Feeding habits of the ichthyofauna in a protected area in the state of São Paulo, southeastern Brazil

Leandro Muller Gomiero[1,2]; Francisco Manoel de Souza Braga[1]

[1]Departamento de Zoologia, Instituto de Biociências, Universidade Estadual Paulista – UNESP, CP 199, CEP 13506-900, Av. 24-A, n. 1515, Rio Claro, São Paulo, Brazil
[2]Autor para correspondência: Leandro Muller Gomiero, e-mail: leanmg@rc.unesp.br

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Abstract: The trophic relationships of a fish community were studied in two basins subjected to a strong human pressure in the interior of the State of São Paulo, southeastern Brazil. A total of 211 stomachs of 14 species were analyzed. Diets varied greatly, with the occurrence of piscivory, benthophagy, insectivory, herbivory, and illiophagy. Food items were described for each species and a great amount of insects was registered. Allochthonous and autochthonous food items showed different importance degrees according to the species analyzed. Stomach fullness was high in spring and summer in both basins; these areas were used as reproduction and foraging sites for the studied species.
Keywords: *feeding habits, trophic relation, ichthyofauna, protected area of São Pedro and Analândia.*

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Resumo: Foram analisadas duas bacias em uma área com forte ação antrópica no interior do Estado de São Paulo, enfocando as relações tróficas das comunidades de peixes. Foram analisados 211 estômagos de 14 espécies. As dietas foram variadas sendo constatadas piscívoria, bentofagia, insetívoria, herbívoria e iliófagia. Os itens alimentares foram descritos para cada espécie analisada e verificou-se grande quantidade de insetos. Os itens alimentares alóctones e autóctones foram importantes em maior ou menor grau para as espécies da área. O índice de repleção estomacal elevou-se na primavera e no verão em ambas bacias, sendo que as áreas abordadas foram usadas para a reprodução e para a alimentação coletiva das espécies analisadas.
Palavras-chave: *alimentação, relação trófica, ictiofauna, APA de São Pedro e Analândia.*

Introduction

Environmental alterations caused by human activities may affect the survivorship of several species of fishes by directly diminishing the available resources or affecting indirectly other components of the trophic chain (Esteves & Aranha 1999). No species lives isolated but interacts with others by predation, competition for space, food, etc. (Gulland 1989), thus communities exhibits complex inter-relationships among components (Lowe-McConnell 1987).

Headwater habitats are small and fragile and canopy exerts an important role in their maintenance (Barrella & Petrere Jr. 2003). There are indicators that tropical fishes depend on the food resources from the riparian forest, suggesting that alterations in the composition and structure of these forests may cause serious impacts on the fish community (Angermeier & Karr 1983). Headwaters are characterized by altitudinal gradient and water discharge is highly variable. Due to the turbulence these waters are well oxygenated, but the low volume is responsible to the relationship between air and water temperatures. These rivulets are formed by rapids and backwaters and the water velocity determines the transport of sediments. Fishes in this habitat are adapted to the water flow variation and the subsequent diary and seasonal fluctuations in temperature. These adaptations are observed in body shapes, presence of modified paired fins, spines that could serve as anchors, and buccal apparatus specialization. Such morphological adaptations enable the species to occupy distinct microhabitats regarding depth and current velocity, which may be important to minimize interspecific competition among species with similar feeding habits (Wootton 1992).

The main objective of this study is to characterize and compare the trophic relationships of the ichthyofauna of two basins (Jacaré-pepira basin and Corumbataí sub-basin) in the State of São Paulo, southeastern Brazil.

Materials and Methods

A total of 12 samples were made bimonthly, from February 2000 to December 2001. Each sample period lasted five days.

