# STREAM FISH, WATER AND HABITAT QUALITY IN A PASTURE DOMINATED BASIN, SOUTHEASTERN BRAZIL

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(With 3 figures)

## ABSTRACT

A fish survey in 35 stream reaches (from 1st to 3rd order) with physicochemical and habitat assessment in the São José dos Dourados system, southeastern Brazil, was conducted. Most of the basin land cover (77.4%) is used for pasture. From the sampled stream reaches, 24 were of good physicochemical quality, 10 of fair quality, and only one of poor quality. A habitat assessment showed that 10 stream reaches were considered fair, 22 were poor, and 3 were very poor. Fifty species were collected and their abundances showed strong correlation with habitat descriptors. In addition to the correlation between fish abundance and habitat, some species also showed optimal distribution related to the degree of physical habitat conservation. Streams located in this region experience organic pollution, but the most important aspect is the decline of the instream physical habitat condition, especially in first order streams, which negatively affects coarse substrates and water column dependent fish species. Effluent control, riparian vegetation restoration programs, siltation control and adequate sustainable soil use are practices which could mitigate such impacts.

*Keywords*: Upper Paraná, integrity, physicochemical, conservation, indices.

## RESUMO

### Ictiofauna de riachos, qualidade da água e do hábitat em uma bacia hidrográfica dominada por pastagens, Sudeste do Brasil

A ictiofauna de 35 trechos de riachos (de 1ª a 3ª ordem) no sistema do Rio São José dos Dourados, Sudeste do Brasil, foi estudada juntamente com a avaliação físico-química e física do hábitat. Na região estudada, 77,4% do solo é utilizado para pastagens. Quanto à avaliação físico-química da água, 24 trechos foram classificados como bons, 10 como regulares e um como pobre; quanto à avaliação física do hábitat, 10 foram considerados regulares, 22 como pobres e 3 como muito pobres. Cinqüenta espécies foram coletadas e suas abundâncias apresentaram forte correlação com descritores do hábitat. Em adição a esta correlação, observou-se que algumas espécies também demonstraram sua distribuição ótima coincidente com o grau de conservação do hábitat físico. Os riachos dessa região estão expostos a impactos provenientes de poluição orgânica, mas especialmente pequenos riachos de primeira ordem estão seriamente afetados pela perda de qualidade física do hábitat, que, negativamente, afeta tanto espécies de peixes dependentes de substratos rochosos como espécies que exploram a coluna d'água. Controle da entrada de efluentes, programas adequados de restauração da vegetação ripária, controle do aporte de sedimento e uso adequado e sustentável do solo são práticas que podem mitigar tais impactos.

*Palavras-chave*: Alto Paraná, integridade, físico-químico, conservação, índices.

## INTRODUCTION

An effective assessment of lotic condition requires comprehending the multiple causes of stress on the aquatic biota, including habitat loss and degradation, the spread of non-native species, overexploitation, secondary extinctions, chemical and organic pollution, and global climate change (Allan & Flecker, 1993). The accuracy in detecting such impacts is clearly limited, but the search for adequate indicators at several levels (*i.e.* chemical, physical, and biological) has been carried out for nearly a century (*e.g.*, Forbes & Richardson, 1919). Dams and anthropogenic deforestation at levels ranging from massive projects to local cumulative alterations are important forces worldwide that are modifying both landscapes and waterways (Allan & Flecker, 1993).

With the exception of some remote Amazonian rivers, most aquatic environments have been altered by human activities in Brazil (Tundisi & Barbosa, 1995), including wetland drainage, dams, road building, and deforestation for human settlements and intensive agriculture. All of these modifications had a negative impact on the hydrology, vegetation cover, and terrestrial-aquatic linkages (Allan & Flecker, 1993) of the affected systems. A prime example is the State of São Paulo, the most industrialized and populous in Brazil that retains only 14% of its original vegetation (Zorzetto *et al.*, 2003), which originally was represented primarily by Semi-Deciduous forests, Atlantic rainforests, and Savannah (Cerrado). These last two biomes were considered biodiversity hotspots for conservation priorities by Myers *et al.* (2000). Semi-Deciduous forests, which were previously the main vegetation coverage of the western portion of the State are now restricted to small, unconnected, residual fragments. This region is drained by the lower rio Tietê, the rio São José dos Dourados, and the rio Turvo, and few studies reported stream fish assemblages in these river basins (Garutti, 1988; Lemes & Garutti, 2002; Castro *et al.*, 2004). We surveyed the São José dos Dourados system as part of a project aiming to develop a fish index of biotic integrity for the upper rio Paraná headwaters and streams. The most important step in the IBI development is to choose and integrate metrics that reflect diverse responses of biological systems to human actions (Karr & Chu, 1999). Because ecology and biology of stream fish in that region are poorly known, in this study we investigated fish assemblage structures in a wide range of physicochemical and habitat conditions, in randomly selected places in order to detect the main kinds of impacts on the fish fauna.

## STUDY AREA AND REGIONAL REFERENCE AREA

The São José dos Dourados system includes the river basin plus some small tributaries of the left margin of the rio Paraná. The system is located in the Serra Geral formation, composed of basaltic and sedimentary rocks of the Cauiá and Bauru groups. The sandy Botucatu and Pirambóia formations (both belonging to the São Bento group) are the aquifers of the region (IPT, 2000). The climate is hot tropical (Nimer, 1989), with a wet season from October to March (January and February are the wettest months, with 54% of the annual rainfall), and a dry season, extending from April to September (Barcha & Arid, 1971). The maximum mean temperature (31 °C) occurs in January, and the minimum average (13 °C) occurs in July (IPT, 2000).

We adopted the regional reference concept to calibrate physicochemical and habitat descriptors, a more adequate design when monitoring is applied to a watershed or river basin (Barbour *et al.*, 1999). The most important reference area was the quasi pristine Morro do Diabo State Park (22° 27' to 22° 40' S, 52° 10' to 52° 22' W), that encompasses approximately 33,000 ha, in the municipality of Teodoro Sampaio, Pontal do Paranapanema region, southwestern São Paulo state. Four streams within the park were previously studied by Casatti *et al.* (2001) and Casatti (2002, 2004). The park's monthly rainfall varied from 14.7 mm (May 2000) to 361 mm (December 2000) and temperatures ranged from - 1.2 °C (July 2000) to 37.8 °C (October 2000) (data from the weather station in the park). Physicochemical unpublished data recorded in the Morro do Diabo State Park streams were also provided by Daniela M. L. da Silva. Additional reference areas included also relatively less impacted streams studied in the upper Rio Paraná basin by Castro *et al.* (2003, 2004).

