Integrating three tools for the environmental assessment of the Pardo River, Brazil

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Abstract There is a growing need for strategic assessment of environmental conditions in river basins around the world. In spite of the considerable water resources, Brazil has been suffering from water quality decreased in recent years. Pardo River runs through Minas Gerais and São Paulo, two of the most economically important states in Brazil and is being currently promoted as a future drinking water source. This study aimed at integrating three different tools to conduct a hydromorphological assessment focused on the spatial complexity, connectivity and dynamism of the Pardo River, Brazil. Twelve sampling stretches were evaluated in four sampling campaigns, in dry and rainy seasons. In each stretch, Permanent Preservation Areas (PPA), hydromorphological integrity by Rapid Assessment Protocol (RAP) and physicochemical parameters were qualified. The Kappa coefficient was used to assess statistical agreement among monitoring tools. The PPA analysis showed that in all stretches the vegetation was modified. RAP results revealed environmental deterioration in stretches located near human activities, less variability of substrates available for aquatic fauna and sediment deposition as well. Low values for dissolved oxygen in the river mouth were noted in the rainy season. Electrical conductivity was higher in stretches near sugarcane crops. The poor agreement (k<0.35) between the RAP and physicochemical parameters indicates that the tools generate different and complementary information, while they are not replaceable. Potential changes of the hydromorphological characteristics and variations in physicochemical indicators must be related to extensive PPA modification.

Keywords Hydromorphology · Pardo River, Brazil · Anthropogenic Impacts · Environmental Assessment

1. Introduction

Because of the anthropogenic influences arising from intensive population growth, increased cultivated areas and industrial expansion, rivers are usually under permanent hydrological stress, being one of the most degraded ecosystems. That situation seems to be more difficult in developing countries where the level of water recycling and wastewater treatment is low, and the intensive use of available water resources can cause severe degradation of water quality (Alcamo et al. 2003). There is a growing need for strategic assessment of the environmental situation of river basins worldwide.

River management tools based on hydromorphological evaluation are used to generate information regarding river benthic communities (Urbanič 2014), habitat characteristics and the preservation status in the surroundings of rivers (Rodrigues et al. 2012). The hydromorphological analysis shows that the channel shape plays a fundamental role in the biodiversity and functioning of river ecosystems, according to the spatial complexity, connectivity and dynamism of the river (Elosegi and Sabater 2013).

The spatial complexity of a channel reflects that elements differ in width, depth, water velocity and sediment size. Therefore, microhabitat complexity may be also different. Connectivity reflects the different relationships between spatial factors that influence the river, expressed in longitudinal, lateral and vertical dimensions. Longitudinal connectivity controls the downstream flux of water and sediment along the river network. Hence, basic processes shape the channel form. Lateral connectivity explains the relationship between the channel and the margins, while vertical connectivity is related to channel complexity, since the variability of hydraulic pressure on the riverbed comes from the interaction of flow with riverbed forms, or slope discontinuities at reach-scale. Dynamism is an intrinsic characteristic of rivers, linked to channel complexity and connectivity (Elosegi et al. 2010).

The anthropogenic impact on river hydromorphology can be analyzed with visual tools as protocols filled by a researcher. There are several Rapid Assessment Protocols (RAPs) used in river monitoring, which are low cost methods consisting of an *in situ* evaluation of river morphological characteristics, covering indicators of spatial complexity, connectivity and dynamism (Rodrigues and Castro 2008). The study of Permanent Preservation Areas (PPA) may represent an interesting complementary tool to hydromorphological assessments, as PPAs are part of the environment around rivers, serving as a water body protection. The Brazilian Forest Code (BFC) (Government of Brazil 2012) determines that PPAs are areas with or without vegetation, intended to protect the environment and to sustain life in all its diversity. With PPA evaluation, it is possible to check the changes in the landscape due to natural and/or anthropogenic actions, seeking possible causes and effects of these morphological changes.

Anthropogenic impact on water bodies can result in changes in physicochemical characteristics of water. Physicochemical parameters such as temperature, pH, dissolved oxygen, turbidity and electric conductivity are used to analyze *in situ* the water quality of rivers (Fernandes et al. 2009). The relationship between changes in the river margins and physicochemical characteristics of water has been demonstrated in various studies (Walling 2006; Silva et al. 2010). Wang et al. (2012) found that agricultural lands worsened water quality and produced the highest nutrient concentrations when compared with forested lands in China. Hydromorphological studies that used together the evaluation of PPA indicators, Rapid Assessment Protocol (RAP) and analysis of physicochemical parameters have not been described yet. It is believed that a more integrated assessment of river characteristics will provide important information on impacted watersheds.

Despite the abundance of water resources, Brazil has been suffering from a decrease in water quality. Urbanization and intense activities of urban population as well as substantial expansion of agriculture areas and cattle are identified as the major causes of environmental problems in Brazil, including pollution of water resources (Tucci 2008; Lorz et al. 2012; Da Silva et al. 2013). The Pardo River is an important water body, which is being considered as a future water supply. It runs through São Paulo and Minas Gerais, two of the richest states of Brazil, with high population densities and potentially great impacts from anthropogenic actions.

The present study was aimed at integrating three tools to conduct a hydromorphological assessment focused on the spatial complexity, connectivity and dynamism of the Pardo River, through the following objectives: (a) to evaluate PPA indicators in accordance with the BFC standards; (b) to assess the spatial complexity, connectivity and dynamism with a Rapid Assessment Protocol (RAP); (c) to verify the physicochemical parameters of water (pH, Dissolved Oxygen, Turbidity, Electrical Conductivity, Temperature); and (d) to verify the agreement between RAP results and physicochemical results.