After preliminary analysis in the region, we determined two study sites: Corumbataí River sub-basin (Piracicaba River basin), with four sample sites: 1) Cabeça River (22° 22' 49'' S and 47° 39' 55'' W), 2) Lapa Stream (22º 23' 38'' S and 47º 47' 16'' W), 3) Passa-cinco River (22º 25' 02'' S and 47º 42' 47'' W), 4) Corumbataí River (22° 08' 15'' S and 47º 39' 37'' W); and Jacaré-pepira River basin, with three sample sites: 5) Tamanduá Stream (22° 21' 17'' S and 47° 45' 00'' W), 6) Jacaré-pepira River (22° 17' 53'' S and 48° 11' 35'' W), and 7) Água Branca Stream (22º 26' 20'' S and 48º 47' 45'' W) (See Gomiero & Braga 2005).

At each sample point, individuals were collected in many parts of the rivulet, using gill nets with mesh sizes of 1.5; 2.0; 2.5, and 3.0 cm, measured between adjacent knots, with 5 m in length and 1.5 m high. Each set of nets totalized 30 m^2. Whenever possible, purse seine with mesh sizes of 1.5 cm and 1.5 m high, sieves, and traps were also used. Afterwards, specimens were kept in plastic containers containing 10% formalin. Each container received a label describing date and sample site.

In the laboratory, fishes were identified up to the lowest taxonomic level. Total and standard length in centimeters and total mass in grams were measured for each specimen, as well as the stomach fullness (SF) (Braga 1990). To the stomach fullness, which indicates the state of repletion of the stomach, according to a scale previously established we attributed three categories: 1 = empty, 2 = partially replete, and 3 = completely replete. The stomachs with degree 3 were removed from the visceral cavity, weighted, and kept in alcohol 70%. The stomach contents were fixed in formalin 5% and preserved in alcohol 70% (Zavala-Camin 1996). Food items were identified up to the lowest taxonomic level. The method of Frequency of Occurrence (Hyslop 1980) was used, which is the percentage between the number of stomachs with items from a determined type and the total number of stomachs with food.

Results

Stomach fullness (SF) was also analyzed in all samples. We verified that SF varied among samples; individuals with degree 2 and 3 occurred in all samples except to *Characidium* aff. *zebra*, *Parodon nasus*, *Rhamdia quelen*, *Hoplias* cf. *malabaricus*, and *Serrapinus heterodon* (Figure 1).

Some omnivorous and detritivorous species foraged during all the study period. The remaining species obtained food items mainly in late winter, spring, and summer.

We analyzed a total of 211 stomachs of 14 species. The species that contributed more with replete stomachs were: *Hypostomus strigaticeps*, *Astyanax altiparanae*, *Astyanax scabripinnis*, *Characidium* aff. *zebra*, *Rhamdia quelen*, *Astyanax fasciatus*, and *Astyanax* sp1.

Numbers of stomachs analyzed, food items registered, and Frequency of Occurrence (%) of the food items for the species are listed below:

