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Habitat preferences of common native fishes in a tropical river in Southeastern Brazil

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We determined in this study the habitat preferences of seven native fish species in a regulated river in Southeastern Brazil. We tested the hypothesis that fishes differ in habitat preference and that they use stretches of the river differing in hydraulic characteristics and substrate type. We surveyed fishes in four 1-km long river stretches encompassing different habitat traits, where we also measured water depth, velocity, and substrate type. We investigated preference patterns of four Siluriformes (*Loricariichthys castaneus*, *Hoplosternum littorale*, *Pimelodus maculatus*, and *Trachelyopterus striatulus*) and three Characiformes (*Astyanax* aff. *bimaculatus*, *Oligosarcus hepsetus*, and *Hoplias malabaricus*), representing approximately 70% of the total number of fishes and 64% of the total biomass. We classified fishes into four habitat guilds: (1) a slow-flowing water guild that occupied mud-sand substrate, composed of two Siluriformes in either shallow (< 4 m, *i.e.*, *H. littorale*) or deep (> 8 m, *L. castaneus*) waters; (2) a run-dwelling guild that occurs in deep backwaters with clay-mud substrate, composed of the Characiformes *A.* aff. *bimaculatus* and *O. hepsetus*; (3) a run-dwelling guild that occurs in sandy and shallow substrate, composed of *T. striatulus*; and (4) a fast-flowing guild that occurs primarily along shorelines with shallow mud bottoms, composed of *H. malabaricus* and *P. maculatus.* Our hypothesis was confirmed, as different habitat preferences by fishes appear to occur in this regulated river.

Determinamos neste estudo a preferência de habitat de sete espécies de peixes abundantes em um rio regulado do Sudeste do Brasil. Testamos a hipótese de que peixes diferem na preferência de habitat e usam trechos do rio com diferentes características hidráulicas e tipos de substratos. Realizamos amostragens de peixes, utilizando redes de espera e tarrafas em quatro trechos do rio de 1 km de extensão, compreendendo diferentes características do habitat, onde também obtivemos medidas de profundidade, velocidade da água e tipo de substrato. Quatro Siluriformes (*Loricariichthys castaneus*, *Hoplosternum littorale*, *Pimelodus maculatus* e *Trachelyopterus striatulus*) e três Characiformes (*Astyanax* aff. *bimaculatus*, *Oligosarcus hepsetus* e *Hoplias malabaricus*) que juntos compreenderam aproximadamente 70% do número total e 64% do peso total de peixes foram estudados. Classificamos os peixes em quatro guildas: (1) peixes que ocorrem em trechos com baixa velocidade de fluxo e substrato constituído predominantemente de lama e areia, compreendendo dois Siluriformes, um de áreas rasas (< 4 m, *i.e.*, *H. littorale*) e outro de áreas profundas (> 8 m, *i.e.*, *L. castaneus*); (2) peixes que utilizam rápidos de áreas laterais mais profundas com substrato lamoso, representados pelos pequenos Characiformes, *A.* aff. *bimaculatus* e *O. hepsetus*; (3) peixes que utilizam rápidos que ocorrem em áreas rasas e substrato arenoso, representado por *T. striatulus*; e (4) peixes de corredeiras que utilizam as margens rasas com fundo lamoso, representados por *H. malabaricus* e *P. maculatus*. As espécies estudadas apresentam diferenciação na preferência por variáveis do hábitat, corroborando a hipótese investigada.

Key words: Ecological flow, Freshwater fishes, Habitat guild, River flow.

Introduction

The study of habitat preferences is an essential step in understanding the distribution patterns of fishes. Most knowledge of this subject is based on native nongame fish habitat preferences for temperate freshwaters (Moyle & Baltz, 1985; Lamouroux *et al*., 1999; Vadas & Orth, 2000, 2001; Boavida *et al*., 2006). However, with the exception of a few studies (*e.g.*, Bührnheim, 2002; Leal *et al*., 2011; Teresa & Casatti, 2013), little effort has been made to understand

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habitat preferences by fish in tropical rivers. Instream habitat preferences are often used to assess flow requirements for fish, usually based on instream flow incremental methodology (IFIM; Bovee, 1982). The habitat component of IFIM (PHABSIM; Milhous *et al*., 1984) predicts water depths and velocities for instream cells and evaluates the suitability of the habitat for a species over a range of flows. Once the habitat suitability or preference curves are defined, they can be applied to hydraulic data, and the amount of suitable habitat or weighted useable area (WUA) can be calculated.

Habitat heterogeneity in lotic environments generally influences fish assemblage distributions, generally downstream, increasing as lateral and vertical profiles are enhanced via increased off-channel habitat complexity and water volume (Pinto *et al*., 2006; Terra *et al*., 2010). Several environmental variables are preferentially selected by fish species in these ecosystems (Bovee, 1982; Baltz *et al*., 1987; Yu & Lee, 2002; Vadas & Orth, 2000, 2001). For instance, habitat availability affects selection by fish species, with the majority of habitat-preference models based on individual factors such as depth, velocity, substrate, and type of cover (Sheppard & Johnson, 1985; Leonard & Orth, 1988).