Several studies have been conducted around the world in order to assess external factors to the rivers that act as protectors against runoff water that carries sediments and contaminants, with main focus on riparian forests (Nigel et al. 2014; Sweeney and Newbold 2014; Hansen et al. 2015). However, the differential of the present study is the integration of three tools in order to make a more completed assessment of the river's hydromorphological conditions, which can be used in various water bodies.

2. Materials and Methods

2.1 Study area and data collection

The Pardo River's headwaters are on the south plateau of Minas Gerais, Brazil. It is the largest tributary in the left margin of the Grande River, where it arrives after a course of about 550 km. It has a drainage basin of 10,694 km^2, covering more than one million inhabitants (CBH PARDO 2013). Between 2011 and 2012, four sampling campaigns were performed, two in the dry seasons (June/2011 and August/2011) and two in the rainy seasons (March/2011 and January/2012). In the southeast region of Brazil, the dry season occurs between June and September, and the rainy season between October and April. In each campaign, duplicate water samples were collected in the 12 sampling points along the Pardo River (Fig. 1) with the same number of samples for each location. The coordinates of the sampling stretches were obtained by GPS (Global Positioning System), being these points sequentially numbered along the river. The first stretch began at the source (Ipuiúna city, Minas Gerais, Brazil), while the last point (#12) was the confluence with the Grande River (Colombia city, São Paulo, Brazil).

2.2 Permanent Protection Area (PPA)

Measurements of PPA were performed by satellite, with images from Google Earth. PPA data were analyzed based on the limits set by the Brazilian legislation (Government of Brazil 2012), which establishes the size of the preservation areas around the rivers. The recommendation for river sources is to preserve at least 50 m in radius. In turn, for rivers less than 10 m wide, the PPA should be at least 30 m, and for those with 10 to 50 m wide the PPA should be at least 50 m. For rivers with 50 to 200 m wide, the PPA should be at least 100 m, and for rivers with 200 to 600 m wide, the PPA should be at least 200 m. Finally, for rivers exceeding 600 m wide, the PPA should be at least 500 m (Government of Brazil 2012).

2.3 Hydromorphological integrity

The Rapid Assessment Protocol is shown in Table 1. This protocol was adapted and applied to Brazilian river stretches by Rodrigues and Castro (2008). The parameters *Substrates and/or habitats available*, *Speed/depth regimes* and *Sediment deposition* characterize the spatial complexity of the evaluated stretch. *Channel flow* *status*, *Channel alteration* and *Channel sinuosity* parameters are related to connectivity in the evaluated environment. Finally, the parameters *Margin stability*, *Protection of the margins by vegetation* and *Nearby vegetation status of protection* are related to the dynamism observed in the sampling stretch. A score between 0 and 20 is attributed to each parameter, which corresponds to the environmental integrity. Scores increase proportionally to environmental integrity and can vary according to the observation site (Rodrigues and Castro 2008). The original protocol was adapted, being completed with a tenth descriptor parameter: *Floating solid materials.*

2.4 Physicochemical assessment

Physicochemical parameters were analyzed *in situ*. Data were evaluated according to the season. Water pH, temperature, dissolved oxygen (DO), electrical conductivity and turbidity were measured with a Phtek (model pH-100), a Minipa digital thermometer (model MV-365), an LT Lutron oximeter (model DO 5510), an LT Lutron conductivimeter (model CD 4303), and a Hanna Instruments turbidimeter (model HI 93703), respectively.

2.5 Data analysis

The Mann–Whitney U-test was performed by means of Graph Pad Prism (version 3.02 for Windows, Graph Pad Software, San Diego, CA, USA) to verify the seasonal influence on physicochemical parameters. The standards established by Resolution n° 357 (CONAMA 2005), which addresses the classification of water bodies and related environmental guidelines, were adopted in order to verify the water quality according to physicochemical parameters.

Kappa test, using Stata software (version 10.2), was performed to verify the agreement between RAP results and physicochemical parameters (Viera and Garrett 2005).

3. Results

The Pardo River suffers from anthropogenic influences arising from the large population living in the surrounding area, as well as the increase of cultivated areas, especially sugarcane. The results for the characterization of the PPA, the hydromorphological assessment and the evaluation of the Pardo River water quality are presented below.

3.1 Permanent Protection Area (PPA) characterization

The PPA characteristics along the Pardo River in the years 2011 and 2012 are summarized in Table 2. The Pardo River begins approximately 1.5 m wide, while it reaches a width of 400 m when joining the Grande River at its mouth. The river goes through a large area with several cities and agricultural zones. The width of the PPA is directly related to the width of the river, according to the Brazilian legislation (Government of Brazil 2012). Satellite images showing the 12 sampling stretches and its margins in the Pardo River, Brazil, are shown in Fig. 2. Excepting the 4^{th} and 5^{th} stretches, none of the evaluated stretches has preserved the PPA width in accordance with the law standards (Government of Brazil 2012).

The stretch showing most changes in the PPA integrity was #12, with sugarcane fields on both sides of the river and no native vegetation for margin protection. The predominant vegetation of stretches #3 and #10, as well as the left margin of stretch #5, was sugarcane crops, showing also small areas with native vegetation. However, these three stretches were not in accordance with the legal standards for PPA. For instance, the PPA of stretch #3 should be 100 m, while is width was 70 m. The PPA integrity of the left margin of stretch #4, as well as stretches #6 and #11, was modified by the presence of urban areas. In stretch #4, the river was approximately 50 m wide, and in stretch #6, the river width was approximately 110 m, while their PPA should be, at least, 100 m wide. In stretch #11, the river width was approximately 100 m, although the PPA should be at least 200 m wide. Stretch #7 is located near the city of Ribeirão Preto, the largest municipality in the Pardo River basin, with about 649,500 inhabitants (IBGE 2014). At the margins of stretch #7, the PPAs were replaced by a recreation club, where the practice of navigation, fishing and other recreational activities is quite common. The BFC standard for rivers with a width of about 150 m is, at least, a 100 m-PPA.