## MATERIAL AND METHODS

Thirty-five sites of first to third order (according to Strahler, 1957, map scale 1:50,000) were selected using a random approach (Kasyak, 2001). The number of sites was approximately proportional to the total length in km for a particular stream order (Roth *et al.*, 1997). One site was selected for each 100 km of length order, for a total of 22 first order, nine second order, and four third order sites. Following Kasyak (2001), a 75 m stream reach was chosen at each site with the aim of including all available macrohabitats. All stream reaches were sampled during the beginning of a single dry season (March to June, 2003) to minimize seasonal effects.

***Land cover***

The land cover map of the São José dos Dourados River system was developed by digitally supervised classification of two TM/Landsat-5 images (path-row: 222/74 and 221/74 already georeferenced), using the maximum likelihood method (Eastman, 2001; Lillesand & Kieffer, 2000). The images of the study area (August 1996) were acquired from the Instituto Nacional de Pesquisas Espaciais (Brazil). Bands 3, 4, and 5 were digitally processed to produce a land cover map with the following categories: pasture, perennial crops, remaining natural vegetation, sugar-cane, reforestation, water-bodies, annual crops, bare soil, urban locations, and others. Training sites were identified using field observations and internet data (www.cati.sp.gov.br) and the classification accuracy was checked using a field survey. Sixty randomly selected points were visited, and the Kappa Index of Agreement (Eastman, 2001) was 0.88, where 90% of the points had corresponding land use.

***Fish***

Fish were collected during two electrofishing passes (modified from Mazzoni *et al.*, 2000; Castro *et al.,* 2003), fixed in 10% formalin and later transferred to 70% ethanol. All specimens were deposited in the ichthyological collection of the Departamento de Zoologia e Botânica da Universidade Estadual Paulista, São José do Rio Preto, Brazil (DZSJRP 5833 to 6190).

***Water and habitat quality***

The combination of water quality and physical description can provide insight to the presence of chemical and non-chemical stressors to the stream ecosystem and for this reason we analyzed both components in separate ways, always comparing them to regional reference conditions (Barbour *et al.*, 1999). In a broad sense, habitat incorporates all aspects of physical and chemical constituents along with the biotic factors, but following Barbour *et al.* (1999), we consider habitat as the instream and riparian zone that influences the structure and function of the ichthyocenosis.

A water quality index for small streams (Stream Water Index, SWI) of the upper Rio Paraná basin is herein proposed and includes physicochemical descriptors usually linked to fish health, specifically dissolved oxygen, conductivity, pH, turbidity (all measured through digital meter Horiba®, model U-10), orthophosphate, nitrate, and ammonia (all analyzed in laboratory). In addition, water odors and water surface oils were also registered (Barbour *et al.*, 1999) as indicators of possible human disturbance of a stream reach. Scores 4 to 1 were determined based on their deviation from the reference conditions and the average final score for each site was classified in four categories (Table 1).

For the physical assessment of the habitat, a visual-based habitat approach was conducted. Many protocols are applied around the world, all of them including descriptors which describe the stream micro/macro features, riparian condition, and bank structure (Barbour *et al.*, 1999). We combined the protocols proposed by Roth *et al.* (1996), Barbour *et al.* (1999), and Kasyak (2001). Scores were established *a priori* according to reference conditions, usually separating sites into high-gradient and low-gradient reaches. To minimize subjectivity, the same person evaluated all sites. All descriptors were evaluated and rated on a numerical scale of 0 to 20 for each sampling reach (see Habitat Form on Appendix). The sum of all scores represented four habitat integrity categories (Table 2) of the Physical Habitat Index (PHI). Habitat descriptors are:

1. Substrate stability. This includes the degree of cover provided by natural structures in each stream, such as cobble (in riffles), large rocks, fallen trees, logs and branches that are available as shelter, feeding, or spawning and nursery sites. Decreases in the variety and abundance of such structures render the habitat more homogeneous, thereby decreasing habitat diversity and recovery

**TABLE 1**
**Scores for physicochemical water descriptors for small streams in the upper rio Paraná basin, southeastern Brazil. SWI (stream water index) is the total score for a site: good (36-30); fair (29-23); poor (22-16); and very poor (15-9).**

| Descriptors | Score 4 | Score 3 | Score 2 | Score 1 |
|---|---|---|---|---|
| Dissolved oxygen (mg/l) | ≥ 6.0 | 5.0-5.9 | 4.0-4.9 | < 4.0 |
| Conductivity (μS/cm) | ≤ 50 | 51-100 | 101-150 | > 150 |
| pH | 6 to 9 | 5.0-5.9 | 4.0-4.9 | < 4.0 |
| | | 9.1-10.0 | 10.1-11.0 | > 11.0 |
| Turbidity (NTU) | ≤ 40 | 41-150 | 151-300 | > 300 |
| Nitrate (mg/l) | ≤ 1.0 | 1.1-1.5 | 1.6-1.75 | > 1.75 |
| Ammonia (mg/l) | ≤ 0.01 | 0.02-0.5 | 0.6-1.0 | > 1.0 |
| Orthophosphate (mg/l) | ≤ 0.03 | 0.04-0.5 | 0.6-1.0 | > 1.0 |
| Odor | normal | - | - | sewage, petroleum, chemical, dead fish |
| Surface oils | absent | - | - | present |