Reductions in river flow may result in a loss of critical habitat for fish (Petts, 1985). In this context, habitat analysis simulations, such as PHABSIM (Milhous *et al*., 1989) and RHYHABSIM (Jowett, 1989), can be used to define requirements for minimum instream flow requirements that must be maintained to preserve the fish fauna (Bovee, 1982). However, the use of these simulations depends on the creation of habitat suitability criteria that define the use of physical habitat variables by fish species. Furthermore, suitability criteria are important because they most likely have more influence on habitat/flow relationships than any other part of the habitat modeling process (Jowett, 2002). Depending on the selected target species, suitability patterns can be extended to other systems to allow the construction of predictive models at large scales (Teresa & Casatti, 2013).

The definition of fish habitat preferences may serve to improve the ability to evaluate the biological consequences of anthropogenic impacts on aquatic ecosystems, helping environmental managers establish policies for river resource conservation at local and regional scales. Local departures from natural conditions can occur, especially if there is longitudinal and/or lateral blockage of the lotic system by damming and channelization. Historically, such perturbations have been associated with impoundments, primarily for hydroelectric power generation and water supply (Petts, 1984). Most large rivers in Southeastern Brazil are regulated by some type of impoundment. A notable instance is the Guandu River, a regulated system that supplies water to the municipality of Rio de Janeiro. This system has been subject to several forms of interference, such as interbasin water transfer and impoundments, which have altered its natural flow regime (CBH - Guandu, 2007).

Although there is a clear consensus that modified flow regimes in regulated rivers are affecting fishes and fish habitat, the severity and direction of the response varies widely (Murchie *et al*., 2008). The Guandu River represents a good opportunity for the study of fish habitat preferences. Accordingly, the aim of this study was to describe habitat suitability for the dominant fish species in the Guandu River. We assessed fish occurrence and measured three physical variables: depth, water velocity, and type of substrate. We sampled four 1-km long river stretches encompassing different mesohabitats, surveying two stretches upstream from the impoundment and two downstream. We tested the hypothesis that fish preferences for a given habitat stretch differ depending on local differences in water velocity, depth, and type of substrate.

Material and Methods

Study area

The Guandu River (Fig. 1) is a regulated system with a watershed area of 1,430 km^2. It is formed by the confluence of the Lajes and Santana streams, with an extension of *ca.* 108.5 km and an average flow of 156 $m^3 s^{-1}$ above the dam (Table 1). The principal contribution of water to the river is made by an interbasin transfer from the Paraíba do Sul River basin since 1952. An electric company pumps water for hydropower purposes, releasing a water discharge of *ca.* 160 $m^3 s^{-1}$ into Lajes stream (Binder, 1998). The river is impounded 30 km upstream from the estuary at 11.8 m above sea level. From this impoundment, *ca.* 47 $m^3 s^{-1}$ are withdrawn to supply tap water for the municipality of Rio de Janeiro and nearby areas, thus decreasing the river flow in the mid-lower segment (CBH - Guandu, 2007). The river is channelized above the estuarine zone.

Sampling

We conducted fish sampling and environmental measurements in four 1-km long river stretches in two (winter/dry and summer/wet) seasons during two years (2010 and 2011). Seven evenly spaced longitudinal sections were established as the sampling sites along each 1-km river stretch. Each river stretch encompassed different mesohabitats, such as runs, riffles, and pools (Table 1). The sampling design comprised a total of 112 samples (2 seasons × 2 years × 4 stretches × 7 sections).

The sampling unit used in each section consisted of three nets (25 m × 2.5 m height; stretch-mesh sizes of 2.5, 5.0, and 7.5 mm), covering an area of ~187.5 m^2. We set up the nets at the end of the afternoon and retrieved them the following morning for a total sampling time of *ca.* 15 hours. A total of 21 nets were used in each river stretch to cover the seven locations (transversal sections). During each sampling visit,