- ***Hypostomus strigaticeps* (11):** sediments (100%), vegetal material (45.4%), insects (larva and pupa of Diptera: Chironomidae) (18.1%);
- ***Geophagus brasiliensis* (4):** insects (larva and pupa of Diptera: Chironomidae; Hymenoptera: Formicidae; naiad of Odonata; larva of Coleoptera; larva of Trychoptera) (75%), sediments (75%), fish (scales) (50%), vegetal material (algae; seeds) (50%), crustaceans (Ostracoda; Daphnia) (25%), mollusks (Gastropoda) (25%), arachnids (Aranae) (25%);
- ***Astyanax altiparanae* (43):** insects (Hymenoptera: Formicidae [Mirmicinae: *Camponotus* sp. and *Zacriptoceros* sp.], Vespidae; Coleoptera: Crysomelidae; Hemiptera; larva, pupa, and adult of Diptera: Chironomidae; nymph of Ephemeroptera; Isoptera; Trychoptera; naiad of Odonata; Orthoptera; larva of Plecoptera; adult of Lepidoptera) (90.6%), vegetal material (leaves; seeds [Croton urucurana]) (53.4%), detritus (39.5%), sediments (37.2%), fish (scales) (11.6%), oocytes (6.9%), arachnids (Aranae) (4.6%);
- ***Astyanax scabripinnis* (31):** insects (Hymenoptera: Formicidae: Mirmicinae; larva, pupa, and adult of Diptera, larva and pupa of Chironomidae; adult Hemiptera; adult and larva of Coleoptera: Anobiidae; insect eggs; Homoptera; larva of Trychoptera; naiad of Odonata; Isoptera; Plecoptera) (70.9%), vegetal material (leaves; seeds) (32.2%), sediments (19.3%), arachnids (Aranae) (9.6%);
- ***Astyanax fasciatus* (20):** insects (Hymenoptera: Formicidae: Mirmicinae, Vespidae: Pompillidae; larva, pupa, and adult of Diptera, larva of Chironomidae; larva of Trychoptera; adult of Coleoptera: Anobiidae and Curcullionidae; Isoptera; naiad of Odonata; Hemiptera; larva of Ephemeroptera; Orthoptera) (85%), vegetal material (seeds; leaves of Elodea sp.) (75%), sediments (65%), mollusks (Bivalvia) (25%), fish (scales; oocytes) (20%), nematods (15%), arachnids (Aranae: Lycosidae) (5%);
- ***Astyanax* sp1. (41):** insects (pupa and adult of Diptera: Cullicidae, larva, pupa, and adult of Diptera: Chironomidae; Coleoptera: Crysomelidae; Hymenoptera: Formicidae: Mirmicinae and Apidae; naiad of Odonata; larva of Trychoptera; Blattaria; Plecoptera; nymph of Ephemeroptera; Hemiptera: Gerridae) (87.8%), sediments (68.2%), vegetal material (algae

