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Influence of environmental integrity on the feeding biology of *Astyanax altiparanae* Garutti & Britski, 2000 in the Ivinhema river basin

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ABSTRACT. This study aimed at analyzing the influence of different levels of environmental integrity of streams of the Ivinhema river basin (Mato Grosso do Sul State, Brazil) on the diet of *A. altiparanae*. Samplings were performed from July 2001 to November 2011 at 101 sites, using sieves, seining and gill nets, and electrofishing. Streams were classified into three levels of environmental integrity. We analyzed 664 stomachs with the methods of frequency of occurrence and volumetric analysis index, combined in the Importance Index (AI). The species was omnivorous, with predominance of allochthonous resources. At the least impacted sites, the most representative resource was allochthonous plant material; and in the altered sites in the rainy period the most consumed item was allochthonous arthropods. On the other hand, at the most impacted sites in the dry period there was a lower consumption of allochthonous plant material and allochthonous arthropods, compared with other levels of environmental integrity considered, with higher consumption of autochthonous arthropods. The results evidenced that in the least impacted sites there was greater contribution from allochthonous resources, probably because these environments show a more preserved riparian forest.

Keywords: stream, fish, gut content, food habits.

Influência da integridade ambiental na biologia alimentar de *Astyanax altiparanae* Garutti & Britski, 2000 na bacia do rio Ivinhema

RESUMO. Este estudo teve como objetivo analisar se os diferentes níveis de integridade ambiental de riachos da bacia do rio Ivinhema (Mato Grosso do Sul, Brasil) influenciam a dieta da espécie *A. altiparanae*. As amostragens foram realizadas entre julho/2001 e novembro/2011, em 101 locais, utilizando peneiras, rede de arrasto, rede de espera e pesca elétrica. Os riachos foram categorizados em três níveis de integridade ambiental. Foram analisados 664 estômagos pelos métodos de frequências de ocorrência e índice de análise volumétrica, combinados no Índice de Importância Alimentar (AI). A espécie apresentou hábito alimentar onívoro, com predomínio de recursos alóctones. Nos locais menos impactados, o recurso mais representativo foi material vegetal alóctone; nos locais alterados, no período chuvoso, o item mais consumido foi artrópodes alóctones. Por outro lado, nos locais mais impactados, no período seco, houve menor consumo de material vegetal alóctone e artrópodes alóctones, em comparação aos outros níveis de integridade ambiental analisados, com maior consumo do item artrópodes autóctones. Os resultados evidenciaram que em locais menos impactados houve maior contribuição de recursos alimentares alóctones, provavelmente porque estes ambientes apresentam mata ciliar mais conservada.

Palavras-chave: riachos, peixes, conteúdo estomacal, alimentação.

Introduction

Human activities have caused different changes in terrestrial landscapes. The agricultural progress and especially the urban sprawl have resulted in diverse impacts on aquatic ecosystems and alterations in biodiversity (UIEDA; MOTTA, 2007). The loss of forest areas adjacent to streams is recognized as a serious threat to aquatic biodiversity, given the negative impacts on the biota through habitat degradation and changes in availability of food resources for fish (LORION; KENNEDY, 2009; CASATTI, 2010; SILVA et al., 2012). As a consequence, these environmental changes can modify significantly the diet of fish, by alterations in the community trophic structure (CASATTI, 2005; FERREIRA; CASATTI, 2006; WINEMILLER et al., 2008; SANDIN; SOLIMINI, 2009).

Forest areas play important roles for the integrity of aquatic systems and for fish (BARRELA et al., 2001). The integrity of the riparian vegetation is of great importance to the survival of aquatic organisms since promotes structural protection of the habitat by controlling the water flow, forming shelters and shadow, besides supplying food to aquatic organisms (CASATTI, 2010). Allochthonous resources have a key role in food chains in streams, being one of the factors that may be related to the maintenance of fish communities in these environments (CASATTI, 2010). On the other hand, is expected that the input of allochthonous material is more pronounced in streams wherein the vegetation cover is greater (REZENDE; MAZZONI, 2006).

Studies on feeding habits of fish are useful to explain the functioning dynamics of aquatic ecosystems (LOUREIRO-CRIPPA et al., 2009), and food consumed by fish allow understanding the integrity of these ecosystems. The origin of the food resources used by fish indicates the interaction of mechanisms between species during the use of these resources and the relationships with adjacent areas (OLIVEIRA; BENNEMAN, 2005; UIEDA; MOTTA, 2007).