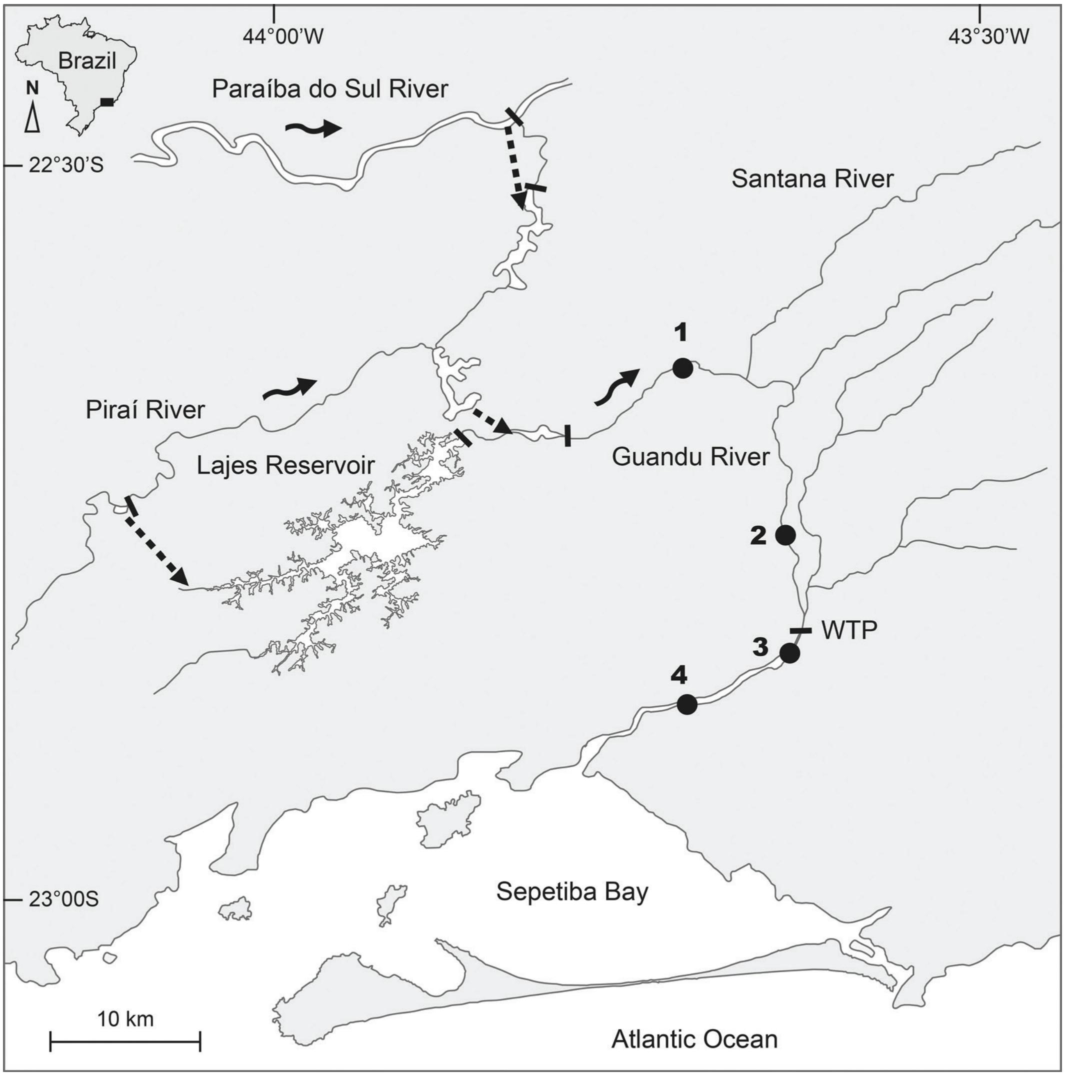

Fig. 1. Study area, Guandu River, indicating the four sampled stretches. WTP, Water Treatment Plant.

Table 1. Physical characteristics of the four sampled river stretches.

River stretch	Dominant Mesohabitat type	Substrate (%)	Width (m)	Depth range (m)	Altitude (m)	Average Flow (m3 sec-1)	Land use	Riparian Cover (%)	Erosion
1	Run	Sand (50)	105.5	1.5-3.5	32.9	137.7	Pasture	Trees	Moderate
		Gravel (20)						Shrubs	
		Mud (15)						Grasses	
		Clay (10)							
		Rock (5)							
2	Backwater	Sand (60)	110.0	4.7-10.1	12.6	156.3	Agriculture	Shrubs	Moderate
		Mud (40)						Grasses	
3	Fast flowing	Sand (60)	87.5	3.3-8.1	8.1	111.7	Urban area	Shrubs	High
		Mud (20)						Grasses	
		Rock (10)							
		Boulder(10)							
4	Moderate flow	Mud (70)	69.0	3.9-6.9	6.3	167.4		Grasses	High
		Sand (30)							

we measured the following habitat traits in triplicate: depth, with a portable echo-sounder; water velocity, with a Global Waters FP-211 flow meter (Global Water Instrumentation, Inc. College Station, TX, USA); and type of substrate, determined visually. The fishes collected were measured (total length, mm), weighed (grams), and fixed in 10% formalin. After 48 hours, we transferred all fishes to 70% ethanol. Voucher specimens are deposited in the fish collection of the Laboratory of Fish Ecology of the Universidade Federal Rural do Rio de Janeiro (UFRRJ-LEP 1001-1007).

Data analysis

Because the numerical abundance of the fish did not differ seasonally or between the two study years based on exploratory data analysis with a Kruskal-Wallis test, we pooled the data from years and seasons to detect habitat use. We defined the dominant species in a given river stretch as those species that included more than 20 individuals and that occurred in more than 35% of the samples.

For the analysis of habitat use, fish occurrence and habitat data were used only from sites where the species was present. Microhabitat use was determined by the frequency at which a given species was observed using specific depths, velocities, and substrate type. For this calculation, microhabitat measurements were weighted by the number of fish in each class. We divided the number of fishes into habitat classes based on intervals of depth, velocity, and substrate size. The percentage fish-use of each habitat class was defined as the average fish number in that class expressed as a percentage of the sum of the average fish numbers over all habitat classes:

$$\mathrm{Pi} = (N_i \ / \ \sum N_i) \times 100, \qquad i{=}1{,}n ,$$

where Pi = percentage fish-use in habitat class i, N_i = average fish number in habitat class i over all sites, and n = the number of habitat classes.

Microhabitat preference curves were derived by comparing the frequency of habitat use (in which fishes were found) with the frequency in which habitat was available (sampled) for each habitat class. We calculated preference as the normalized ratio of the frequency of use to the frequency of availability determined from the ordinates of kernel smoothed frequency curves (Bovee, 1986; DeGraaf & Bain, 1986; Hayes & Jowett, 1994; Jowett & Richardson, 1995). Because we scaled the curves to a maximum preference value of 1 by dividing by the maximum ordinate, the suitability scale ranged from 0 (minimum suitability) to 1 (maximum suitability). Following Jowett (2002), we use the term 'habitat suitability criteria' to refer to curves developed from a subjective interpretation of habitat use and preference. All suitability curves were generated by the software HABPRF (Analysis of Habitat Suitability - version 2.0; Jowett, 2005).