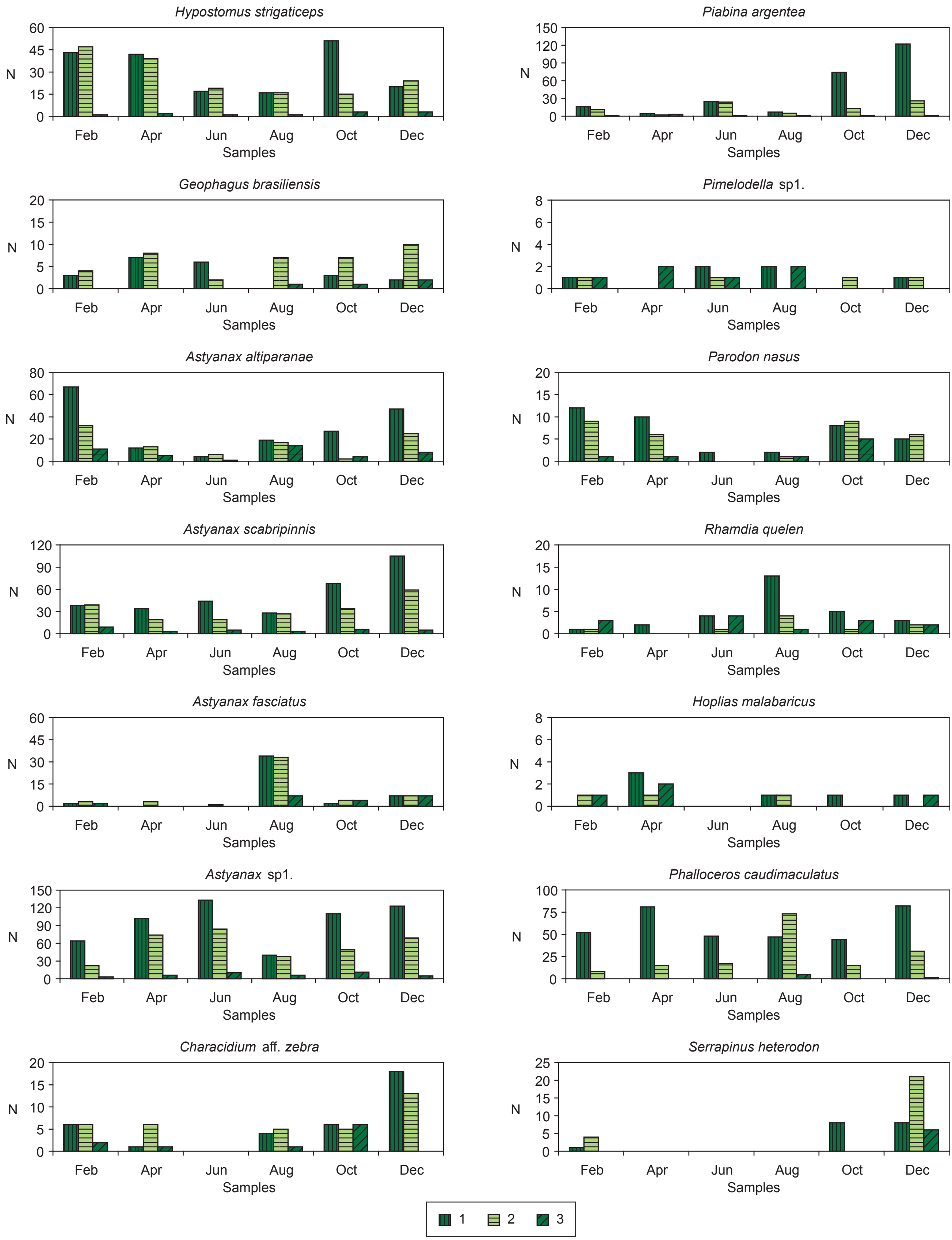

Figure 1. Numerical distribution of the repletion degree of the stomach (1. empty, 2. partially replete and 3. completely replete) per period of sample and in each specie analyzed.

Figura 1. Distribuição numérica do grau de repleção estomacal (1. vazio, 2. parcialmente cheio e 3. repleto) por período de coleta e para cada espécie analisada.

[Desmidium sp.]) (63.4%), fish (oocytes, scales) (21.9%), nematods (7.3%);

- ***Characidium* aff. *zebra* (10):** insects (larva of Ephemeroptera; larva, pupa, and adult of Diptera: Chironomidae; Hemiptera: Gerridae; larva of Coleoptera; larva of Trychoptera) (80%); sediments (40%), arachnids (adults of Acarina) (20%), fish (scales) (20%), crustaceans (Ostracoda) (10%);
- ***Piabina argentea*** (8): insects (Hymenoptera: Vespidae and Formicidae; larva, pupa, and adult of Diptera) (62.5%), sediments (50%), nematods (25%), crustaceans (*Daphnia*) (12.5%), vegetal material (12.5%);
- ***Pimelodella* sp.1** (6): insects (larva, pupa, and adult of Diptera, larva and pupa of Chironomidae; adult of Coleoptera; naiad of Odonata; nymph of Plecoptera) (66.6%), sediments (50%), nematods (33.3%), vegetal material (33.3%), arachnids (Aranae) (16.6%);
- ***Parodon nasus*** (8): sediments (87.5%), vegetal material (filamentous algae) (75%), insects (larva and pupa of Diptera; larva of Coleoptera; adult of Orthoptera) (62.5%);
- ***Rhamdia quelen*** (13): insects (Hymenoptera: Formicidae [winged form of *Atta* sp.]; Megaloptera: Corydalidae; larva of Lepidoptera; larva and adult of Coleoptera; Odonata; Orthoptera; larva and pupa of Diptera; Hemiptera) (76.9%), fishes [*Astyanax scabripinnis* and *Astyanax fasciatus*] (46.1%), sediments (46.1%), vegetal material (leaves) (30.7%), nematods (23%), crustaceans (Cladocera) (15.3%);
- ***Hoplias* cf. *malabaricus*** (4): insects (Diptera) (75%), fish (*Astyanax* eigenmaniorum) (50%);
- ***Phalloceros caudimaculatus*** (6): sediments (100%), vegetal material (83.3%), insects (larva of Diptera) (50%), fish (*Phalloceros* sp. alevin) (33.3%);
- ***Serrapinus heterodon*** (6): insects (pupa of Diptera; larva of Trychoptera) (83.3%), sediments (66.6%), vegetal material (50%).