3.2 Hydromorphological integrity of the Pardo River

The hydromorphological integrity of the Pardo River using a RAP at each one of the 12 stretches is depicted in Fig. 3. A seasonal study by comparing data from the wet and dry campaigns was conducted. Differences in integrity for each stretch and sampling date were observed. The stretch with the lowest scores in the integrity assessment was stretch #11, while the stretch with the highest scores was #1. Observing all the evaluated stretches, we noted that the parameter with the lowest scores was *Nearby vegetation status of protection*. The highest scores were observed for the parameter *Channel flow status*.

The results of the RAP parameter *Substrates and/or habitats available* showed that for stretches #2 and #11, between 20 and 30% of each stretch contained substrates favorable to benthic fauna colonization. Most stretches received the best scores for this parameter in dry season sampling. *Speed/depth regimes* parameter indicates that the stretches #1 and #2 had only two types of regimes: fast/deep and slow/shallow.

Sediment deposition parameter indicates that in some stretches the natural river course was currently affected by the sediment deposition. These situations were observed in locations with human activities, as stretches #2 and #3, situated near urban areas, and in stretches #8, #9, #10, #11 and #12 (sugarcane agriculture, residential area and industry). The *Channel alteration* parameter indicated a low score for stretch #7, where margins have been modified to establish a private recreation area, as well as with stretches #2, #3, #8 and #10.

Protection of the margins by vegetation parameter indicates that stretches #2, #7, #8 and #12 were the most impacted sites, showing three predominant situations, such as soil sealing (#7), absence of vegetation (#2 and #8) and agriculture (#12). *Nearby vegetation status of protection* parameter indicates that the low scores were assigned to stretches #2, #7, #8, #11 and #12. Finally, *Floating solid materials* parameter indicates that materials such as plastic, metal, paper or glass on the margins, or on the own river were observed at stretch #7, near a private recreation area.

3.3 Water quality of the Pardo River according to physicochemical parameters

The median of the physicochemical results, depending on the season, are shown in Table 3. Stretch #1 (rainy and dry season), and stretches #2, #3 and #6 (rainy season) showed pH values lower than those recommended by the Brazilian legislation (CONAMA 2005). By comparing the temperature values according to the season, a statistically significant difference (p<0.05) was found. Furthermore, higher temperatures were recorded in stretch #12 during the rainy season. A significant variation was observed in dissolved oxygen levels between seasons, being lower in the rainy season (p<0.05). It is relevant to note that the lower dissolved oxygen concentrations was verified in stretch #12, in both the rainy and dry seasons.

Higher oxygen-dissolved values were found during the rainy season in stretches #1, #4 and #5 (Table 3), being coincident with larger zones of preserved riparian vegetation (Fig. 3). The electrical conductivity was greater in the stretches #8, #9, #10, #11 and #12. Seasonal sampling had no effect on river water electrical conductivity in any of the evaluated stretches ($p>0.05$). The turbidity was significantly higher in the rainy season than in the dry campaigns ($p<0.05$), with the lowest value in stretch #1, corresponding to the source of the Pardo River.

3.4 Kappa Test

The comparison between tools (RAP and physicochemical parameters assessment) by Kappa coefficient showed poor statistical agreement between the variables ($k<0.35$).

4. Discussion

4.1 PPA conditions

As it can be seen in Table 2 and Fig. 2, all stretches showed modified PPA. Although stretch #1 (river source) contained the most preserved riparian vegetation, it was not yet in accordance with the limits set by the Brazilian legislation (Government of Brazil 2012). In order to preserve water resources, it is established to preserve a radius of 50 m in river sources. In stretch #3, in the left margin of stretch #5, and in stretches #10 and #12, the integrity of the PPA was modified because the forest was replaced by sugarcane crops (Fig. 2). Deforestation results in removal of natural barriers that may contain sediment transport. Furthermore, sugarcane field requires the application of herbicides, pesticides and fertilizers during different cultivation stages, therefore resulting in water river impacts through the leaching process (Corbi et al. 2006).

Livestock on the river margins in stretches #2, #8 and #9 can block the growth of sprouts native to the forest (Fagundes and Gastal Junior 2008). Additionally, the flow of animal waste into the riverbed may enhance the concentration of organic matter and can transmit waterborne diseases (Seganfredo et al. 2003).

Urban areas on the left margin of stretch #4, and on stretches #6 and #11, are related to population growth and human settlement in areas of flood-plains. Occupation and modification of river margins is one of the main sources of impact, associated with an increased impervious surface area and water temperatures, as well as reduction in channel and habitat structure (Allan 2004).

A recreation club at stretch #7 might potentially impact the local ecosystem. The artificial cover of river margins may eliminate the input of terrestrial insects into the river, impacting fish and macroinvertebrate populations, which are a part of the subsistence of terrestrial predators (Elosegi et al. 2010).

4.2 Hydromorphological assessment

The hydromorphological complexity of the channel reflects differences in velocity, depth, sediments and habitat composition (Elosegi et al. 2010). The results suggest that there was a variation of the integrity of every parameter in each one of the studied stretches. Due to river extension (550 km), this diversity scenario along the Pardo River could be expected. However, the individual evaluation of each RAP parameter is important, since it allows visualizing the factors that alter the habitat's integrity and might help the local authorities to make decisions for a better preservation and restoration of the riparian environment.