**TABLE 2**
**Descriptions of stream physical habitat condition (adapted from Roth *et al.*, 1996).**

| Categories | Sum of scores | Description |
|---|---|---|
| Good | 180-136 | Comparable to minimally disturbed reference streams. Falls within upper 75% of theoretical reference condition. |
| Fair | 135-91 | Some aspects of physical habitat may not resemble those found in minimally disturbed streams. Falls within the lower portion of the range of the theoretical reference sites (75-50% of the reference). |
| Poor | 90-46 | Significant deviation from minimally disturbed reference conditions, with many aspects of physical condition not resembling those of minimally disturbed streams, indicating some degradation (50-25% of the reference). |
| Very poor | 45-0 | Strong deviation from minimally disturbed reference conditions, with most aspects of physical condition not resembling those found in minimally disturbed streams, indicating severe degradation (below 25% of the reference). |

potential. Logs and branches in low gradient streams are often critical habitats for such purposes (Barbour *et al*., 1999);

2. Velocity and depth variability. The different combinations of velocity and depth represent another component of habitat diversity. High gradient streams often show four patterns of flow: slow/deep, slow/shallow, fast/deep, fast/shallow. Low gradient streams show four patterns of pools: large/shallow, large/deep, small/shallow, small/deep (Barbour *et al*., 1999; Kasyak, 2001);
3. Flow stability. This represents the occurrence of natural and continuous flows versus flashy or ephemeral flow (Roth *et al*., 1996), such as typically found in areas with dams, obstructions, diversions for irrigation or during droughts;
4. Bottom deposition. Fine sediments accumulate mainly in pools, but may also embed in riffles, or create islands, point bars, or embayments. Depending on the channel slope, an increase in fine sediment indicates a less suitable environment for aquatic biota (Barbour *et al*., 1999); however, islands, point bars, and embayments increase channel complexity;
5. Combinations of pool-riffles-runs. This describes the variety of macrohabitats present; *i.e.* the combinations between pools, riffles, runs, and small marginal pools, against the predominance of channelized reaches (Roth *et al*., 1996);

6. Channel alteration. Measures large-scale changes in the shape of the stream channel such as artificial embankments, artificial bank stabilization, channelization, and dredging (Barbour *et al*., 1999);
7. Streamside cover. Riparian zones are areas along water bodies, often with flood tolerant plants. When these zones support complex woody vegetation, they play a vital role in the structure and maintenance of physical habitat, energy flow, and aquatic assemblage composition. Riparian vegetation buffers against siltation, and elevated pollutants and water temperature, while providing habitat, nutrient input, and shelter and substrate for microorganisms (Millard *et al*., 1999; Barbour *et al*., 1999). The limits of the riparian zone are not easily defined and may vary with the season (Lima & Zakia, 2000). There is no definitive method to establish the minimal riparian width for satisfactorily protecting water courses (Bren, 1993). For temperate streams in Ontario, Canada, Barton *et al*. (1985) defined a minimum buffer zone of 18 m from each bank. In Australia, Clinnick (1985) recommended 30 m. For Maryland streams, Kasyak (2001) proposed at least 50 m, but FEMAT (1993) proposed a 70 m minimum buffer zone in the northwest USA. Brazilian legislation requires a minimum of 30 m of riparian vegetation for water bodies 10 m wide. In the absence of scientific consensus concerning the ideal riparian width, we used the minimal limits required by Brazilian laws. The mere presence of riparian vegetation is not indicative of natural conditions, since the presence of non-native species (Roth *et al*., 2001) and the absence of larger trees indicate a decline of integrity. This metric was consequently scored considering both the width and integrity of riparian vegetation;
8. Bank vegetative stability. Measures the extent of the streambank surface covered with vegetation or rubble, both of which provide protection from erosion (Roth *et al*., 1996; Barbour *et al*., 1999); and
9. Bank stability. This metric verifies whether stream banks are eroded, thereby including their potential for erosion. Higher potential for erosion is found in steeper and therefore more unstable banks. Erosion signs include crumbling, unforested banks, exposed roots and exposed soil. Each bank is evaluated separately (Barbour *et al*., 1999; Kasyak, 2001).

***Data analysis***

In order to ordinate the information about species abundance along sites, a detrended correspondence analysis (DCA) was conducted, using the option of 26 segments in the PCOrd software (McCune & Mefford, 1999). Following Cao *et al*. (1998) rare species were not excluded from ordination because of the importance of this class of species in bioassessment. The mean velocity, mean depth, amount of riparian coverage (absent, present, or abundant), amount of marginal vegetation in contact with water (absent, present, or abundant), and predominant substrate (sand, sand/gravel, or sand/gravel/woody debris) were correlated with an ichthyocenosis structure using the Mantel test and Euclidean Distance for the abiotic matrix and Morisita-Horn for the species matrix; comparisons were made with the option of normalization and 5,000 permutations in the NTSYSpc software (Rohlf, 2000).

## RESULTS

The São José dos Dourados system covers 6,793 km$^2$, most of which (77.4%) is pasture. The original vegetation, mostly represented by Semi-Deciduous forests, is found in only 5.6% of the system (Table 3), and is represented by very degraded, small, and unconnected fragments.

Among the 35 stream reaches sampled, 24 had good SWI, 10 had fair, and only one had poor water quality (Fig. 1a). Expressive differences were not registered stream among orders (mean SWI for first order = 32.8, second order = 31.0, third order = 32.5). The physical habitat assessment (Fig. 1b) suggests greater disturbance in the structure of the habitat than the physicochemical conditions of the water. Ten stream reaches had regular PHI (mean score = 98.3), 22 were considered poor (mean score = 69.4), and 3 had very poor habitats (score = 28.3). The lowest PHI scores were registered for streamside cover, bank stability, bank vegetative stability, and bottom deposition, in that

**TABLE 3**
**Land use in the São José dos Dourados system (total area 6,793 km²), southeastern Brazil.**

| Categories | Coverage (%) |
|---|---|
| Pasture | 77.45 |
| Bare soil | 6.24 |
| Perennial crops | 2.40 |
| Remaining natural vegetation | 5.62 |
| Water bodies | 5.18 |
| Sugar cane | 2.15 |
| Urban places | 0.78 |
| Annual crops | 0.16 |
| Reforestation | 0.02 |
| Others | 0.01 |