Feeding habits analysis evidenced the great importance of insects as food items; diets of the 14 studied fish species are shown in Figure 2.

Discussion

Rivulets have a relatively low primary productivity, depending on the allochthonous resources coming from the riparian forest to maintain the predominantly heterotrophic community (Vannote et al. 1980). The input of terrestrial resources is important for fish feeding in two ways: a) increasing the quantity of allochthonous material (fruits, seeds, and terrestrial insects) directly consumed by the fishes and/or b) increasing the amount of organic material, important food source for invertebrates and detritivorous fishes (Castro 1999, Esteves & Aranha 1999).

Foraging activity intensity depends on several factors; for some species the reproductive period exert a great influence, thus immediately before and after reproduction foraging intensity increases. Another important factor is the temperature, that when increases stimulates an increase in food consumption by fishes (Pauly 1998). Additionally, during the rainy season, food availability increases, causing fishes to increase foraging activity (Angermeier & Karr 1983, Esteves & Galetti Jr. 1995).

In streams, so insect larvae as adults are important food items for a great number of fish species (Sabino & Castro 1990, Uieda et al. 1997, Catella & Petrere Jr. 1998, Mazzoni & Lobón-Cerviá 2000). Insects were very important in the diet of the analyzed fishes (13 species), with Chironomidae larvae being more frequent. This group of insects is the most abundant and diversified in several types of aquatic habitats, playing an important role in trophic chains by linking producers and consumers (Henriques-Oliveira et al. 2003).

Herbivory was common but in different degrees among 12 species; however, even the more herbivorous species feed on animal material sometimes during their lifespan (Gerking 1994).

Detritus are commonly found in the diet of several fish species (Gerking 1994) and some species are indeed specialist in this type of food. In order to use such food source (illiophagy), the species developed a great number of oral adaptations, from suctorial or suctorial-rasping lips in the loricariids and prochilodontids, up to jaws spade shaped in the parodontids and curimatids (Agostinho & Júlio Jr. 1999).

Benthophagy occurred in seven omnivorous and opportunist species, mainly those visually-oriented or exhibiting sensorial organs (barbels).

Loricariids are primarily benthic herbivorous that can feed on algae and periphyton by sucking and rasping (Power 1984a, b, Schaefer & Lauder 1986, Buck 1994, Castro & Casatti 1997, Uieda et al. 1997, Casatti et al. 2001, Delariva & Agostinho 2001). Competition among species may be avoided by resource partitioning, as such foraging substratum and shelter sites; some species use shallow water and others deep areas with higher water current (Buck 1994, Buck & Sazima 1995).

Geophagus brasiliensis fed on various food items, so allochthonous as autochthonous. The variety of these food items shows the occurrence of omnivory and opportunistic behavior in this species; the occurrence of gastropod parts was unique among the analyzed species. In a rivulet in the Atlantic Forest, southeastern Brazil, Sabino & Castro (1990) verified omnivory for *G. brasiliensis* that was active during the day in the backwaters. Barbieri & Santos (1980), at the Lobo dam (SP), registered omnivory-illiophagy for the same species, while feeding on gastropod mollusks was common observed in laboratory and semi-natural environments (Weinzettl & Jurberg 1990).