The parameters showing the greatest sensitivity were *Substrates and/or habitats available*, *Sediment deposition*, *Channel alteration*, *Protection of the margins by vegetation*, *Nearby vegetation status of protection parameter* and *Floating solid materials*. The results found for the parameter *Substrates and/or habitats available* in stretch #2 (Fig. 3) may be related to the changes in the river affected by channeling for bridge construction and removal of the surrounding vegetation for grazing area. It can reduce the amount of woody debris that falls into the river, functioning as a favorable habitat colonization of aquatic fauna. In stretch #11, the low scores may be related to residences on the river margins and the sugar and alcohol industries. The land use for urban occupation and industry near rivers strongly influences ecosystems (Maloney and Weller 2011). It may have increased sediment transport from the margins to the river. Physical complexity in ecosystem functioning is important, being the high diversity of substrate sized clearly linked to biodiversity, as they constitute different functional habitats (Adeyemo 2008).

It is well known that sediment deposition and decreased river depth are determinants of benthic community structure, being this factor more significant than water variables (Lisboa et al. 2011). In the present study, the hydromorphological assessment was shown to be highly dependent on the presence of a riparian area, and the dense margin vegetation of the riparian zone prevented excess sediment deposition due to margin erosion (Tran et al. 2010). The low scores for the parameter *Sediment deposition* observed in stretches #2, #3, #8, #9, #10, #11 and #12 (Fig. 3), was related to the formation of islands in the water body, which may affect the euphotic zone depths, resulting in a decrease in the diversity of benthic communities (Henry 2009; Lisboa et al. 2011).

Aquatic organisms are sensitive to river channel alterations, which often may reduce drainage area and the density and diversity of animal species (Rodrigues et al. 2010). Therefore, it is not surprising that the current lowest scores for the parameter *Channel alteration* came from sites located near urban areas (stretches #2, #3,

#7, #8 and #10). Impervious surfaces in urban areas result in altered channel morphology, stability and elevated nutrient and contaminant concentrations (Maloney and Weller 2011).

It is known that the vegetation cover contributes to reduce lateral sediment influx into water bodies, mainly during rainy periods (Henry 2009). In the present investigation, lowest scores for the *Protection of the margins by vegetation* parameter (Fig. 3) were obtained. These were related to human activities developed on the river margins, where the native vegetation has been removed. In stretches #2 and #8, pasture area was observed; in stretch #7, there was a recreation area, while in stretch #12 there were sugarcane crops. The removal of river vegetation is associated with an increase of the organic load in the river water and increased occurrences of *Enterococcus* spp., notably in locations near pastures (Ragosta et al. 2010).

The study of habitat assessment and riparian bird diversity indicated that the width of the riparian vegetation was more important than the height. Moreover, there was a correlation of bird species richness and diversity of tree species in riparian vegetation (Cooke and Zack 2009). Low scores for the *Nearby vegetation status of protection* parameter in stretches #2, #7, #8, #11 and #12 (Fig. 3) were related to exotic vegetation, such as grasses and bamboo, as well as human activities, like urbanization, pastures and sugarcane crops replacing native vegetation. The riparian vegetation is considered to filter river margins, retaining sediment, organic matter, and also increasing water storage along the river by evaporation decreasing. Thus, its absence can reduce the flow, especially in the dry season (Rodrigues et al. 2010; Fu and Burgher 2015).

Management of municipal solid waste is relevant to environmental health and requires government organization, planning, citizen participation, collection, transportation, storage and disposal (Ulnikovic et al. 2013). In the current study, there were different types of *Floating solid materials* in stretch #7 (Fig. 3), such as plastic bottles, bags and cans, all improperly disposed at the river. In this stretch, there is a recreation area on the river margin, very frequented by Ribeirão Preto citizens, and also activities such as small vessel navigation were observed. The National Solid Waste Policy (NSWP) defines appropriate disposal, reuse, recycling, recovery, energy recovery, and final disposal of waste to avoid damage or risk to public health and to minimize adverse environmental impacts (Government of Brazil 2010). Consequently, the disposal of solid waste in riverbeds can cause damage to human health, including the proliferation of the vector that causes diseases, such as yellow fever and dengue.

The hydromorphological assessment of the Pardo River showed an environmental deterioration in stretches located near urban areas (e.g., stretches #2, #3 and #7). A score improvement at downstream stretches was observed, showing potential recovery and possible river depuration concomitant with urban areas detachment. A number of studies have conducted habitat assessments using visual tools like RAP (Flotemersch et al. 2006; Rodrigues and Castro 2008; Rodrigues et al. 2010; Tran et al. 2010; Ulnikovic et al. 2013). Most of these studies have taken into account the whole list of parameters over a total score of 200. In contrast, individual results of each parameter were here used making possible the identification of critical parameters in each stretch. For aquatic habitat preservation, the restoration of riparian vegetation along the Pardo River should be performed to reduce sediment transport from soil to river, as well as to preserve river substrates and to maintain habitats for wildlife, including birds and mammals.

4.3 Water quality of the Pardo River

In contrast to our expectations, low pH values were found in stretch #1, at the source of the Pardo River (Table 3). Despite of the fact that stretch #1 has visibly preserved vegetation and organic contamination sources are not present, organic matter is likely to be carried from soil to water. Furthermore, the decomposition of organic matter from fallen leaves and twigs could have produced humic substances that reduce water pH (Gorayeb et al. 2010). The pH results of stretch #2 in the rainy season were attributed to the grazing area situated on the river margin. When it rains, animal waste, which contains a range of pollutants and nutrients (e.g., nitrogen and phosphorous) in excess, is likely to be transported to the river. Nitrogen can also degrade ecosystems by making water more acidic (Carpenter et al. 1998; Khan et al. 2014). Low pH values in stretch #3 were due to the proximity to the sugarcane crop and the inputs applied to the crop can be leached into the river, especially on rainy days. The pH results of stretch #6 may be related to the residences situated nearby the river, since the release of domestic sewage can reduce the pH of freshwater.

