serrasalmus* spp., *Serrapinnus* spp., *Hoplias* spp., *Hypostomus* spp., *Pimelodella* spp., Characidae, Siluriformes, and Gymnotiformes) due to identification uncertainties related to the stage of development. *Serrapinnus* spp., *Hoplias* spp., *Hypostomus* spp., Characidae, Siluriformes and Gymnotiformes were not counted as species, due to the possibility of double counts. The number of fish collected in each mat was 59, 48, 96 and 15, for mats 1, 2, 3, and 4, respectively (Table 2). On the other hand, the number of species was 12, 9, 24 and 6, for mats 1, 2, 3, and 4, respectively (Table 2). We did not discuss these results because differences in the number of individuals and species among mats are difficult to interpret once we did not control for the size of the mats, the size of floodplain lake where it originated, and the distance travelled by the mats.

Orders Characiformes (10 species), Siluriformes (8 species), and Gymnotiformes (6 species) included 86% of the total taxa collected in the floating mats. Characidae was the most abundant family (46 individuals; 21.1% of the total), and the family with the highest number of species (5 species; 17.8%). Auchenipteridae was the second most abundant family (31 individuals), but was represented by a single species, *T. galeatus*. All remaining families (except Loricariidae with three species) were represented by one or two species. The most abundant taxa were *T. galeatus* (n = 31; larvae and juveniles), followed by *Serrasalmus* spp. (n = 23; only larvae), and *Aphyocharax dentatus* (n = 17; only juveniles). The only species collected in all four mats were *T. galeatus* and *Crenicichla britskii*. The former represented 14.2% of the total number of individuals collected, whereas the latter included few individuals (n = 7; all juveniles). Larvae and

Table 1. Characteristics of the four floating macrophyte mats sampled while drifting on the Ivinhema River, Brazil, in January and March, 2005. The order of macrophyte species represents numerical dominance.

Characteristics	Sample number			
	1	2	3	4
Sampling month	January	January	March	March
Mat size (length x width, m)	1.0 X 1.5	1.5 X 1.5	4.0 X 2.0	2.0 X 2.0
Macrophyte species	*S. herzogii* *P. stratiotes* *E. azurea* *S. minima*	*E. crassipes* *P. stratiotes* *S. minima* *H. ranunculoides* *L. laevigatum* *R. natans*	*Polygonum* spp. *E. crassipes* *S. auriculata*	*E. crassipes* *S. auriculata* *S. minima*

Table 2. Number of fish captured in each of the floating macrophyte mats sampled in the Ivinhema River, Mato Grosso do Sul, Brazil (N: total number of individuals of a given species). It is also presented the trophic categories and reproductive guilds (R.G.) of each species. Reproductive guilds are identified as 1 = long distance migratory species with external fertilization and do not develop parental care; 2 = sedentary or short-distance migratory, external fertilization and no parental care; 3 = sedentary with external fertilization and parental care; and 4 = internal fertilization. * = species with few data available in the literature.