The four species of lambari analyzed, *Astyanax altiparanae*, *A. scabripinnis*, *A. fasciatus*, and *Astyanax* sp1., exhibited a great variety of allochthonous and autochthonous food items. The species *A. fasciatus* showed the greatest amount of ingested items. The autochthonous insects and mainly those allochthonous were very important food items in the diets of these species. Vegetal material was also important, thus characterizing omnivory. Foraging habits of the lambaris were also much variable, depending on the environment and availability of the food items. In the literature, these species were very studied in diverse habitats. In the Tibagi River, State of Paraná, south Brazil, *Astyanax bimaculatus* foraged on all trophic levels and exhibited ability to change its diet according to environmental changes or food availability (Lobón-Cerviá & Bennemann 2000). The lambaris are mid-water inhabitants that collect food items carried by the current (Casatti et al. 2001) and may be characterized as being mainly insectivorous in certain habitats (Uieda et al. 1997), or zooplanktophagous (Arcifa et al. 1991).

Characidium aff. *zebra* was insectivorous-benthophagous, feeding mainly on autoctones insects, mites, and crustaceans. At the State Park of Morro do Diabo, State of São Paulo, fishes of the genus *Characidium* were benthonic that captured preys by ambush (Casatti et al. 2001). Insectivory seems to be predominant in these species, such as in the Mergulhão Stream (Aranha et al. 1998), Pardo River, SP (Castro & Casatti 1997), Atlantic forest, SP (Sabino & Castro 1990), and in the Itaúna Stream (Uieda et al. 1997).

Piabina argentea was omnivorous, feeding both on allochthonous and autochthonous items.

Pimelodella sp1. were mainly insectivorous-benthophagous that captured aquatic insects searching on the substratum (Casatti et al. 2001); they were also insectivorous in the Itaúna Stream, State of São Paulo (Uieda et al. 1997), and in the Pantanal (Sazima 1986).