Freshwater degradation may imperil diversity of fish species, facilitating the appearance of invader species (Oyugi et al. 2014). Higher temperatures recorded in stretch #12 may be related to low vegetation protection verified with RAP (Fig. 3). Native vegetation on the river margins in this stretch was completely replaced by sugarcane plantations. A number of studies have demonstrated a strong association between destruction of riparian habitat, increased stream temperatures and reduction of shading, which can impact river biodiversity (Blevins et al. 2013). The difference between seasonal temperature values (Table 3) can be explained by the increase of mean temperature during the rainy season, about 23.6°C, compared with the environmental temperature during the dry season, about 19.5°C (CIIAGRO 2012). In general, Brazil does not present extreme seasonal variations due to the tropical climate of the country. Similar temperature variations were described in Espírito Santo state, Brazil (Souza and Fernandes 2009).

The DO concentrations in river water are usually high. They vary along the water body due to changes in the watercourse's characteristics, as a result of environmental and weather conditions (Rixen et al. 2010). In this study, the low results of DO concentrations in the rainy season (Table 3) may be related to the increased concentration of organic matter in the water, because the high rainfall can leach organic matter from the margins into the river. This occurs mainly in places where riparian vegetation has been removed, or when agricultural crops constitute the margins (Silva et al. 2010), such as in stretch #12. According to Resolution n° 357 (CONAMA 2005), DO concentrations should not be less than 5 $mg \cdot L^{-1}$, mainly because oxygen is an essential element in the metabolism of aquatic aerobic organisms. We found that there was a decrease in DO concentrations when water temperatures were higher, which may be related to the decrease in gas solubility at higher temperatures (Souza and Fernandes 2009).

It was expected that there would be an increase in river water electrical conductivity in locations near agricultural and pasture areas (Brion et al. 2011). We found the greatest values of electrical conductivity were found in stretches #8, #9, #10, #11 and #12, all of them located near sugarcane crops. Seasonal sampling had no effect on electrical conductivity for any of the evaluated stretches.

The high values of water turbidity in the rainy season (Table 3) may be explained by the increase of suspended solids in water. Intense rains and high river turbulence can result in suspension and transport of sediments, increasing turbidity during the rainy season (Poma et al. 2012). During seasons of high flow and high turbidity in rivers containing fine sediments, it is possible that autochthonous production is limited (Roach et al. 2014). According to CIIAGRO (2012), the value of mean precipitation during the rainy season in the year 2011 was 472.3 mm, while in the dry season of the same year, it was 36.6 mm. A low result for turbidity was found in stretch #1, the river source, possibly due to the preserved vegetation in this stretch (Fig. 3). Riparian vegetation may have contributed to reduce the lateral sediment influx to the water bodies, which is noted mainly during the rainy period (Henry 2009). Moreover, because it is the source of the Pardo River, this stretch does not receive discharge of other rivers, which minimizes possible influences on water turbidity.

4.4 Agreement between habitat assessment and water quality data

Defining links between hydromorphological assessment and physicochemical water quality can improve our ability to predict how riparian changes can impact river communities, which is relevant for management activities (Blevins et al. 2013). The Kappa test showed no significant agreement between RAP and physicochemical parameters, which means that both tools generate different and complementary information, but each tool cannot be replaced by another. In contrast to our findings, a recent study from New York State (USA) found significant relationships between land-use types and water quality, using tools such as RAP (Tran et al. 2010). However, several studies confirm that assessment protocols are important complementary tools for environmental assessments and contribute to river water quality monitoring (Falcone et al. 2010; Rodrigues et al. 2010; Flotemersch et al. 2011).

5. Conclusion

When performing a hydromorphological assessment using the RAP, the parameters with more changes were *Substrates and/or habitats available*, *Sediment deposition*, *Channel alterations*, *Margins stability*, *Protection of the margins by vegetation* and *Nearby vegetation status of protection*. This may be related to changes in the PPA. The Pardo River presents several areas with inadequate occupation of the PPA. The changes in the hydromorphological characteristics, low values for dissolved oxygen, and the higher values of electrical conductivity may be related to the extensive modification of the PPA. According to this, the current reformulation of the Brazilian Forest Code (Government of Brazil 2012) should be integrated with the National Water Policy (Government of Brazil 1997). Otherwise, the environmental conditions of large rivers basins, such as the Pardo River, could be easily and quickly degraded.

The hydromorphological integrity assessment in the rivers of northeastern of São Paulo state and information regarding PPA are still limited. The integration of three different tools allowed conducting a more integrated assessment of the river hydromorphological conditions. Furthermore, the use of low-cost, easily applicable tools for river assessment are interesting in low-income countries in order to generate current information on environmental integrity. These visual tools, such as RAP, enabled the hydromorphological assessment of rivers. It was here demonstrated that hydromorphological assessment with RAP may indicate areas that require intervention for environmental recovery, preservation of biodiversity and water resources. An intensification of fresh water quality studies, mainly focused on the chemical status (e.g., content of pesticides, metals and microbiological agents) is necessary to evaluate water quality in more detail.

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7. Ethical statement and conflict of interest

This article does not contain any studies with human participants or animals performed by any of the authors. The authors declare no conflict of interest.

8. References

Adeyemo, O. K. (2008). Habitat assessment for seasonal variation of river pollution in Ibadan, Nigeria, in a geographic information systems interface. Veterinaria Italiana 44, 361-371.