The study of fish diets in streams under the influence of different environmental disturbances is useful to assess the biotic integrity of streams, providing important information on the adaptability of species tolerant to such environmental conditions and the actual needs to support conservation and restoration actions of degraded areas (BONATO et al., 2012). Using fish as bioindicators of environmental conditions is justified by their biological and socioeconomic importance, and indeed indices based on fish species have been developed worldwide to assess the ecological status of rivers where they live (ROSET et al., 2007). Besides that, Cetra and Petrere (2006) stated that fish provide an integrated view of the aquatic environment by the availability of information, wide range of foods, habitats and by their representativeness in aquatic food webs.

This study stands out for examining the diet of *Astyanax altiparanae* Garutti; Britski, 2000, popularly known as tambiú and lambari-do-rabo-amarelo, belonging to the family Characidae and widely distributed throughout the upper Paraná river basin. Individuals can reach 15 cm maximum length, reaching up to 60 g weight (PORTO-FORESTI et al., 2001). They are agile swimmers and occupy the upper layer of the water column for feeding (CASATTI et al., 2001).

In this context, this study aimed to describe the diet of *A. altiparanae* in sites with different levels of environmental integrity in the Ivinhema river basin (Mato Grosso do Sul State, Brazil). More specifically, we intend to determine the source of food items consumed by the species and analyze if different levels of environmental integrity of streams have any influence on the diet of *A. altiparanae*.

Material and methods

Study area

The study was developed in the Ivinhema river basin, located on the central-southern region of Mato Grosso do Sul State, to the south of the upper Paraná river basin, between latitudes 21° and 23°S and longitudes 52°30' and 56°W (SEPLAN, 1990). The upper Paraná river basin is one of the regions most affected by human activities in Brazil, the result of centuries of human occupation and high number of inhabitants, which leads to increased pressure on natural resources. Among direct anthropogenic activities on aquatic environments, the construction of reservoirs to produce electricity is one of the most common and highly impactful (AGOSTINHO et al., 2000), besides the removal of riparian vegetation and water pollution.

Samplings were conducted between July 2001 and November 2011 at 101 sites of the Ivinhema river basin (Figure 1), selected by presenting different phytophysiognomies and different levels of environmental integrity.

Data collection

Fish collected came from various research projects with different periodicities, and sampled during the daytime, using a rectangular sieve measuring 0.8 x 1.2 m, with 2 mm aperture. It was also used seining nets (1.5 x 5 m), gillnets with mesh size varying from 1.5 to 5.0 cm and electrofishing.

In the samplings were evaluated the following environmental variables: water electrical conductivity (μS cm^{-1}), turbidity (NTU), dissolved oxygen (mg L^{-1}) and riparian vegetation index (qualitative scale: 1 – without vegetation; 2 – degraded vegetation; 3 –preserved vegetation, based on RUTHERFORD et al., 2001). At the field, fish were fixed in 10% formaldehyde and later identified and preserved in 70% alcohol. In the laboratory, standard and total lengths were determined in mm, using a digital caliper. Through a ventral incision, all exemplars were opened and viscera were removed. For the diet inference, the stomach content of each individual was removed, weighed and later analyzed under the stereomicroscope.