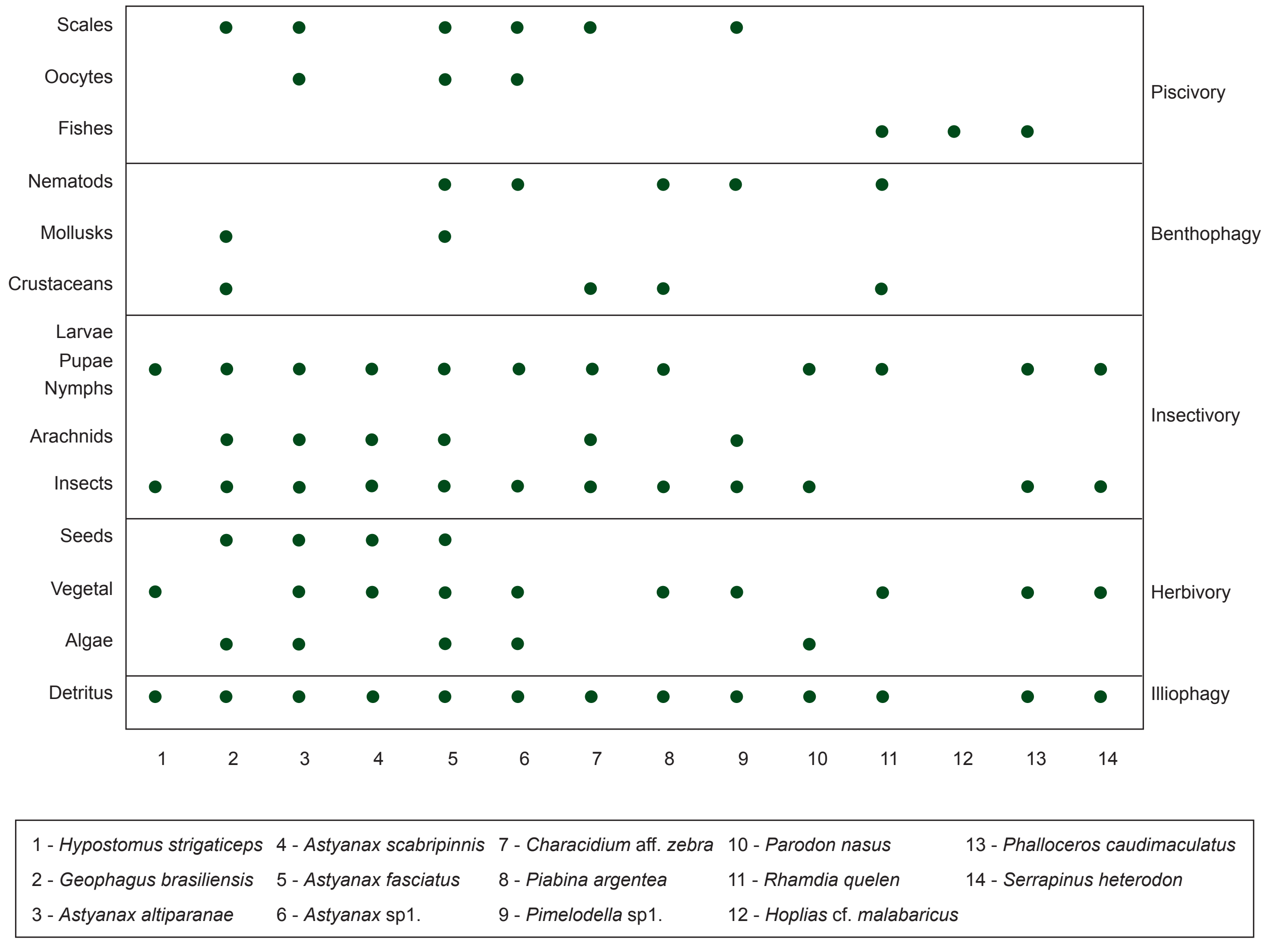

Figure 2. Feeding habits and food items registered for each fish species during the study period in the Protected Area of São Pedro and Analândia, State of São Paulo, southeastern Brazil.

Figura 2. Hábitos e itens alimentares registrados para cada espécie durante o período de estudo na Área de Proteção Ambiental de São Pedro e Analândia, estado de São Paulo, sudeste do Brasil.

The parodontids, *Parodon nasus* were insectivorous-illiophagous; this specie was very abundant in the Corumbataí River, an area very polluted with a great deposition of organic material, in the Passa-cinco River, fed on phytoplankton (Barbieri & Cruz-Barbieri 1989).

Piscivory occurred in nine species, including the items oocytes and scales, besides parts and entire fishes. Only three species were fish predators: *Rhamdia quelen*, *Hoplias* cf. *malabaricus*, and *Phalloceros caudimaculatus*; the latter species is cannibalistic, preying on conspecific fish larvae.

Rhamdia quelen, a very common nocturnal pimelodid, was omnivorous but small individulas tended toward insectivory and adults tended to piscivory. This tendency toward insectivory-piscivory seems to be common for the species. Some vegetal material could also be found. In the Pardo River, State of São Paulo, and at the State Park of Morro do Diabo this species exhibited the same foraging pattern (Castro & Casatti 1997, Casatti et al. 2001, respectively).

The piscivorou specie *Hoplias* cf. *malabaricus* exhibited ontogenetic differences, with the occurrence of insects in the stomachs of the juveniles and fish in those of the adults, being this a common pattern for piscivorous species (Lowe-McConnell 1999, Gomiero & Braga 2004a). *Hoplias malabaricus* is a mid-water fish that captures preys by ambush (Casatti et al. 2001), and its abundance is correlated with the aquatic vegetation, puddles, muddy substratum, and prey density (Mazzoni & Iglesias-Rios 2002). In the Pantanal, this species was piscivorous (Catella & Petrere Jr. 1998) and in the Pardo River, State of São Paulo, it was insectivorous-piscivorous (Castro & Casatti 1997).

Phalloceros caudimaculatus was omnivorous, feeding mostly on autochthonous items. Cannibalism registered may characterize high population density or lack of food sources and shelter for the juveniles (Gomiero & Braga 2004b). In Trinidad, the guppies (*Poecilia reticulata*) exhibited different reproductive characteristics related to different types of predators (Reznick & Endler 1982). *P. caudimaculatus* prefer shallow and calm waters, being algivorous (Aranha et al. 1998). In the Pardo River, State of São Paulo, this species was also omnivorous tending to insectivory (Castro & Casatti 1997), but in a stream in the Atlantic forest, the species was omnivorous tending to herbivory (Sabino & Castro 1990) and mainly insectivorous in the Itaúna Stream (Uieda et al. 1997).