Alcamo, J., P., Döll, T., Henrichs, F., Kaspar, B., Lehner, T., Rösch & S., Siebert (2003). Global estimates of water withdrawals and availability under current and future “business-as-usual” conditions. Hydrological Sciences Journal 48, 339-348.

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology and Systematics 35, 84-257.

Alves, R. I. S., C. F., Sampaio, M., Nadal, M., Schuhmacher, J. L., Domingo & S. I., Segura-Muñoz (2014). Metal concentrations in surface water and sediments from Pardo River, Brazil: Human health risks. Environmental Research 133, 55-149.

Blevins, Z. W., E. L., Effert, D. H., Wahlb & C. D., Suskia (2013). Land use drives the physiological properties of a stream fish. Ecological Indicators 224–235.

Brion, G., K. R., Brye, B. E., Haggard, C., West & J.V., Brahana (2011). Land-use effects on water quality of a first-order stream in the Ozark Highlands, mid-southern United States. River research and applications 27, 772–790.

Carpenter, S. R., N. F., Caraco, D. L., Correl, R. W., Howarth, A. N., Sharpley & V. H., Smith (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8, 559–568.

Integrated Center for Agrometeorological Information (CIIAGRO) (2012). Ciiagro Online. Database: http://www.ciiagro.sp.gov.br/ciiagroonline.

Comitê de Bacias Hidrográficas do Rio Pardo (CBH-Pardo) (2013). Relatório de situação dos recursos hídricos da bacia hidrográfica 2013 (ano base 2012)/Comitê da Bacia Hidrográfica do Pardo; Grupo de Trabalho Permanente do Relatório Anual de Situação dos Recursos Hídricos e Plano de Bacia/UGRHI-4 Pardo - Ribeirão Preto 67.

Conselho Nacional do Meio Ambiente (CONAMA) (2005). Resolução nº 357, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providencias. Diário Oficial da União, Brasília.

Cooke, H. A. & S., Zack (2009). Use of standardized visual assessments of riparian and stream condition to manage riparian bird habitat in Eastern Oregon. Environmental Management 44, 173-184.

Corbi, J. J., S. T., Strixino, A., Santos & M., Del Grande (2006). Diagnóstico ambiental de metais e organoclorados em córregos adjacentes a áreas de cultivo de cana-de-açúcar (Estado de São Paulo, Brasil). Química Nova 29, 61-65.

Da Silva, A. R. I., C. O., Oliveira, T. K. A., Abreu, F. C., Julião, T. M. B., Trevilato & S. I., Segura-Muñoz, (2013). Water quality of the Ribeirão Preto Stream, a watercourse under anthropogenic influence in the southeast of Brazil. Environmental Monitoring Assessment 185, 61-1151.

Elosegi, A., J., Díez & M., Mutz (2010). Effects of hydromorphological integrity on biodiversity and functioning of river ecosystems. Hydrobiologia 657, 199–215.

Elosegi, A. & S., Sabater (2013). Effects of hydromorphological impacts on river ecosystem functioning: a review and suggestions for assessing ecological impacts. Hydrobiologia 712, 129–143.

Fagundes, N. A. & C. V. S. Gastal Júnior (2008). Diagnóstico ambiental e delimitação de Áreas de Preservação Permanente em um assentamento rural. Acta Scientiarum, Biological Sciences 30, 29-38.

Falcone, J. A., D. M., Carlisle & L. C., Weber (2010). Quantifying human disturbance in watersheds: Variable selection and performance of a GIS-based disturbance index for predicting the biological condition of perennial streams. Ecological Indicators 10, 264–273.

Fernandes, J. G., M. B. G. S., Freire, J. C., Cunha, J. D., Galvíncio, M. M., Correia & P. R., Santos (2009). Quality of the water for irrigation in the Irrigated Perimeter Cachoeira II in the municipality of Serra Talhada/PE. Revista Brasileira de Ciências Agrárias 4, 27-34.

Flotemersch, J. E., J. B., Stribling, R. M., Hughes, L. Reynolds, M. J., Paul & C., Wolter (2011). Site length for biological assessment of boatable rivers. River Research and Applications 27, 520–535.

Flotemersch, J. E., J. B., Stribling, M. J., Paul (2006). Concepts and approaches for the bioassessment of non-wadeable streams and rivers. US Environmental Protection Agency, Office of Research and Development.

Fu, B. & I. Burgher (2015). Riparian vegetation NDVI dynamics and its relationship with climate, surface water and groundwater. Journal of Arid Environments 113, 59-68.

Government of Brazil (1997). National Water Policy, Lei n° 9.433, de 8 de janeiro de 1997. Diário Oficial da União, Brasília.

Government of Brazil (2010). National Solid Waste Policy, Lei nº 12.305, de 2 de Agosto de 2010. Diário Oficial da União, Brasília.

Government of Brazil (2012). Brazilian Forest Code, Lei nº 12.651, de 25 de maio de 2012. Diário Oficial da União, Brasília.

Gorayeb, A. M. A., Lombardo & L. C. C., Pereira (2010). Qualidade da água e abastecimento na Amazônia: o exemplo da Bacia Hidrográfica do Rio Caeté. Mercator 9, 135-157.

Hansen, B. D., P., Reich, R., T. R., Cavagnaro & P. S. Lake (2015). Challenges in applying scientific evidence to width recommendations for riparian management in agricultural Australia. Ecological Management & Restoration 16, 50-57.

Henry, R. (2009). Annual changes in sediment entrapment efficiency in lakes lateral to a river (Paranapanema River, São Paulo, Brazil). Acta Limnologica Brasiliensia 21, 25-34.