Order Family (number of species) Species	Number of fish Mat 1	Mat 2	Mat 3	Mat 4	N	Trophic category	R.G.	Vouchers
Characiformes								
Anostomidae (2)								
Leporinus friderici (Bloch, 1794)	1		1		2	Omnivore	2	NUP 11084
Leporinus lacustris Campos, 1945	2	2	1		5	Herbivore	2	NUP 11110
Crenuchidae (1)								
Characidium aff. *zebra* Eigenmann, 1909	11		5		16	Invertivore	2	NUP 11224
Characidae (5)								
Moenkhausia aff. *sanctaefilomenae* (Steindachner, 1907)			1	1	2	Insectivore	2	NUP 11238
Serrasalmus spp.	17		6		23	*	3	
Aphyocharax anisitsi Eigenmann & Kennedy, 1903			1		1	Omnivore*	2	NUP 10631
Aphyocharax dentatus Eigenmann & Kennedy, 1903		11	6		17	Omnivore*	2	NUP 11384
Serrapinnus notomelas (Eigenmann, 1915)			1		1	Algivore*	2	NUP 11249
Serrapinnus spp.			2		2	*	2	
Erythrinidae (1)								
Hoplias sp. 1 "grupo *malabaricus*"			1		1	Piscivore	3	NUP 3456
Hoplias spp.	2				2	*	3	
Lebiasinidae (1)								
Pyrrhulina australis Eigenmann & Kennedy, 1903	2	3			5	Invertivore	2	NUP 11587
Siluriformes								
Cetopsidae (1)								
Cetopsis gobioides (Kner, 1858)			1		1	Invertivore	2*	
Loricariidae (3)								
Hypostomus ancistroides (Ihering, 1911)	1		1		2	Detritivore	3	NUP 10547
Hypostomus cf. *strigaticeps* (Regan, 1908)				1	1	Detritivore	3	NUP11840
Hypostomus spp.		2	1		3	Detritivore	3	
Pterygoplichthys ambrosettii (Holmberg, 1893)			10		10	Detritivore	3	NUP 2115
Heptapteridae (1)								
Pimelodella spp.	1		1		2	Insectivore	2	
Doradidae (2)								
Oxydoras eigenmanni (Boulenger, 1895)			15		15	Invertivore	2*	
Pterodoras granulosus (Valenciennes, 1821)			1		1	Omnivore	1	NUP 1855
Auchenipteridae (1)								
Trachelyopterus galeatus (Linnaeus, 1766)	10	13	6	2	31	Omnivore	4	NUP 11104
Gymnotiformes								
Gymnotidae (1)								
Gymnotus inaequilabiatus (Valenciennes, 1839)	3	4	3		10	Insectivore	3	NUP 11226
Sternopygidae (2)								
Eigenmannia trilineata López & Castello, 1966			7		7	Insectivore	2*	NUP 4174
Sternopygus macrurus (Bloch & Schneider, 1801)		5	3		8	Insectivore	2*	NUP 11216
Rhamphichthyidae (1)								
Gymnorhamphichthys sp.				7	7	*		NUP 11515
Apteronotidae (2)								
Apteronotus albifrons (Linnaeus, 1766)		3	1		4	Insectivore	2*	NUP11225
Apteronotus sp.			5		5	Insectivore*	2*	
Cyprinodontiformes								
Rivulidae (1)								
Rivulus apiamici Costa, 1989	3	2			5	Insectivore*	2*	NUP 10864
Synbranchiformes								
Synbranchidae (1)								
Synbranchus marmoratus Bloch, 1795	2		3	1	6	Insectivore	3	NUP 4244
Perciformes								
Cichlidae (2)								
Astronotus crassipinnis (Heckel, 1840)			1		1	Insectivore/ piscivore	3	NUP 1464
Crenicichla britskii Kullander, 1982	3	1	2	1	7	Insectivore	3	NUP 2355
Larvae not identified at species level								
Characidae	1	2			3			
Siluriformes			1		1			
Gymnotiformes			9	2	11			
Total	59	48	96	15	218			

juveniles accounted for 85% of the collections, and 65% of the species collected were captured only in these life stages. Nine species were captured as adults only (*Aphyocharax anisitsi*, *Characidium* aff. *zebra*, *Gymnorhamphichthys* sp., *Moenkhausia* aff. *sanctaefilomenae*, *Pyrrhulina australis*, *Rivulus apiamici*, *Gymnotus inaequilabiatus*, *Synbranchus marmoratus*, and *Sternopygus macrurus*).

In reference to species guilds representation, insectivores represented the highest number of species collected (11 species), followed by omnivores (5), invertivores (4), and detritivores (4; Table 2). For the reproductive guilds, 12 species were sedentary or short distance migratory, with external fertilization and no parental care. Another 12 species were sedentary or short distance migratory, with external fertilization and parental care. The most abundant species *T. galeatus* was the only which exhibited internal fertilization; and *P. granulosus* (one individual) was the only long distance migratory species collected.