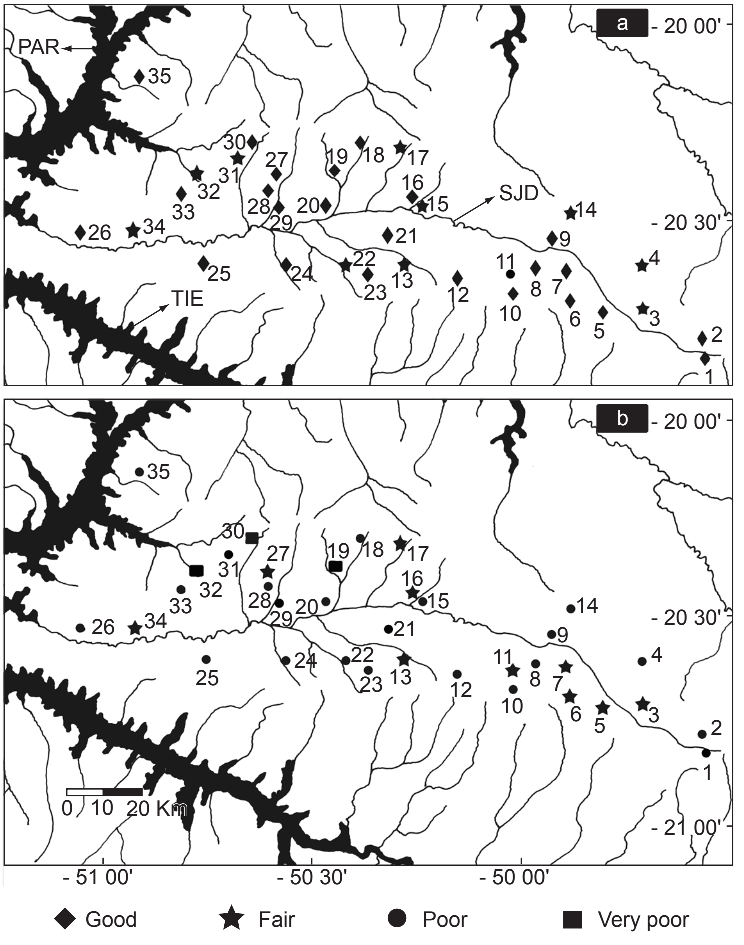


**Fig. 1 —** Physicochemical condition of water integrity (a) and physical habitat integrity (b) for 35 streams in the São José dos Dourados system, southeastern Brazil. PAR, rio Paraná; SJD, rio São José dos Dourados; and TIE, rio Tietê.

order. First order streams showed the lowest PHI scores (mean = 66.4) in comparison to the second (mean = 86.7) and third order streams (mean = 88.5). SWI and PHI were not significantly correlated (Spearman coefficient = - 0.1923, p = 0.2685).

Fifty species of fish, belonging to six orders and 18 families (Table 4) were collected, for a total of 7,324 specimens and 19.7 kg. *Astyanax altiparanae* was the most abundant species (26% of the total abundance), followed by *Poecilia reticulata* (18%), and *Knodus moenkhausii* (12%). In terms of biomass, *Astyanax altiparanae*, *Hoplias malabaricus*, and *Gymnotus carapo* were the most important species. *Poecilia reticulata*, *Oreochromis niloticus*, and *Tilapia rendalii* are introductions from outside the upper Rio Paraná system in the first case and outside South America in the two last cases. *Knodus moenkhausii*, *Laetacara* sp., and *Satanoperca pappaterra* represent species whose origin is not clearly defined in the upper rio Paraná basin. The mean richness increased according to stream order (5 for first order, 7 for second order, and 12 for third order). Higher abundance and biomass were registered in stream 34, a second order stretch, whereas lowest abundance and biomass were obtained in stream 12, a first order stretch (Table 5).

Mantel statistics showed that species abundance and habitat descriptors were correlated (r = - 0.26024, p = 0.0012, $\alpha$ = 0.01) and DCA analysis indicated that species gradient is, in general, compatible with physical habitat conditions (Fig. 2). Sites 5, 6, 7, 11, 16, 17, 18, 27, 31, and 34, all with the best PHI values, were placed in close ecological proximity. Some species reflect such ordination (Fig. 3) and thus can potentially indicate habitat conservation (*i.e.*, *Bryconamericus stramineus*, *Characidium zebra*, *Hypostomus* sp., *Imparfinis schubarti*, *Moenkhausia sanctaefilomenae*, *Pamphorichthys hollandi*, *Piabina argentea*, *Pimelodella avanhandavae*, *Pseudopimelodus pulcher*, and *Steindachnerina insculpta*). In contrast, in the opposite ordination gradient (Fig. 2), sites 19, 30, and 32 showed the lowest values for PHI. Similarly, species whose optimum reflects this ordination (Fig. 3) could reveal signals of habitat degradation (*i.e.*, *Aspidoras fuscoguttatus*, *Callichthys callichthys*, *Cichlasoma paranaense*, *Geophagus brasiliensis*, *Gymnotus carapo*, *Knodus moenkhausii*, *Laetacara* sp., *Oreochromis niloticus*, *Pyrrhulina australis*, *Poecilia reticulata*, *Rivulus pictus*, *Satanoperca pappaterra*, and *Tilapia rendalli*).

## DISCUSSION

### *Environmental conditions*

Streams located in the northeastern region of São Paulo State are subject to two major classes of environmental impacts which could negatively affect fish biotic integrity. One of them is organic pollution derived from domestic sewage. Despite the fact that a high percentage (97%) of sampled streams demonstrated a water condition which was theoretically adequate for fish assemblages, at least three other streams in the basin (not selected in our analysis) received untreated sewage (IPT, 2000), and we believe that this number could be higher and this source of impact must be evaluated at the basin scale. Rapid population growth after 1970 intensified problems associated with urbanization. In 1970, the São José dos Dourados system had 194,000 inhabitants, and by 2010 it is expected to have 213,000, corresponding to 0.52% of the total population expected for São Paulo State (IPT, 2000). Despite its low population densities when compared to the rest of the State, only 12% of the municipalities in the basin had any kind of municipal planning (IPT, 2000). Continuous uncontrolled human growth rates combined with little attention paid to aquatic resources suggest a future decrease in the stream water quality within the basin.