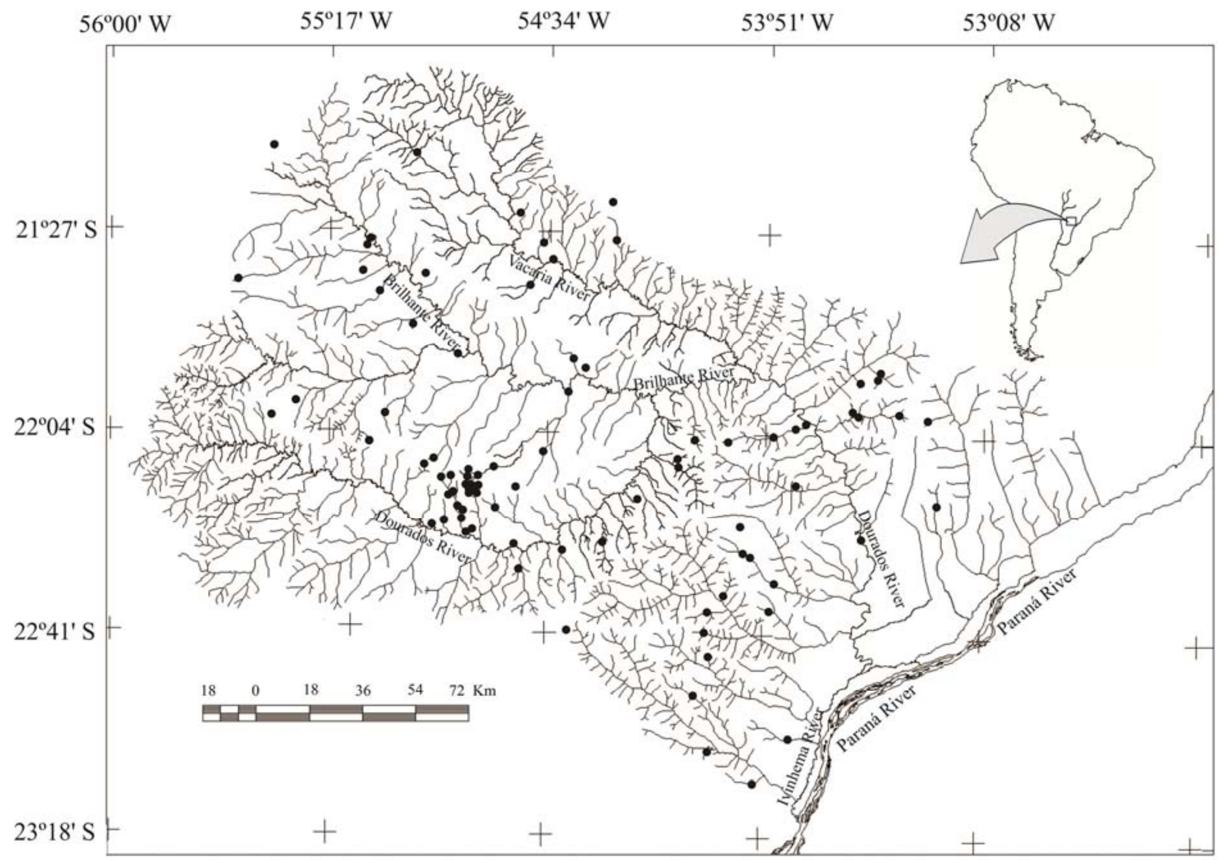

Figure 1. Location of sampling sites in the Ivinhema river basin, upper Paraná river.

Data analysis

A Principal Component Analysis (PCA) was run to determine the environmental variables with greater influence on the differentiation of categories of degradation of streams, applied according to Manly (1994), and a subsequent comparison of variables between categories was performed by the Kruskall-Wallis test.

After identifying food items according to specific literature (BARNES, 1990; NEEDHAM; NEEDHAM, 1982; PETERSON, 1960), data were evaluated following the method proposed by Lima-Junior and Goitein (2001). This method allows calculating the Importance Index (AI = F*V) of each food category (or item) using data of frequency of occurrence (F), which is the percentage of stomachs with a given item within a sample, and Volumetric Analysis Index (V), which indicates the relative abundance of each food item. The calculation of AI was performed for each trimester of the year, in order to isolate the effect of seasonality and prevent its interference with the comparative analysis of sites. The trimesters including the months from January to March and October to December represent the warmer and wetter periods of the year, whereas the two trimesters between April and September are characterized by lower mean temperatures and lower rainfall (SOUZA, 2012).

To test the spatial variation of the diet as for the hierarchy of food items consumed, the comparison of results obtained from different integrity levels was undertaken by the method of Fritz (1974). In this method, food items are ranked (based on their relative importance) in each sample and compared by a Spearman rank correlation coefficient (using the significance level of 0.05).

All tests were run using BioEstat 5.0 (AYRES et al., 2007) and PAST (HAMMER et al., 2001).

Results

The PCA results identified the electrical conductivity and vegetation index as variables that better differentiated the streams into classes of environmental integrity. The first PCA axis explained 39.86% of variance, with eigenvalue of 1.59. The second axis explained 26.26% of variance, with eigenvalue of 1.05. The conductivity was negatively correlated with the first principal component, whereas the vegetation index was positively correlated with this same axis (Table 1).