Results

Fish composition

We recorded 50 species belonging to 20 families and six orders. Of these species, 31 were natives, five were non-natives, and 14 were marine. Siluriformes were prominent contributors to species richness (12), followed by Perciformes (11) and Characiformes (9). The seven most abundant native species, *Loricariichthys castaneus* (Castelnau, 1855), *Hoplosternum littorale* (Hancock, 1828), *Pimelodus maculatus* Lacepède, 1803, *Trachelyopterus striatulus* (Steindachner, 1877), *Astyanax* aff. *bimaculatus* (Linnaeus, 1758), *Oligosarcus hepsetus* (Cuvier, 1829), and *Hoplias malabaricus* (Bloch, 1794) contributed more than 70% of total fish numbers and 64% of total weight and collectively occurred in all of the habitat types observed.

Habitat type

The distribution and relative abundance of the seven examined fish species differed among river stretches (Table 2). The average abundance (fish numbers) was higher in the river stretch having a predominance of runs (upper stretch) than in the other stretches. In the upper stretch, *A.* aff. *bimaculatus* and *O. hepsetus* (Characiformes) and *P. maculatus* (Siluriformes) reached their highest abundance. The highest abundance of *L. castaneus* was recorded in the backwater stretch (middle-upper stretch); *H. malabaricus* was most abundant in the fast-flowing stretch (middle-lower stretch); and *T. striatulus* and *H. littorale* were most abundant in the moderate-flow lower stretches.

Table 2. Numbers of selected fish species collected in the four river stretches and their percent occurrence (in parentheses). Dominant species for each river stretch are boldfaced.

River stretches	Upper	Middle-upper	Middle-lower	Lower
Predominant Mesohabitat	Run	Backwater	Fast-flowing	Moderate-flow
Astyanax bimaculatus	**66 (45.2)**	**60 (41.1)**	10 (6.9)	10 (6.9)
Oligosarcus hepsetus	**28 (49.1)**	**17 (29.8)**	3 (5.3)	9 (15.8)
Hoplias malabaricus	**22 (35.5)**	8 (12.9)	**23 (37.1)**	9 (14.5)
Pimelodus maculatus	**39 (66.1)**	12 (20.3)	4 (6.8)	4 (6.8)
Loricariichthys castaneus	26 (4.8)	**260 (48.4)**	136 (6.9)	**214 (39.9)**
Trachelyopterus striatulus	36 (25.9)	38 (27.3)	2 (1.4)	**63 (45.3)**
Hoplosternum littorale	4 (1.8)	13 (5.8)	59 (26.5)	**147 (65.9)**
Total	221 (18.1)	408 (33.4)	138 (11.3)	456 (37.3)

Habitat relationships

The depth of the sampling units ranged from 0.4 to 9.7 m, with the highest frequency of sampling units occurring in the shallowest waters (Fig. 2). The sampling frequency was not uniform over water depths because it was difficult to set up the fishing gear in mid-channel. The distribution of fish with water depth varied among species. *Loricariichthys castaneus* was dominant in deeper waters, whereas *P. maculatus* and *T. striatulus* occurred primarily in water < 4.0 m deep (Table 2).

Velocities in the sampling units ranged from 0 to 1.3 m s^{-1}. More than half of the sampling habitat units had average velocities < 0.3 m s^{-1}, and only 10% of the units had velocities in excess of 0.6 m s^{-1} (Fig. 2).

The substrate types ranged from clay to rocks, with a modal type of muddy and sandy substrate (Fig. 2). Three species, namely, *A.* aff. *bimaculatus*, *O. hepsetus*, and *P. maculatus*, were most abundant in sites with a diversified substrate, whereas *H. malabaricus* was most abundant in sites with mud and rock substrates and *L. castaneus* and *T. striatulus* were more abundant in sites with fine substrates (mud and clay) (Table 2).

Habitat preference

All fish species showed well-defined microhabitat preferences for depth, velocity, and type of substrate (Fig. 3). The optimum depths for the two species of Siluriformes (*H. littorale* and *T. striatulus*) and the Characiformes species *H. malabaricus* were all less than 4 m. However, the Characiformes species *A.* aff. *bimaculatus* and *O. hepsetus* and the Siluriformes species *L. castaneus* primarily used deeper water, with optimum depths at > 6 m, whereas *P. maculatus* occupied a wider depth range.

The species presented well-defined velocity preferences. *Loricariichthys castaneus* and *H. littorale* occurred primarily mainly in the slowest-flowing water (< 0.6 m s^{-1}), whereas other species preferred more rapidly flowing water (> 0.8 m s^{-1}) (Fig. 4).

Substrate preferences were less well-defined, as most species used wide ranges of substrate types. *Oligosarcus hepsetus*, *H. malabaricus*, and *P. maculatus* preferred midsized substrates (Fig. 5); *L. castaneus*, *H. littorale*, and *T. striatulus* preferred coarser sand and gravel substrates; and *A.* aff. *bimaculatus* preferred the finest substrates, especially sand (Fig. 5).