Studies of drifting macrophyte mats are rare in the literature. Oliver & Mckaye (1982) sampled six wind-drifted mats in Lake Malawi (Malawi-Mozambique-Tanzania) and captured 129 fish of 10 species (average of 22 individuals/mat and 2 species/mat). Schiesari *et al*. (2003) captured 286 fish of 39 species in 8 drifting mats in the Solimões River, Central Amazon (average of 36 individuals/mat and 5 species/mat). Henderson & Hamilton (1995) studied wind-drifted and anchored mats in an Amazonian lake but reported only broad taxa. There are various reasons for the few studies available dealing with this subject, some of which were mentioned by Henderson & Hamilton (1995). Drifting mats are largely inaccessible because it is difficult to sample under them. If it is possible to net them as we did, it is usually not possible to drag them to shore or dry land for processing. Moreover, the specific environmental conditions needed to set off drifting mats are infrequent and unpredictable, so finding floating mats to sample requires good timing and placing. To better understand drifting macrophyte mats as mechanisms for fauna dispersal, tools to determine drift velocity, pathway, and final destination are needed. Remote sensing (Landsat Images) could improve our ability to monitor drifting mats, and was applied by Petr (2000) to monitor mobility and location of drifting mats in Naivasha Lake, Kenya.

Our collections coincided with the spawning season of most species in the study region (Suzuki *et al*., 2004). The initial phases of development in fish are critical to the recruitment of new individuals to the stocks, and predation increases the risks of mortality. The greater number of individuals associated with the drifting mats belonged to one species with internal fertilization (*e.g.*, Auchenipteridae) and to several species with parental care (*e.g.*, Gymnotiformes) that usually produce fewer eggs. These species have developed strategies to guard against the high risk of predation. Our study suggests that dispersal within the protection afforded by drifting mats of aquatic macrophytes may be one of these strategies (Sazima & Zamprogno, 1985; Henderson & Hamilton, 1995; Schiesari *et al*., 2003).

Adult fishes also inhabited drifting macrophyte mats. For small sized sedentary species represented by adults (*A. anisitsi*, *C.* aff. *zebra*, *Gymnorhamphichthys* sp., *M.* aff. *sanctaefilomenae*, *P. australis*, and *R. apiamici*), submerged parts of macrophytes (stems, leaves, and roots) serve as shelter against visual predators and possibly as feeding grounds (Grenouillet & Pont, 2001; Sánchez-Botero & Araújo-Lima, 2001; Casatti *et al*., 2003; Petry *et al*., 2003; Pelicice *et al*., 2005; Padial *et al*., 2009). Insects and other aquatic invertebrates are commonly found attached to roots and leaves of aquatic plants, and potentially may serve as food for most fish species associated to these plants (Neiff & Carignan, 1997; Padial *et al*., 2009). Moreover, Rossi & Parma de Croux (1992) report that macrophytes can be directly used as food and, additionally, contribute to the production of detritus and may serve as substrate to the colonization of periphyton. All these aspects may be contributing to the predominance of certain trophic groups (*i.e.*, insectivores, omnivores, invertivores, and detritivores) in the macrophyte mats analyzed. While these species may be attracted to mats for shelter and food, or are unintended travelers, the mats provide these species relatively rapid dispersal vectors.