The significantly correlation between conductivity and vegetation index (r = -0.4782 and p < 0.0001) indicated that both variables can represent in isolation the first principal component. In this way, once the conductivity is a quantitative variable and reveals more information about the water quality, it was selected as reference to distinguish the sites. So, streams with lower conductivity values were considered as less impacted, while higher values of conductivity were indicative of impacted streams.

Table 1. Loadings of environmental variables with the first two principal components generated by the PCA.

Environmental variables	PC1	PC2
Turbidity	-0.005803	1.7002
Dissolved Oxygen	0.644186	-1.2472
Conductivity	-1.794600	-0.2419
Vegetation index	1.807878	0.2097
Explained variance (%)	39.86	26.26

Streams were grouped into three classes of environmental integrity: least impacted (conductivity < 50 μS cm^{-1}), impacted (conductivity between 50 and 100 μS cm^{-1}) and most impacted (conductivity > 100 μS cm^{-1}). The establishment of these classes was based on the results obtained by Lima-Junior et al. (2006) and Cetesb (2009). Afterwards, the comparison of these three levels as for the other environmental variables allows a more complete characterization, as listed in Table 2.

Table 2. Medians of turbidity, dissolved oxygen and vegetation index of the three levels of environmental integrity. Different letters indicate significant difference between the levels of environmental integrity (Kruskall-Wallis test).

Environmental integrity	Turbidity	Dissolved Oxygen	Vegetation index
Least impacted sites (conductivity <50 μS cm^{-1})	6.48^{a}	7.09^{a}	2^{a}
Altered sites (conductivity between 50 and 100 μS cm^{-1})	12.60^{b}	6.97^{a}	2^{a}
Most impacted sites (conductivity >100 μS cm^{-1})	19.29^{b}	6.24^{a}	1^{b}

The analysis of 664 stomachs of *A. altiparanae* showed the consumption of diverse food items, which were grouped into eight large food categories: algae (Chlorophyta), allochthonous plant material (fragments of root, stem, leaf, and seed, especially of the family Poaceae), autochthonous plant material (macrophytes), autochthonous arthropods (fragments of larvae and pupae of insects of the orders Diptera, Ephemeroptera, Trichoptera and Coleoptera), allochthonous arthropods (fragments of terrestrial insects – Coleoptera, Hymenoptera, Hemiptera, Diptera and Araneae), non-identified material, sediment (sand and small pebbles), and fish remains (scales, muscle remains and fingerlings).

Samplings were divided into trimesters accompanying the seasons of the year. At the least impacted sites, the most important food items were allochthonous plant material (ALP) – Jan.-Mar. 48.30%, Apr.-June 20.60%, July-Sep. 31.60% and Oct.-Dec. 39.27% – and allochthonous arthropods (ALA) – Jan.-Mar. 38.25%, Apr.-June 6%, July-Sep. 22.54% and Oct.-Dec. 23.07% (Figure 2A). In the altered sites, the most consumed food items were the same: allochthonous plant material (ALP) – Jan.-Mar. 29.65%, Apr.-June 20.11%, July-Sep. 49.34% and Oct.-Dec. 35.71% – and allochthonous arthropods (ALA) – Jan.-Mar. 14.65%, Apr.-June 18%, July-Sep. 23.50% and Oct.-Dec. 96.42% (Figure 2B).