Discussion

We found that the seven dominant Guandu River fish species had differentiated habitat preferences for a given water depth, velocity, and substrate type. These preferences appear to represent an adaptation for coexistence in this regulated system. The Characiformes *A.* aff. *bimaculatus* and *O. hepsetus* differed from the other five species; they

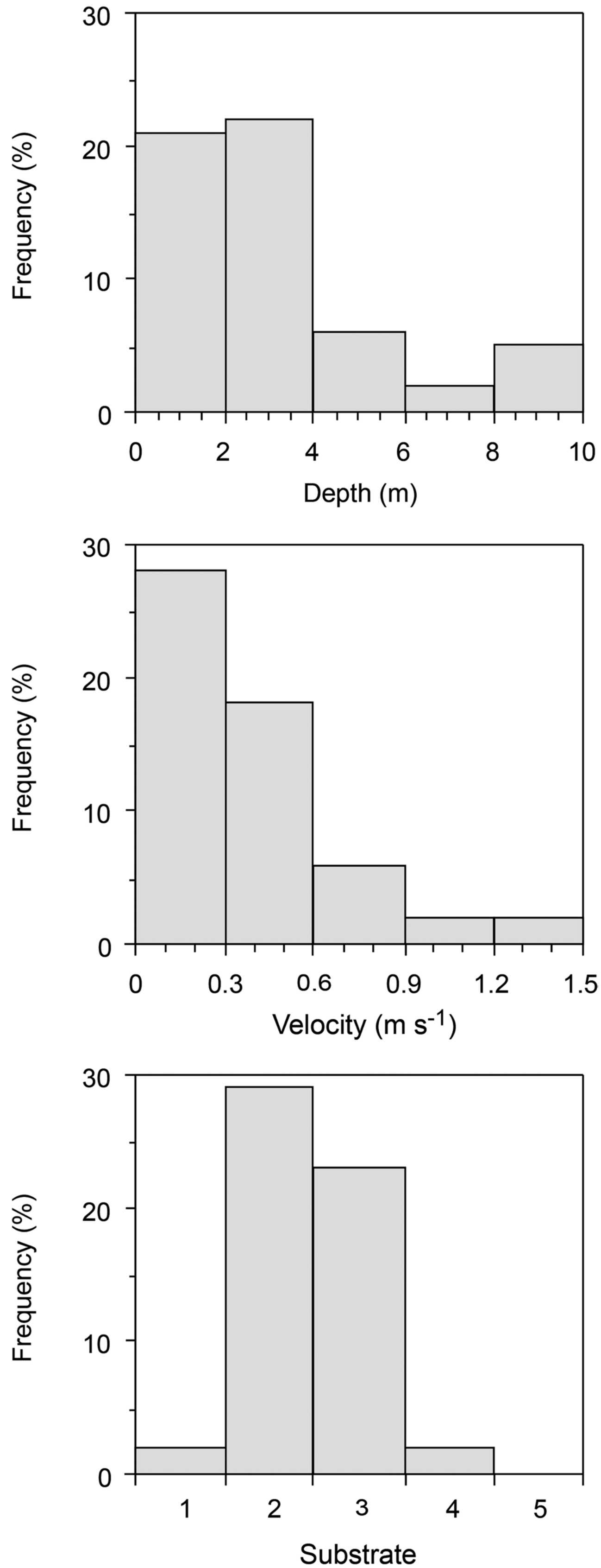

Fig. 2. Distribution of sampling by habitat availability (%) in terms of depth (m), velocity (m s^{-1}), and type of substrate. (1, clay; 2, mud; 3, sand; 4, boulder/cobble/gravel; 5, bedrock).

were the only water-column dwelling species that occurred across the entire habitat and occupied various substrate types. These species preferred the deepest areas (depth > 6 m) but also used the margins, where they presumably fed on insects, leaf packs, and submerged roots. *Astyanax* spp. are prey for large, carnivorous species (Câmara *et al*., 1991), whereas *O. hepsetus* is a small carnivore that uses densely vegetated areas to prey on small fishes and insects (Araújo *et al*., 2005). *Hoplias malabaricus* is a highly unique characiform fish, differing from most other species within this order because it is a top carnivore and bottom dweller that ambushes its prey by hiding in shallow, high-velocity waters near rocky substrates (Oliveros & Rossi, 1991).

Astyanax aff. *bimaculatus*, *O. hepsetus*, and *L. castaneus* preferred areas deeper than 6 m, whereas the other examined species preferred shallow areas. Similarly to *T. striatulus* and *H. littorale*, *L. castaneus* preferred slowly flowing waters in areas with sandy and gravel substrates, although the latter two species occurred primarily in shallow water (depth < 4 m). These three Siluriformes are typical fishes of lentic or slow-moving systems (Suzuki *et al*., 2000; Duarte & Araújo 2001; Santos *et al*., 2010) and were found in a wide range of microhabitats and aquatic systems, including reservoirs (Araújo & Santos, 2001), shallow riverine zones (Santos *et al*., 2010; Terra *et al*., 2010), and floodplains (Hostache & Mol, 1998).