The agency responsible for monitoring surface water chemical quality in São Paulo State traditionally uses a water quality index (WQI), developed by the National Sanitation Foundation, that employs nine parameters which are combined to classify water for human usage (Braga *et al*., 2002). Despite being 500 km long, in the São José dos Dourados river, the WQI is currently calculated for only one site in the main course of the river (Braga *et al*., 2002), which is clearly insufficient to assess water quality of the entire basin. Seasonal water quality changes were not tested in our study, but in two agricultural streams in a close region, the WQI showed better conditions in the winter than in the summer (Carvalho *et al*., 2000). The authors attributed these differences to the increased water temperature, turbidity, pH, and fecal bacteria load resulting from land degradation

**TABLE 4**
**Fish species collected in streams of the São José dos Dourados system, southeastern Brazil.**

| | | |
|---|---|---|
| Characiformes | Erythrinidae | *Hoplias malabaricus* (Bloch, 1794) |
| | Lebiasinidae | *Pyrrhulina australis* Eigenmann & Kennedy, 1903 |
| | Characidae | *Astyanax altiparanae* (Garutti & Britski, 2000) |
| | | *Astyanax fasciatus* (Cuvier, 1819) |
| | | *Astyanax* sp. |
| | | *Bryconamericus stramineus* Eigenmann, 1908 |
| | | *Hemigrammus marginatus* Ellis, 1911 |
| | | *Moenkhausia sanctaefilomenae* (Steindachner, 1907) |
| | | *Knodus moenkhausii* (Eigenmann & Kennedy, 1903) |
| | | *Oligosarcus pintoi* Campos, 1945 |
| | | *Piabina argentea* Reinhardt, 1866 |
| | | *Serrapinnus notomelas* (Eigenmann, 1915) |
| | | *Serrasalmus marginatus* Valenciennes, 1837 |
| | | *Planaltina britskii* Menezes, Weitzman & Burns, 2003 |
| | Acestrorhynchidae | *Acestrorhynchus lacustris* (Reinhardt, 1874) |
| | Crenuchidae | *Characidium zebra* Eigenmann, 1909 |
| | | *Characidium* aff. *lagossantense* Travassos, 1947 |
| | Curimatidae | *Cyphocharax modestus* (Fernández-Yépez, 1948) |
| | | *Cyphocharax vanderi* (Britski, 1980) |
| | | *Steindachnerina insculpta* (Fernández-Yépez, 1948) |
| | Anostomidae | *Leporinus friderici* (Bloch, 1794) |
| | | *Leporinus paranensis* Garavello & Britski, 1987 |
| | | *Leporinus striatus* Kner, 1859 |
| | Parodontidae | *Apareiodon piracicabae* (Eigenmann, 1907) |
| | | *Parodon nasus* Kner, 1859 |
| Siluriformes | Pseudopimelodidae | *Pseudopimelodus pulcher* (Boulenger, 1887) |
| | Heptapteridae | *Cetopsorhamdia iheringi* Schubart & Gomes, 1959 |
| | | *Imparfinis mirini* Haseman, 1911 |
| | | *Imparfinis schubarti* (Gomes, 1956) |
| | | *Pimelodella avanhandavae* Eigenmann, 1917 |
| | | *Rhamdia quelen* (Quoy & Gaimard, 1824) |
| | Callichthyidae | *Callichthys callichthys* (Linnaeus, 1758) |
| | | *Aspidoras fuscoguttatus* Nijssen & Isbrücker, 1756 |
| | | *Corydoras aeneus* (Gill, 1858) |
| | Loricariidae | *Hypostomus ancistroides* (Ihering, 1911) |
| | | *Hypostomus* sp. |
| Gymnotiformes | Sternopygidae | *Eigenmannia virescens* (Valenciennes, 1847) |
| | Gymnotidae | *Gymnotus carapo* Linnaeus, 1758 |
| | | *Gymnotus inaequilabiatus* (Valenciennes, 1842) |
| Cyprinodontiformes | Poeciliidae | *Pamphorichthys hollandi* (Henn, 1916) |
| | | *Poecilia reticulata* Peters, 1859 |
| | Rivulidae | *Rivulus pictus* Costa, 1989 |
| Synbranchiformes | Synbranchidae | *Synbranchus marmoratus* Bloch, 1795 |
| Perciformes | Cichlidae | *Oreochromis niloticus* (Linnaeus, 1758) |
| | | *Tilapia rendalli* (Boulenger, 1897) |
| | | *Cichlasoma paranaense* Kullander, 1983 |
| | | *Laetacara* sp. |
| | | *Crenicichla britskii* Kullander, 1982 |
| | | *Geophagus brasiliensis* (Quoy & Gaimard, 1824) |
| | | *Satanoperca pappaterra* (Heckel, 1840) |

and higher inputs of sediments and nutrient during the summer wet season.

Decline in the physical habitat conditions is the second class of impairment over fish assemblages within the studied basin. Physical habitat is one of the most important factors affecting the abundance and diversity of aquatic biota (Gorman & Karr, 1978; Kasyak, 2001), mainly because of influences

**TABLE 5**
**Location, stream order, richness (S), abundance (N), and biomass (BM, g) of the fish assemblages in 35 streams sampled in the São José dos Dourados system, southeastern Brazil.**