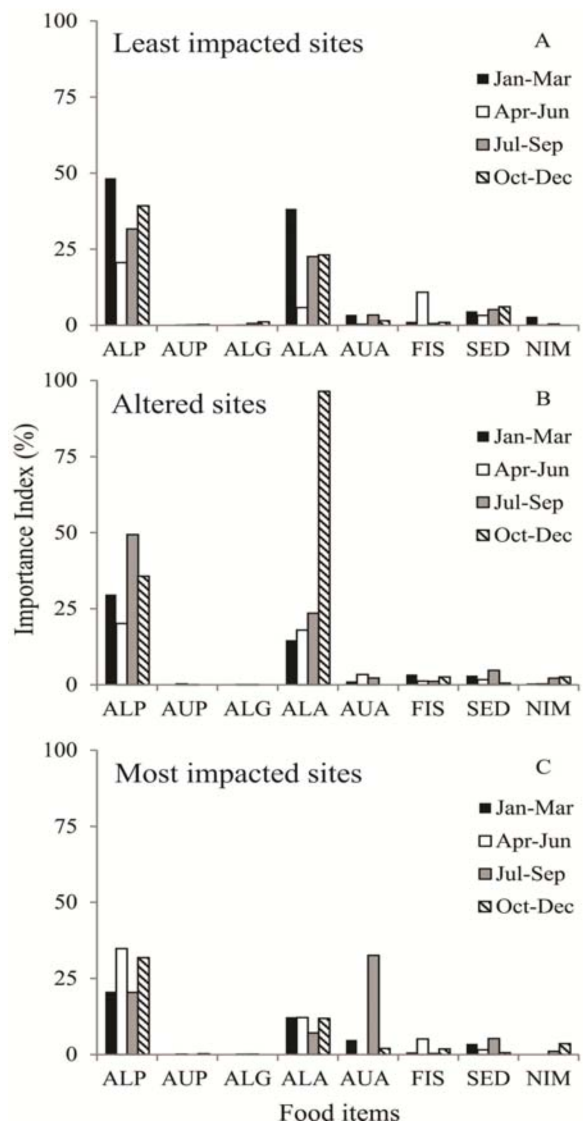

Figure 2. Importance index of food items found in the diet of *A.altiparanae* in the three levels of environmental integrity. ALP = allochthonous plant material; AUP = autochthonous plant material; ALG = algae; ALA = allochthonous arthropods; AUA = autochthonous arthropods; FIS = fish remains; SED = sediment; NIM = non-identified material.

In the most impacted sites, the most important food items were allochthonous plant material (ALP) – Jan.-Mar. 20.66%, Apr.-June 34.80%, July-Sep. 20.37% and Oct.-Dec. 31.80% –, followed by autochthonous arthropods (AUA) – Jan.-Mar. 4.77%, Apr.-June 0%, July-Sep. 32.56% and Oct.-Dec. 2% – and allochthonous arthropods (ALA) – Jan.-Mar. 12.25%, Apr.-June 12.15%, July-Sep. 7.09% and Oct.-Dec. 11.86% (Figure 2C). On the third trimester, the drier period, there was a reduction in the consumption of allochthonous plant material and allochthonous arthropods compared with other levels of environmental integrity analyzed, with a greater consumption of autochthonous arthropods (Figure 2C).

It was observed that allochthonous resources of plant origin (especially Poaceae seeds) composed most of the diet of the species. Among the allochthonous arthropods, the species consumed a high abundance of terrestrial insects, mainly represented by Coleoptera and Hymenoptera. Among the autochthonous arthropods, Diptera larvae particularly of the families Chironomidae and Simuliidae were the most abundant.

The Spearman correlation pointed out a significant variation in diet between environmental integrity classes ($p > 0.05$; absent correlation): in the second trimester, between altered sites and most impacted sites ($p = 0.083$); on the fourth trimester in the comparison between least impacted sites and altered sites ($p = 0.2729$); on the fourth trimester between least impacted sites and most impacted ones ($p = 0.2329$).

Discussion

Based on our results, the water electrical conductivity was the variable most indicated to distinguish the streams into classes of environmental integrity. According to Lima-Junior et al. (2006) in the Corumbataí river (São Paulo State), the least impacted site of the river presented conductivity <50 μS cm^{-1}, while the most degraded, >100 μS cm^{-1}. Besides that, the Cetesb (2009) sets that electrical conductivity above 100 μS cm^{-1} is usually associated with impacted environments, providing a good indicative of changes in water composition, mainly in its mineral concentration. In agreement with Moraes (2001), the conductivity is important for detecting pollution sources, enabling to check the direct and indirect influence of land use and activities developed in the hydrographic microbasins, such as discharge of domestic and industrial effluents, and animal wastes, in which the result of contamination can be detected by increased conductivity in the watercourse. Therefore, the use of electrical conductivity to classify the levels of environmental integrity was effective to depict the environmental conditions.