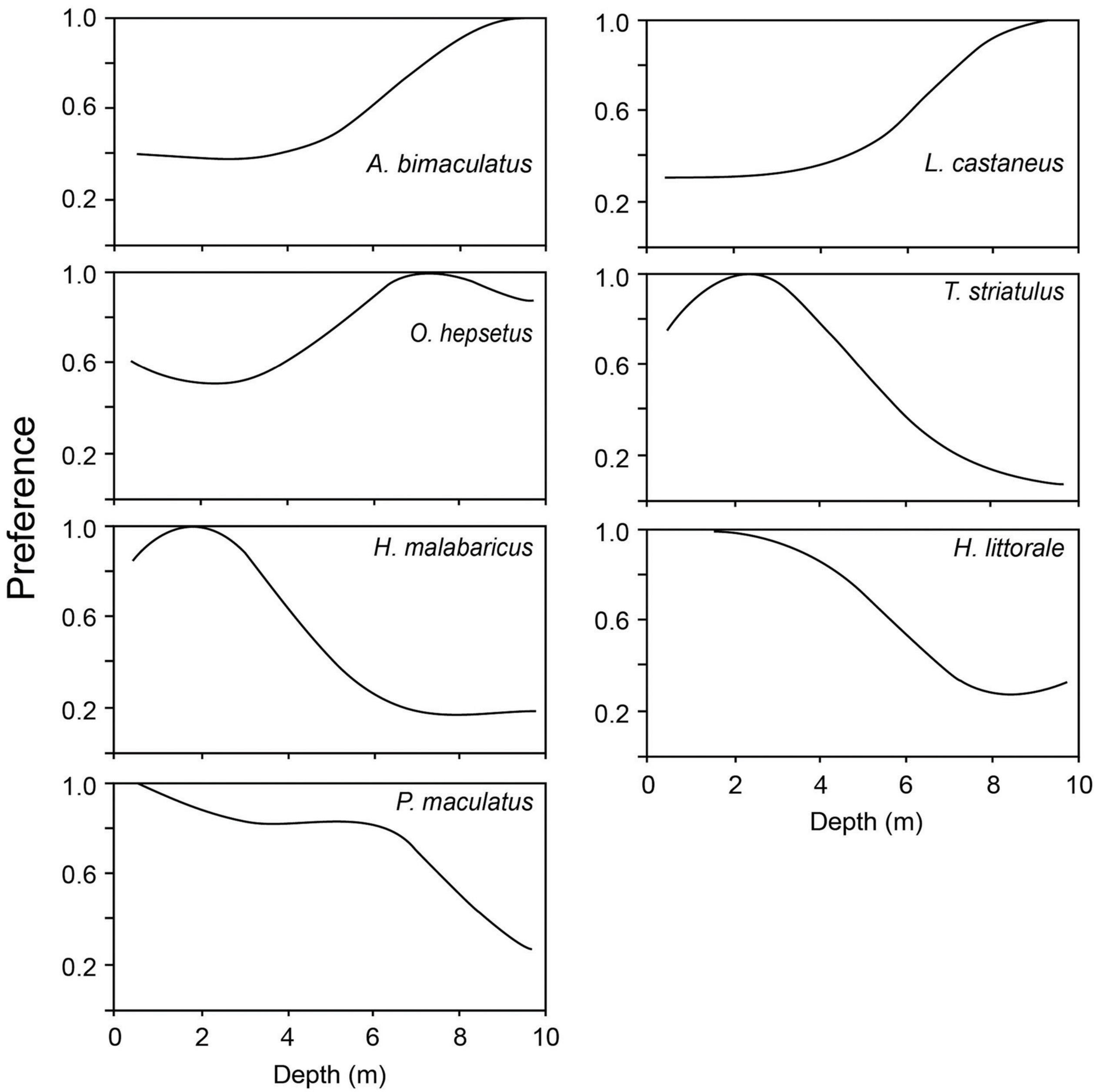

Fig. 3. Depth preferences of seven dominant native fish species in the Guandu River.