As in Mazzoni & Lobón-Cerviá (2000), many species were omnivorous and opportunists, making use of the available resources. When the trophic structure is studied in tropical and subtropical rivers, it seems that the ichthyofauna uses the maximum level of available resources, with many generalist species that is a good strategy to survive in environments that are constantly changing (Resende 2000).

Serrapinus heterodon were omnivorous. Casatti et al. (2003), in the Rosana dam, registered algivory for *S. notomelas*.

The diversity of species analyzed in the various sample sites showed a great variety of food items, being favored by the small size (Casatti et al. 2001). Both the allochthonous and the autochthonous resources were important for the studied ichthyofauna. The allochthonous resources were mainly used by group of species that are diurnal and visually-oriented. The herbivorous and illiophagous species fed on autochthonous items. The loricariids, that were very abundant, were mainly herbivorous and detritivorous; at polluted sites, the presence or absence of sun does not influenced the occurrence of these species. The organic material poured into the rivers produces inorganic carbon that consumes the oxygen dissolved in the water (Ferraz et al. 2001). This fact could modify the occurrence of loricariids in polluted areas; however, in conditions of hypoxia these fishes become air-breathing, using their stomachs as accessory organs for gas exchanges (Graham & Baird 1982, Mattias et al. 1998).

Even the autochthonous items (immature forms of insects) depend on the surrounding biotic and abiotic conditions. The relationship of the gallery forests with the relatively narrow and shallow streams is much stricter than its relationship with large rivers, offering more resources and habitats for a more structured and diversified ichthyofauna.

The antropic pressure caused by deforestation, pollution, and at a certain degree the fisheries may influence qualitatively and quantitatively the fish communities of streams. The consensus that in the headwaters the insectivorous increase and downstream the algivorous/herbivorous dominate (Vannote et al. 1980, Angermeier & Karr 1983, Lowe-McConnell 1999) can be altered by human actions. The dominance of loricariids in much polluted environments signalize for environmental changes caused by these actions.

In more pristine sites, some species make use of the same food items, with a great niche overlap. Feeding overlap suggests interspecific competition by consuming the same items. In contrast, it may simply indicate that resource is abundant, with no reason for competition (Aranha et al. 1993).

The different periods of activity may lead to exploitation of the same habitat, and if the periods are the same for different species, the exploitation of distinct sites may avoid the real feeding overlap and competition (Uieda 1984, Sabino & Castro 1990, Arcifa et al. 1991), being competition more common among territorial species (Weatherley 1963).

Resource partitioning is a very important factor for the coexistence of species that inhabit a certain water body (Aranha et al. 1998, Casatti et al. 2003); partitioning also may occur by the alternation of food resources use (animal and vegetal items) during the seasons (Mazzoni & Rezende 2003). The majority of fishes exhibit a considerable plasticity related to their diet (Lowe-McConnell 1999).

Disturbs caused mainly by the increase in the water flow can promote the coexistence, by periodic population size reductions, of those species that do not have specific adaptations for sudden alterations (Meffe 1984). Besides this, the predators may play an important role, permitting the coexistence of preys by controlling the populations (Lowe-McConnell 1999).

The determination of the importance of the allochthonous or autochthonous items in the diet of a large and diverse fish community occurring in a variety of habitats is less expressive due to the ample interactions and foraging differences among species. Furthermore, plasticity in feeding habits is very common in detriment to the availability of the food items in the environment. The allochthonous items were more important for some species that made use of an ample array of resources, in contrast, the autochthonous items, mainly the periphyton and immature forms of insects, were very important for other species, as registered by Silva (1999).

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