In this study, *A. altiparanae* exhibited flexibility in the diet by consuming diverse food resources, presenting omnivorous feeding habit and opportunistic behavior. Brandão-Gonçalves et al. (2009) mentioned that the feeding flexibility is an adaptive feature of animal behavior, since natural environments vary over time and space. According to Gomiero and Braga (2005), Uieda and Motta (2007) and Winemiller et al. (2008), omnivorous and/or opportunistic species have advantages and can increase their probability of survival, especially considering environmental changes.

The consumption of plant items, such as seed and fruit, reinforces the importance of preserving riparian forests, which influence the maintenance of fish communities, while fish serve as biological dispersers (REYS et al., 2008).

The high consumption of allochthonous items at the least impacted sites should be associated with riparian vegetation, which is more preserved in these environments. Diverse resources like allochthonous plant material (leaf, fruit and seed) and allochthonous arthropods living in riparian forests are carried to the aquatic environment by the rainfall, wind or simply fall from trees into the water. Literature data have shown that mid-water swimming species feed on items dragged by the current (CASTRO; CASATTI, 1997; CASATTI, 2002; UIEDA; PINTO, 2011). The availability of allochthonous food in streams is influenced by hydrological periods, because during the rainy period there is transport of allochthonous arthropods to the aquatic environment through the rainfall runoff (REZENDE; MAZZONI, 2005; BORBA et al., 2008; TÓFOLI et al., 2010).

In the altered sites it was verified a high dominance of allochthonous arthropods (mainly represented by Coleoptera and Hymenoptera), especially in the trimesters corresponding to spring and summer, which indicates a greater abundance of these resources, once during this season, trees fructify and terrestrial insects perform nuptial flights for breeding (CASSEMIRO et al., 2002). A greater participation of these items in the rainy period is related to their displacement to the aquatic environment by the rainfall, as afore discussed.

Along with allochthonous items, sediments from the banks of streams are carried to aquatic systems. Given little riparian vegetation on the banks, which shows a damping function, can result in a higher transfer of sediment to the aquatic environment, affecting the dynamics and functioning of the whole ecosystem (FERREIRA; CASATTI, 2006; SILVA et al., 2007; KASANGAKI et al., 2008; MORMUL et al., 2009; FERREIRA et al., 2012).

The composition of the diet of *A. altiparanae* at more impacted sites showed that the species has consumed a great proportion of autochthonous arthropods, especially Diptera of the families Chironomidae and Simulidae. The ingestion of large amounts of organisms of these families can be explained by environmental changes at these sites, which are characterized by a higher level of environmental degradation compared with other studied sites, with lower vegetation cover surrounding the streams. Diptera larvae (especially Chironomidae) are more common in impacted environments, because they are tolerant and can easily adapt to extreme conditions, including large amounts of nutrients, such as phosphorus from domestic sources and industrial pollution (KLEINE; TRIVINHO-STRIXINO, 2005; MILESI et al., 2009; MORMUL et al., 2009; BONATO et al., 2012). Thus, groups resistant to these conditions reach high densities (MORMUL et al., 2009) and become prey to a great number of fish tolerant to degraded environments. Chironomidae larvae are opportunistic omnivorous, ingesting a wide variety of food items (HENRIQUES-OLIVEIRA et al., 2003; KLEINE; TRIVINHO-STRIXINO, 2005). This information explains the high occurrence and abundance of these larvae in the feeding of this lambari species. This suggests that they are common in degraded environments, being an indicator of the environmental condition.

The lower contribution of allochthonous items at the most impacted sites in relation to the other sites can be justified by the lower vegetation cover in these sites. The removal of riparian vegetation can severely impact the integrity of fish communities of tropical streams that depend on allochthonous resources (ANGERMEIER; KARR, 1983; BORBA et al., 2008). Barreto and Aranha (2006) also suggested that the elimination of this vegetation, with consequent reduction in allochthonous resources, would increase inter- and intraspecific competition for autochthonous resources, compromising the maintenance of communities, which further accentuates the importance of preserving the riparian vegetation for aquatic communities (CASATTI, 2010).

Conclusion

Astyanax altiparanae presented a high feeding plasticity, because the most exploited resources were possibly those available at the moment, without feeding specificity. This evidences the opportunistic behavior of this species, taking advantage of the conditions in the environment and the supply of food items for consumption. These characteristics allow the permanence of this species in moderately eutrophicated streams, since it is tolerant to such environmental conditions.

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