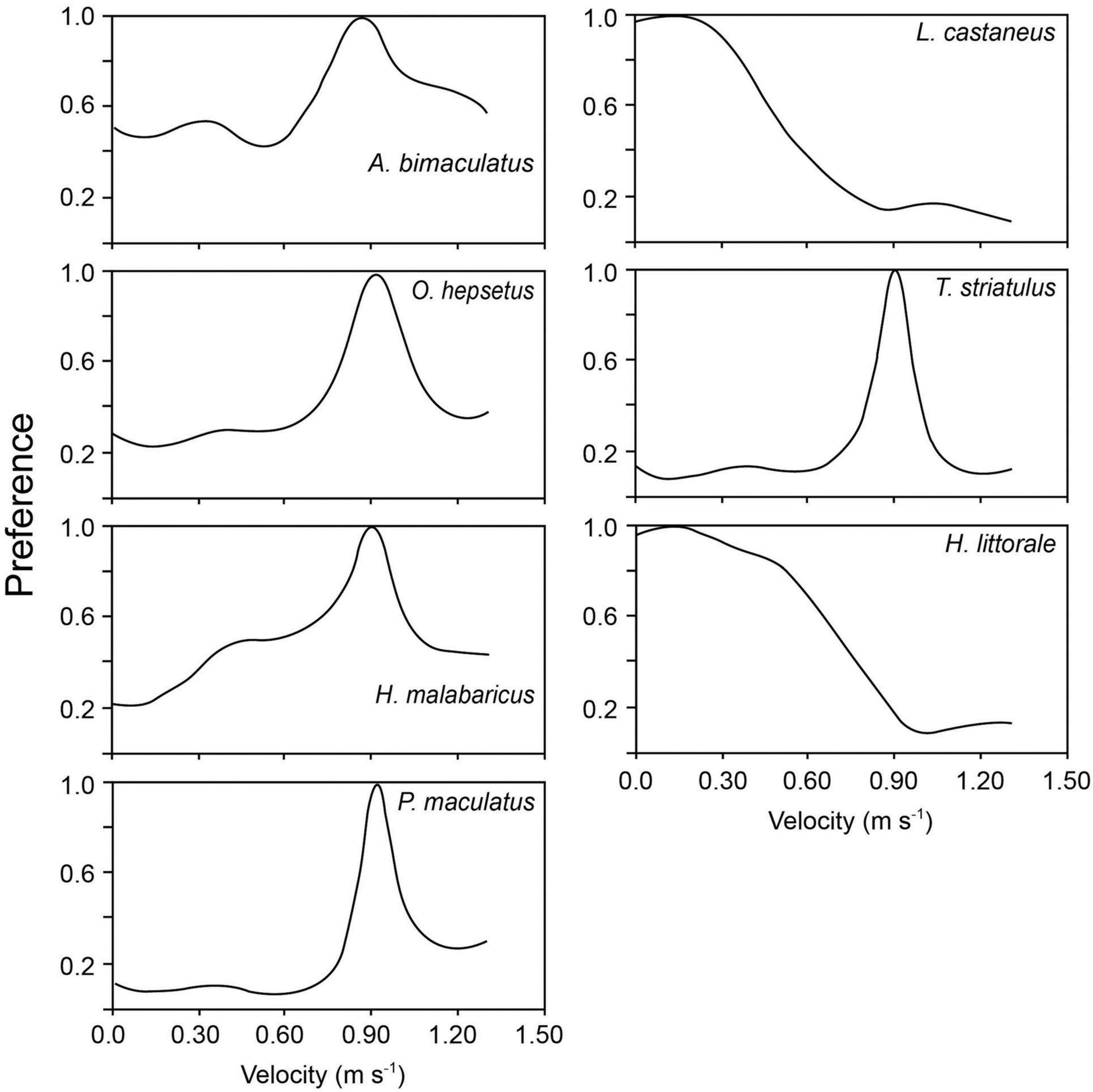

Fig. 4. Velocity preferences of seven dominant native fish species in the Guandu River.

Preferences for low or moderate velocity by *T. striatulus*, *H. littorale*, and *L. castaneus* depart from the general pattern described for Siluriformes, which generally prefer rapids and higher-velocity waters than Characiformes (Casatti *et al*., 2001; Casatti, 2005). However, Duarte & Araújo (2001) found that *L. castaneus* is one of the most abundant fish species in Lajes Reservoir, confirming that this species shows great adaptive plasticity in habitat use. *Trachelyopterus striatulus* and *H. littorale* are benthic invertivores that predominate in lentic waters (Araújo & Santos 2001) such as reservoirs, floodplains, and swamps (Hostache & Mol, 1998). They were particularly common in the lower stretch of the Guandu River. Leal *et al*. (2011), studying morphology and habitat use by fishes in a tropical river, found that Siluriformes generally had morphological and behavioral adaptations to habitats with fast-moving waters and that they were found more frequently than Characiformes in microhabitats with greater water velocities. Most fishes examined by Leal *et al*. (2011) were smaller species that appeared to be particularly sensitive to water velocity. In our study, most fishes were medium-sized, and this difference in size structure could at least partially explain such differences. Furthermore, establishing patterns of habitat preferences for such rich and diverse groups of fishes as Characiformes and Siluriformes will never completely characterize the entire group of fishes for a given water body.