| Streams | Latitude | Longitude | Stream order | S | N | BM |
|---|---|---|---|---|---|---|
| 1 | 20° 49' 20.4" S | 49° 33' 47.0" W | 1 | 14 | 95 | 623.1 |
| 2 | 20° 46' 45.7" S | 49° 34' 52.2" W | 2 | 13 | 387 | 843.7 |
| 3 | 20° 42' 53.0" S | 49° 42' 36.0" W | 2 | 9 | 145 | 597.1 |
| 4 | 20° 36' 29.2" S | 49° 42' 41.9" W | 1 | 6 | 71 | 277.8 |
| 5 | 20° 43' 02.5" S | 49° 48' 41.5" W | 2 | 6 | 31 | 173.9 |
| 6 | 20° 41' 16.5" S | 49° 53' 05.7" W | 3 | 10 | 86 | 436.1 |
| 7 | 20° 37' 31.6" S | 49° 53' 33.4" W | 1 | 11 | 102 | 359.6 |
| 8 | 20° 36' 46.4" S | 49° 58' 05.7" W | 1 | 13 | 96 | 821.9 |
| 9 | 20° 32' 31.4" S | 49° 56' 07.1" W | 1 | 8 | 26 | 38.7 |
| 10 | 20° 40' 27.4" S | 50° 01' 15.9" W | 1 | 13 | 124 | 550.8 |
| 11 | 20° 37' 53.3" S | 50° 01' 17.4" W | 2 | 16 | 99 | 1,350.3 |
| 12 | 20° 38' 16.4" S | 50° 09' 09.9" W | 1 | 5 | 9 | 15.9 |
| 13 | 20° 35' 51.3" S | 50° 16' 54.2" W | 2 | 16 | 141 | 763.6 |
| 14 | 20° 28' 32.6" S | 49° 53' 13.1" W | 1 | 8 | 112 | 89.2 |
| 15 | 20° 27' 32.1" S | 50° 14' 33.3" W | 1 | 4 | 119 | 205.0 |
| 16 | 20° 26' 39.2" S | 50° 15' 47.8" W | 2 | 16 | 239 | 1,079.0 |
| 17 | 20° 19' 45.9" S | 50° 17' 03.9" W | 3 | 10 | 82 | 374.4 |
| 18 | 20° 18' 51.7" S | 50° 23' 04.8" W | 1 | 9 | 145 | 856.5 |
| 19 | 20° 22' 35.0" S | 50° 27' 03.3" W | 1 | 3 | 49 | 187.4 |
| 20 | 20° 27' 46.4" S | 50° 28' 20.6" W | 1 | 8 | 185 | 756.4 |
| 21 | 20° 31' 41.6" S | 50° 19' 15.0" W | 3 | 13 | 129 | 259.0 |
| 22 | 20° 36' 08.9" S | 50° 25' 20.0" W | 1 | 7 | 143 | 299.3 |
| 23 | 20° 37' 43.1" S | 50° 22' 17.8" W | 1 | 11 | 271 | 1,810.8 |
| 24 | 20° 36' 20.7" S | 50° 34' 05.0" W | 1 | 16 | 345 | 1,408.5 |
| 25 | 20° 35' 49.5" S | 50° 45' 29.2" W | 2 | 8 | 65 | 109.4 |
| 26 | 20° 31' 28.8" S | 51° 02' 56.4" W | 1 | 9 | 338 | 312.4 |
| 27 | 20° 22' 58.6" S | 50° 35' 08.6" W | 3 | 15 | 111 | 309.1 |
| 28 | 20° 25' 28.3" S | 50° 36' 10.5" W | 1 | 6 | 69 | 361.1 |
| 29 | 20° 27' 48.5" S | 50° 35' 06.1" W | 2 | 4 | 42 | 22.6 |
| 30 | 20° 18' 29.3" S | 50° 38' 28.6" W | 1 | 7 | 23 | 77.0 |
| 31 | 20° 20' 51.3" S | 50° 40' 42.6" W | 1 | 15 | 344 | 441.6 |
| 32 | 20° 23' 11.3" S | 50° 46' 54.3" W | 1 | 11 | 1313 | 570.8 |
| 33 | 20° 25' 53.7" S | 50° 48' 50.3" W | 1 | 7 | 129 | 146.7 |
| 34 | 20° 31' 08.1" S | 50° 55' 37.1" W | 2 | 21 | 1495 | 2,717.5 |
| 35 | 20° 09' 05.9" S | 50° 54' 46.5" W | 1 | 10 | 164 | 430.4 |

in the availability of sites for feeding, shelter, and reproduction. Ninety-four percent of the sites had poor or very poor physical habitats for supporting fish assemblages, which means substantial deviation from regional reference conditions and indicates high levels of degradation. Furthermore, we observed that many small first order streams listed in our 1970 map database are dry and completely silted.

The lowest PHI scores were obtained for metrics related to riparian vegetation. The replacement of the original forests by pasture in more than 77% of the region is critical and considers this area as the most degraded in

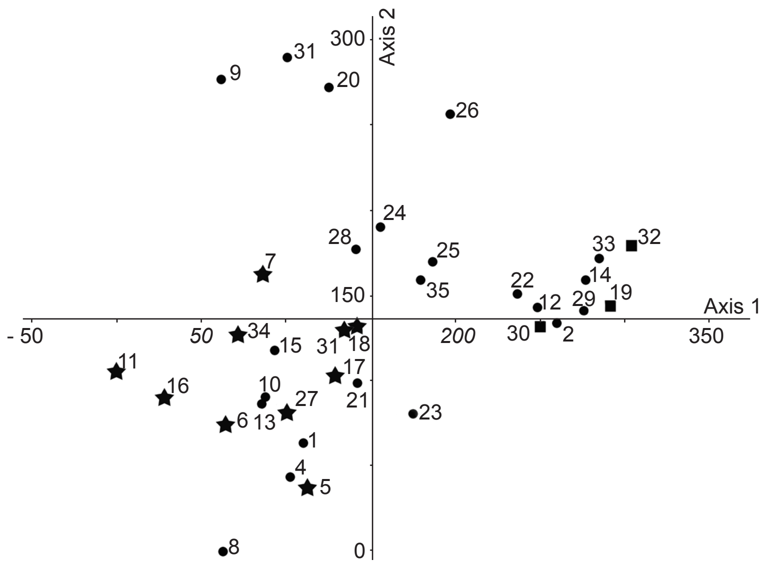


**Fig. 2 —** Ordination of 35 streams in the São José dos Dourados system (eigenvalues: axis 1 = 0.625, axis 2 = 0.375). Symbols represent Physical Habitat Index: square = very poor; circle = poor; and star = fair.