Instituto Brasileiro de Geografia e Estatística (IBGE) (2014). Cidades. Ribeirão Preto, São Paulo. Database: http://cidades.ibge.gov.br/xtras/perfil.php?codmun=354340.

Khan, F. A., F., Naushin, F., Rehman, A., Masoodi, M., Irfan, F., Hashmi & A. A., Ansari (2014). Eutrophication: Global Scenario and Local Threat to Dynamics of Aquatic Ecosystems, Eutrophication: Causes, Consequences and Control. Springer 2, 17-27.

Lisboa, L. K., A. L. L., Silva & M. M., Petrucio (2011). Aquatic invertebrate's distribution in a freshwater coastal lagoon of southern Brazil in relation to water and sediment characteristics. Acta Limnologica Brasiliensia 23, 119-127.

Lorz, C. G., Abbt-Braun, F., Bakker, P., Borges, H., Bornick, L., Fortes, F. H., et al. (2012). Challenges of an integrated water resource management for the Distrito Federal, Western Central Brazil: climate, land-use and water resources. Environmental Earth Sciences 65, 1575-1586.

Maloney, K. O. & D. E. Weller (2011). Anthropogenic disturbance and streams: land use and land-use change affect stream ecosystems via multiple pathways. Freshwater Biology 56, 611–626.

Nigel, R., K., Chokmani, J., Novoa, A. N. Rousseau & A. E. Alem (2014). An extended riparian buffer strip concept for soil conservation and stream protection in an agricultural riverine area of the La Chevrotière River watershed, Québec, Canada, using remote sensing and GIS techniques. Canadian Water Resources Journal 39, 285-301.

Oyugi, D. O., K. M., Mavuti, P. A., Aloo, J. E., Ojuok & J. R. Britton (2014). Fish habitat suitability and community structure in the equatorial Lake Naivasha, Kenya. Hydrobiologia 727, 51–63.

Poma, H. R., D. G., Cacciabue, B., Garcé, E. E., Gonzo & V. B. Rajal (2012). Towards a rational strategy for monitoring of microbiological quality of ambient waters. Science of the Total Environment 433, 98-109.

Ragosta, G., C., Evensen,, E. R., Atwill, M., Walker, T., Ticktin, A., Asquith & K. Tate (2010). Causal connections between water quality and land use in a rural tropical island watershed. Ecohealth 7, 105-113.

Rixen, T., A., Baum, H., Sepryani, T., Pohlmann, C., Jose & J. Samiaji (2010). Dissolved oxygen and its response to eutrophication in a tropical black water river. Journal of Environmental Management 91, 1730–1737.

Roach, K. A., K. O., Winemiller & S. E., Davis (2014). Autochthonous production in shallow littoral zones of five floodplain rivers: effects of flow, turbidity and nutrients. Freshwater Biology 59, 1278–1293.

Rodrigues, A. S. L. & P. T. A., Castro (2008). Adaptation of a rapid assessment protocol for rivers on rocky meadows. Acta Limnologica Brasiliensia 20, 291-303.

Rodrigues, A. S. L., G., Malafaia & P. T. A., Castro (2010). A importância da avaliação do habitat no monitoramento da qualidade dos Recursos Hídricos: uma revisão. SaBios-Revista de Saúde e Biologia 5, 26-42.

Rodrigues, A. S. L., G., Malafaia, A. T., Costa & H. A., Nalini-Junior (2012). Adaptation and applicability assessment of a Rapid Assessment Protocol for the Gualaxo do Norte river basin, East-Southeast of the Quadrilátero Ferrífero, MG, Brazil. Ambi-Agua 7, 231-244.

Seganfredo, M. A., I. J., Soares & C. S., Klein (2003). Qualidade da água de rios numa região de pecuária intensiva de SC. Concórdia, Embrapa. Comunicado Técnico: 4.

Sweeney, B. W. & J. D. Newbold (2014). Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review. Journal of the American Water Resources Association 50, 560-584.

Silva, M. S. G. M., J. F., Queiroz, R. Cesnik, J. M. G., Ferraz & J. F., Moraes (2010). Assessment of Oriçanga and Itupeva rivers water quality at the Pardo-Mogi watershed (São Paulo State, Brazil). Acta Limnologica Brasiliensia 22, 335-343.

Souza, B. D. & V. O. Fernandes (2009). Estrutura e dinâmica da comunidade fitoplanctônica e sua relação com as variáveis ambientais na lagoa Mãe-Bá, Estado do Espírito Santo, Brasil. Acta Scientiarum. Biological Sciences 31, 245-253.

Tran, C. P., R. W., Bode, A. J., Smith & G. S., Kleppel (2010). Land-use proximity as a basis for assessing stream water quality in New York State (USA). Ecological Indicators 10, 727-733.

Tucci, C. E. M. (2008). Urban waters. Estudos Avançados 22, 97–111.

Ulnikovic, V. P., M. Vukic & A. Milutinovic-Nikolic, (2013). Analysis of solid waste from ships and modeling of its generation on the river Danube in Serbia. Waste Management Research 31, 24-618.

Urbanič, G. (2014). Hydromorphological degradation impact on benthic invertebrates in large rivers in Slovenia. Hydrobiologia 729, 191-207.

Viera, A. J. & J. M., Garrett (2005). Understanding Interobserver Agreement: The Kappa Statistic. Family Medicine 37, 360-363.

Walling, D. E. (2006). Human impact on land–ocean sediment transfer by the world's rivers. Geomorphology 79, 192–216.

Wang, R., T., Xu, L., Yu, J. Zhu & X. Li (2012). Effects of land use types on surface water quality across an anthropogenic disturbance gradient in the upper reach of the Hun River, Northeast China. Environmental Monitoring Assessment 185, 4141-51.