In contrast, for *G. inaequilabiatus*, *S. macrurus*, and *S. marmoratus* for which larvae, juveniles, and adults were collected in the drifting mats, macrophyte stands seem to be a habitat used during all life stages. Presence of all life stages indicates the close relation of the life strategy of these species with aquatic vegetation, confirmed by species characteristics such as sedentary habit, elongated and thin body, insectivory, cryptic coloration, and adaptations to thrive in low dissolved oxygen concentration. The family Synbranchidae and the Gymnotiformes (including the three aforementioned species) have adaptations to inhabit macrophyte stands (Machado-Allison, 1993; Henderson & Hamilton, 1995; Crampton & Hopkins, 2005). However, Henderson & Hamilton (1995) reported that Synbranchidae, Gymnotiformes, and Erythrinidae avoided drifting mats and preferred the anchored stands in the margins of the Amazonian plain. They report that these groups are capable of sensing the changes related to detachment of the stands and will flee floating mats towards anchored stands. Our results contradict their observations as we captured all life stages drifting in mats. On the other hand, in our study, we collected few individuals of long distance migratory species in this type of habitat, which may be an indication that they do not stay in floating mats.

A surprising finding was the collection of several fish species considered uncommon in the region. For example, *Apteronotus* sp. and *Gymnorhamphichthys* sp. are considered rare as they are seldom collected in other habitats or by other gear (Graça & Pavanelli, 2007). Other infrequent species in standard surveys conducted in the region include *A. albifrons*, *R. apiamici*, and *C. gobioides* (Agostinho *et al*., 2005) that were captured in the macrophyte mats sampled. Thus, while floating macrophyte mats represent an ephemeral habitat type, they do appear to attract a unique set of species and life stages.

The high abundance of *Serrasalmus* spp. larvae in the drifting mats may be due its reproductive strategy. According to Machado-Allison (1993), *Serrasalmus* spp. lay eggs in the marginal vegetation, with larvae and initial phases of development strongly associated to this environment. After attaining certain size, they move to explore open water, displaying ontogenetic variations in habitat use. Sazima & Zamprogno (1985) studied the Atibaia River (Tietê River - upper Paraná River basin) and suggested that macrophyte stands serve as shelter and are rich feeding places for larvae and juveniles of *Serrasalmus spilopleura* (nowadays *Serrasalmus maculatus*). In addition, they report that drifting macrophyte mats disperse this species, explaining its wide distribution. Thus, the high synchronization between the drift of the mats and the spawning season of this species (Schiesari *et al.*, 2003) may favor the establishment of viable populations at a regional scale.

The same pattern may apply to *T. galeatus* in the upper Paraná River. This species has internal fertilization and lay eggs in macrophyte roots, where early developmental stages also stay in macrophytes until later stages. This mechanism may be important regionally because below the upper Paraná River floodplain section there is the Itaipu Reservoir, where *Serrasalmus* spp. are common (Hahn *et al.*, 1998; Oliveira *et al.*, 2005), explained by its preference for lentic environs. However, the high abundance of species with internal fertilization in this reservoir, such as the siluriform *T. galeatus*, is unexplained (Agostinho *et al.*, 1999) and possibly attributed to drifting macrophyte mats, once density of floating aquatic macrophytes (the habitat considered in this study) in this reservoir is low (Thomaz *et al.*, 2006), with dominance of submerged species (Thomaz *et al.*, 1999). In fact, Henderson & Hamilton (1995) reported that siluriforms favored drifting mats over anchored stands, and concluded that for this group the downstream drift may represent a seasonal migration to the main river channel. Thus, these authors consider the possibility of a life strategy related to dispersal through drifting under the safety and sustenance of drifting macrophyte stands.

Macrophyte stands in the upper Paraná River basin support several fish species (at least 28 species in four mats) and the underwater parts of these plants provide shelter and forage for all life stages of fish. Although preliminary and based on limited samples, this study of drifting macrophyte mats was the first one in the last unregulated stretch of the Paraná River remaining inside Brazilian territory, and alerts us to their potential role as dispersers of fish species in the region. Constant or sporadic dispersion through this mechanism may maintain genetic flow among metapopulations, reducing isolation and favoring the homogeneity of the biota, locally or regionally. However, more studies are needed to clearly determine utilization by key species and guilds. Additional studies will contribute to understanding if movements of fish through drifting macrophyte mats are simply random or a dispersal life strategy used by segments of the fish community.

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