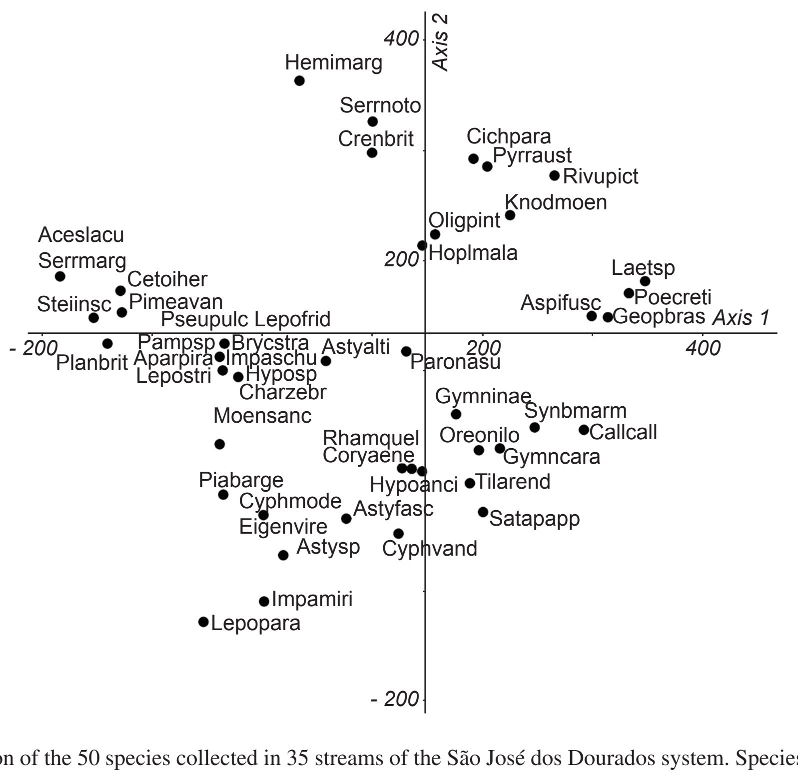


**Fig. 3 —** Ordination of the 50 species collected in 35 streams of the São José dos Dourados system. Species acronyms refers to the first four letters of the generic and specific names.

the State of São Paulo, since about 12% of the forested area has been logged during the last ten years (Zorzetto *et al.*, 2003). Deforestation of riparian buffers follows agriculturalization, often without environmental planning or conservation (Rodrigues & Gandolfi, 2000), increasing thermal and nutrient sediment inputs into water courses (Rabeni & Smale, 1995). Wichert & Rapport (1998), assessing agricultural watersheds, suggested that enhancement of stream habitat for fish may be achieved by rehabilitating the riparian vegetation. Nonetheless, rehabilitation of riparian areas must be prioritized and intensified in headwaters because the negative impacts of deforestation are more significant in these small water bodies (Gregory *et al*., 1991), extending along downstream sites (Dale Jones *et al*., 1999).

***Fish fauna***

We evaluated small streams ranging from the first to third order. The mean species number increased according to the stream order, reflecting the predictive power of this descriptor in richness (Matthews, 1998). Along a stream-order, gradient changes in habitat features may reflect species addition, species replacement or changing relative abundances (Gorman & Karr, 1978). In fact, streams belonging to similar orders have similar physical attributes influenced by peculiar combinations of current, discharge, depth, and substrate, which select for fish species adapted to local features (Matthews, 1998), but in some cases discharge can be a better predictor concerning richness, abundance, and biomass than order (Hughes & Omernik, 1983). In some cases there is not a unique descriptor that can satisfactorily predict richness because of the sinergistic combination among many of them. In site 34, a second order stretch, we found the highest richness, abundance, and biomass. This site presents high macrohabitat diversity, regular habitat integrity, absence of riparian vegetation, and also a relative amount of debris from aviculture. The two last features may sinergistically increase in situ primary production, and consequently the secondary production. However, this condition may be transitory because the absence of riparian vegetation facilitates sediment intake with further embeddedness of specific microhabitats, thereby further affecting fish assemblage integrity.

Fish abundance correlates with habitat, as indicated by results of the Mantel test. A similar association was also found by Wilkinson & Edds (2001) in temperate streams and was considered consistent with the hypothesis that community organization depends on environmental factors at the basin-wide scale. We have observed not only correlations between fish abundance and habitat, but also noted that some species have their optimal distribution coincident with the degree of habitat conservation (see Fig. 3) or specific impacts. The land is mainly used for pasture, which means low inputs of nutrients when compared to sewage, and probably also herbicides and pesticides pollution when compared to crops. Thus, the main threat for streams in the region is the physical habitat degradation, mostly substrate simplification and water column reduction, both consequences of the excessive sedimentation or siltation. In spite of being a natural process, siltation is difficult to document, but probably the process has been greatly increased in the studied region since the early last century, after the initial deforestation mainly for coffee plantation (Monbeig, 1998). Either in temperate regions and tropics, high sediment loading is considered the major problem affecting the quality of continental waters and aquatic biota (Lemly, 1982; Dudgeon, 2000).

As examples of fish species particularly associated with good physical habitat conditions, *Bryconamericus stramineus* and *Moenkhausia sanctaefilomenae* are considered good water column swimmers (Casatti & Castro, 1998; Casatti, 2002), depending on adequate habitat volume which decreases with severe siltation. *Characidium zebra*, *Hypostomus* sp., *Imparfinis schubarti*, and *Pseudopimelodus pulcher* have reophilic preferences (Castro & Casatti, 1997; personal observations) and must also be negatively affected with siltation due to the embeddedness of the rocky substrate. The toothless *Steindachnerina insculpta* probably requires special soft substrates to ileophagy (see Fugi *et al*., 1996 for feeding data) being also negatively affected with siltation.

Through substrate changes, siltation could benefit some species; specifically those adapted to sandy bottoms, as in the case of *Knodus moenkhausii*, a feeding generalist species (M. Ceneviva-Bastos, personal communication). Reduction of the water column caused by siltation negatively affects water oxygenation and only species with behavioral or physiological strategies can support these changes. In a very silted stream (site 32) *Poecilia reticulata* represented 62% of the fish abundance. This species is considered as having expressive phenotipic plasticity (Trexler, 1988), including swimming strategies for living in hypoxic waters (Kramer & Mehegan, 1981). *Laetacara* sp., *Satanoperca pappaterra*, *Cichlasoma paranaense*, and *Geophagus brasiliensis*, despite presenting distinct feeding tactics, all feed on soft bottoms (Sabino & Castro, 1990; Casatti *et al*., 2003; personal observations), largely available in silted streams. In addition, *Laetacara* sp. was often observed in hypoxic waters (about 1 mg/l). *Oreochromis niloticus* and *Tilapia rendalli* are species introduced in many aquatic systems worldwide, and the hypoxia tolerance for the first species was documented by Chapman *et al*. (1995). Native species like *Aspidoras fuscoguttatus*, *Callichthys callichthys*, *Pyrrhulina australis*, *Rivulus pictus*, and *Gymnotus carapo* were found in low oxygen waters (Araújo & Garutti, 2003; Mol, 1994; Shibatta & Bennemann, 2003; personal observations), a condition often found in shallow silted streams. Thus, ecology of these species and their responses to a range of human interference could reveal reliable metrics for the regional IBI.