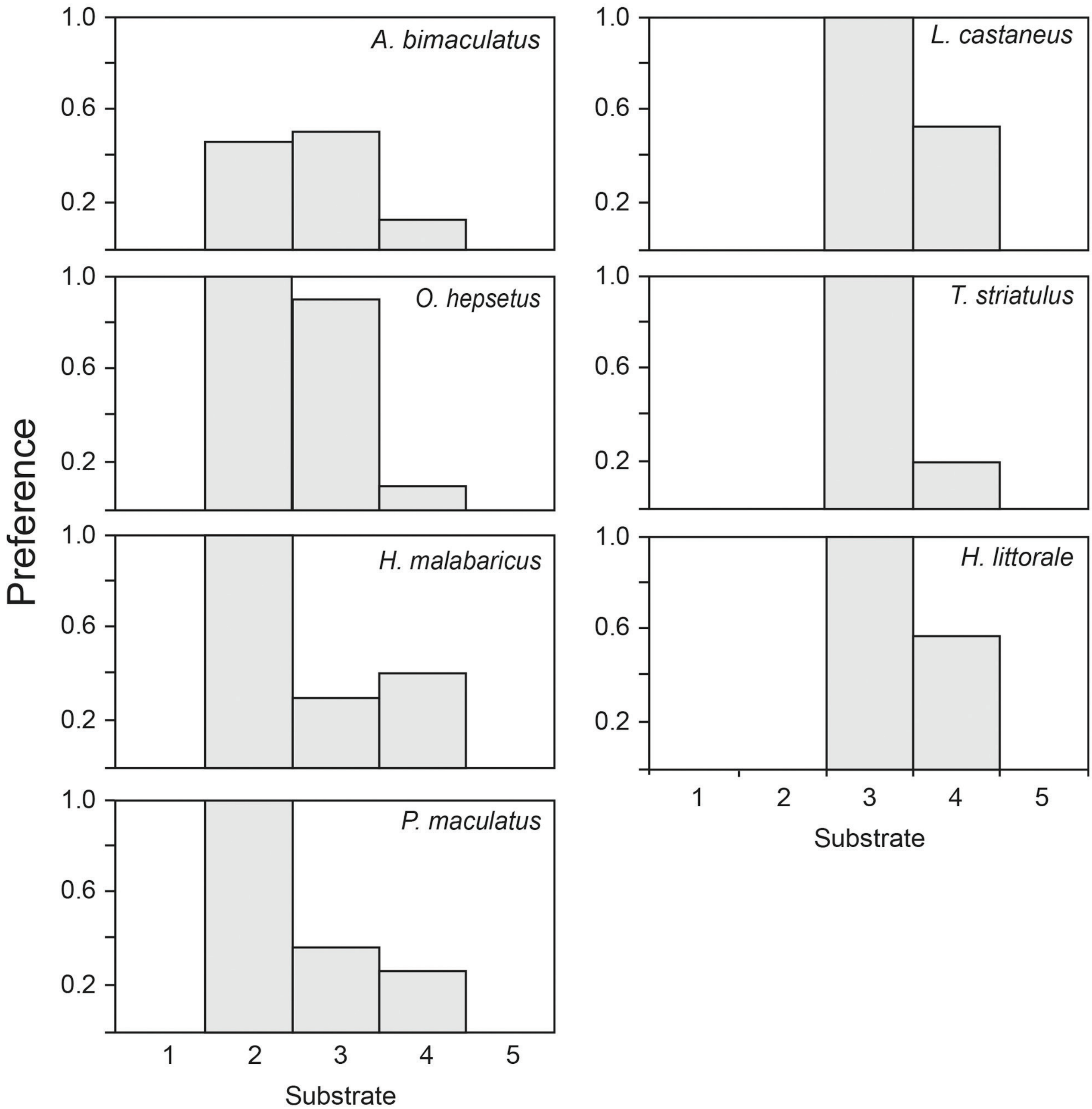

Fig. 5. Substrate preferences of seven dominant native fish species in the Guandu River. Type of Substrate: 1, clay; 2, mud; 3, sand; 4, boulder/cobble/gravel; 5, bedrock.

Pimelodus maculatus is the only examined Siluriformes species with rheophilic habits. It performs upriver migrations, especially during the reproductive period (Vono *et al*., 2002). Because of its capacity to move among different habits, it used several types of substrate and was not confined to a narrow range of depth or water velocity. Santos *et al*. (2010) studied the effects of river inflow on a reservoir and a stretch located downriver from a dam and reported *P. maculatus* as a typical species of riverine zones, primarily during the wet season, when the flow is higher. In contrast, Agostinho *et al*. (2007) found that *P. maculatus*, unlike other migratory species, predominated in the lacustrine zone of Lajeado Reservoir. The use of various aquatic macrohabitats by this species suggests its high habitat plasticity.

Except for *A.* aff. *bimaculatus*, *O. hepsetus*, and *H. malabaricus*, *i.e.*, two water-column and one benthic species, respectively, the remaining species (all benthics) showed substrate preferences. The lower stretch of the Guandu River is homogeneous and has a low water quality (Lameira *et al*., 2010) because of human activities that have resulted in a predominantly silty bottom substrate, a lack of riparian cover, and low shoreline complexity. Tidal influence also contributes to increased sedimentation in this lower stretch. However, *L. castaneus*, *T. striatulus*, and *H. littorale* were capable of withstanding such unfavorable conditions. In particular, *H. littorale* has been reported to be able to breathe air, an adaptation that allows the exploration of extreme or altered habitats with low oxygen availability (Persuad *et al*., 2006).

The recent and remarkable hydrologic changes in the Guandu system, with the introduction of an additional water discharge of 160 $m^3 s^{-1}$ and the withdrawal of 47 $m^3 s^{-1}$, may have influenced habitat availability, among other physical constraints, most likely affecting fish distributions throughout the river. According to Poff (1997), each aquatic system has peculiar characteristics that act as filters to determine which species are apt to occupy the habitats, and the patterns of abundance and distribution are a result of the ways in which the species adjust to local environmental conditions. The strong fish-habitat relationship observed in this study suggests that hydraulic and substrate variables are important environmental filters affecting the Guandu River. Although our findings are specific to the Guandu River basin, the patterns of preferences observed may be consistent and transferable to other Neotropical river basins.

The precise description of habitat preferences of species through different parts of the life cycle is fundamental for protecting river fishes and facilitating their recovery (Brookes *et al*., 1983; Copp, 1990). We observed that the studied species had specific affinities for hydraulic and substrate variables and differed in abundance among the sampled stretches. The habitat preferences described here are an improvement over a subjective classification that associates a given species with a given habitat type, but further studies on this subject are needed to obtain a more detailed picture of habitat selection by fishes.

Acknowledgments

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