The validity of assemblage structure descriptors in the evaluation of the biotic integrity has been discussed by some authors (Fausch *et al*., 1990). Despite showing indications of disturbance, such methods are strongly influenced by sample size (Fausch *et al*., 1990). The great challenge in stream biological monitoring is to find, define, measure, and test metrics which can integrate elements and biological processes at several organization levels and reflect the antropic influence on such communities (Karr, 1999). As we demonstrated in this study, routine ecological analysis and ordination techniques, together with natural history and biogeographical knowledge, can give meaningful signals when searching for good biological attributes.

Measurements of physicochemical or habitat conditions cannot replace biological assessments and do not capture all the ways humans influence water resources (Karr & Chu, 1999). Fish require more than only good chemical or physical conditions to thrive, and such restrict assessments are insufficient to evaluate biological integrity. Our survey is the first attempt to produce a method to assess stream habitat for the region and an alert to resource managers and society about the anthropogenic threats to surface water resources in the São José dos Dourados system. Based on our cursory analysis in this pasture dominated landscape, mitigation efforts should be centered on reversing the degradation in the physical quality of the streams, specifically those of the first order, minimizing physical habitat losses of aquatic biota by rehabilitating riparian vegetation, controlling siltation, and conserving soil. Specifically in the case of riparian zones restoration, this could be an important opportunity for improving connectivity between terrestrial habitats (Becker *et al*., 2004). In addition, effluents should be treated and land use controls must be developed for, at least, the most populous municipalities in the system. The next steps of this study will include tests on biological attributes in order to develop a fish biotic integrity index. Thus, we expect to obtain a more complete scenario regarding the multiple sources of threats to the streams in this region.

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**APPENDIX**

**Habitat assessment sheet (modified from Roth *et al.*, 1996; Barbour *et al.*, 1999; Kasyak, 2001). Descriptors 7 to 9 must be evaluated broader than sampling reach. HG, high gradient; LG, low gradient.**

| Descriptors | Good | Fair | Poor | Very Poor | Total |
|---|---|---|---|---|---|
| 1. Substrate stability | > 70% (50% for LG streams) of substrate favorable to colonization; mix of snags, submerged logs, or other stable habitat not temporary | 40-70% (30-50% for LG streams) of substrate favorable to colonization; presence of additional substrate in the form of newfall, but not prepared for colonization | 20-40% (10-30% for LG streams); substrate often removed or disturbed | < 20% (10 for LG streams) of stable substrate; obvious absence of habitats | - |
| 2. Velocity and depth variability | HG streams: slow-deep, slow-shallow, fast-deep, fast-shallow<br>LG streams: large-shallow, large-deep, small-shallow, small-deep in pools | HG: 3 of 4 patterns present<br>LG: majority of pools large-deep; very few shallow | HG: 2 of 4 patterns present<br>LG: shallow pools much more prevalent than deep pools | HG: dominated by one pattern (often slow-deep)<br>LG: majority of pools small-shallow, or pools absent | - |
| 3. Flow stability | water reaches base of both lower banks, and minimal amount of channel substrate is exposed | water fills 75% of the available channel | water fills 25-75% of the available channel; and/or riffle substrate is exposed | very little water in channel and mostly present as standing pools | - |
| 4. Bottom deposition | little or no enlargement of island or point bars and less than 5% (< 20% for LG streams) affected by sediment deposition | 5-30% (20-50% for LG streams) affected by sediment deposition; slight deposition in pools | 30-50% (50-80% for LG streams) affected by sediment deposition; sediment deposition at obstructions; moderate deposition in pools | > 50% (80% for LG streams) affected by sediment deposition; pools almost absent due to substantial deposition | - |
| 5. Combinations of pool-riffles-runs | HG: riffles, runs in lesser extent, and small marginal pools<br>LG: runs, pools, riffles in lesser extent, and small marginal pools | HG streams: runs more predominant than riffles, and small marginal pools<br>LG streams: runs, pools, and small marginal pools | HG and LG streams: runs and small marginal pools | HG and LG streams: only runs | - |
| 6. Channel alteration | channelization or dredging absent or minimal | some channelization present, usually in areas of bridges, includind signals of past dredging | extensive channelization; embankments or shoring structures; 40-80% of the stream reach channelized or disrupted | banks shored with cement; over 80% of the stream reach channelized or disrupted | - |
| Scale: | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 | - |
| 7. Streamside cover (see stream width) | up to 10 m: 30-20 m<br>10 to 50 m: 50-38 m | 21-14 m<br>37-26 m | 13-6 m<br>25-13 m | < 5 m<br>< 12 m | - |

**APPENDIX**

**Continued...**

| Descriptors | Good | Fair | Poor | Very Poor | Total |
|---|---|---|---|---|---|
| 8. Bank vegetative stability | > 90% of the streambank surfaces protected by native vegetation, including trees, shrubs, nonwoody macrophytes; almost all plant growing naturally | 70-90% of the streambank surfaces protected by native vegetation; but none class is well-represented; disruption evident but not affecting full plant growth potential | 50-70% of the streambank covered by vegetation; disruption obvious, patches of bare soil common | < 50% of the streambank surfaces covered by vegetation; disruption very high | - |
| 9. Bank stability | stable; 0-10% of evidence of erosion | moderately stable; 5-30% of bank in reach has areas of erosion | moderately unstable; 30-60% of bank in reach has areas of erosion; high erosional potential during floods | unstable; many eroded areas; 60-100% of bank has erosional scars | - |
| Right | 10 9 | 8 7 6 | 5 4 3 | 2 1 0 | |
| Left | 10 9 | 8 7 6 | 5 4 3 | 2 1 0 | |