Table 1 Rapid Assessment Protocol parameters and descriptions of hydromorphological characteristics depending on the integrity category

Table 2 Permanent Protection Area characteristics along the Pardo River, Brazil, 2011-2012.
*Brazilian Forest Code standards for source, the PPA should have minimum radius of 50 m around it. For watercourses 50-200 m wide, the minimum PPA is 100 m. For watercourses 200-600 m wide, the minimum PPA is 200 m.

Table 3 Median values of physicochemical parameters according to the season in the Pardo River, Brazil, 2011-2012.

Fig. 1 Location of study area and sampling stretches in the Pardo River, Brazil, 2011-2012. (Adapted from Alves, et al., 2014. Metal concentrations in surface water and sediments from Pardo River, Brazil: Human health risks)

Fig. 2 Satellite images showing the 12 sampling stretches and their margins on the Pardo River, Brazil. According to river width, the images were approximated in the software, following the adjustments: 100 m for images 1 to 7; 150 m for image 8; 250 m for images 9 to 11 and 1,000 m for image 12. The arrows indicate the sampling stretch.

Fig. 3 Hydromorphological integrity of Pardo River using the RAP at the 12 stretches in the dry and rainy seasons, Brazil, 2011-2012. Score: 0 to 5 – Poor, 6 to 10 – Fair, 11 to 15 – Good, 16 to 20 – Excellent.


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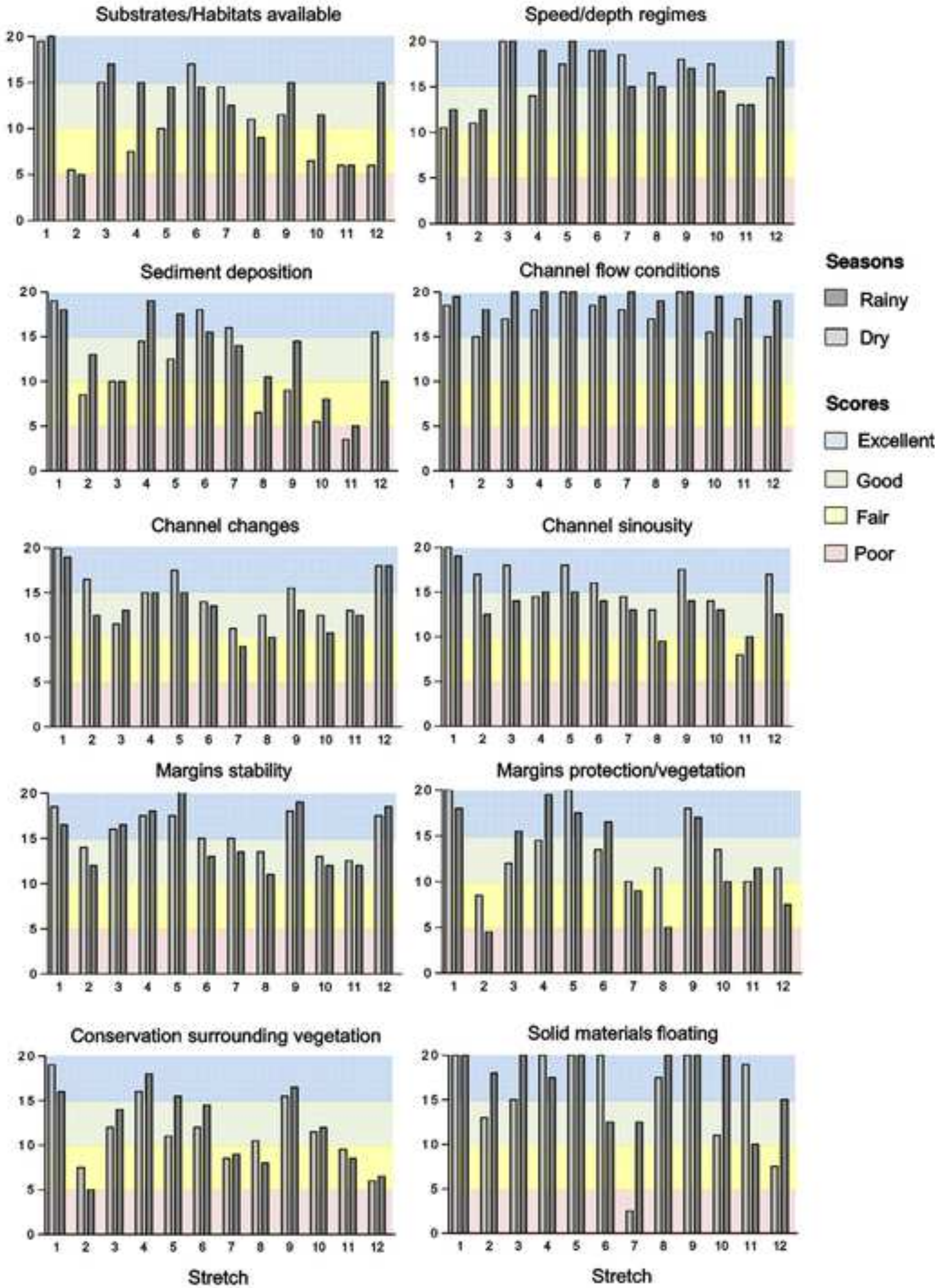
Substrates/Habitats available
Speed/depth regimes
Sediment deposition
Channel flow conditions
Channel changes
Channel sinousity
Margins stability
Margins protection/vegetation
Conservation surrounding vegetation
Solid materials floating
Stretch
Stretch
Seasons
Rainy
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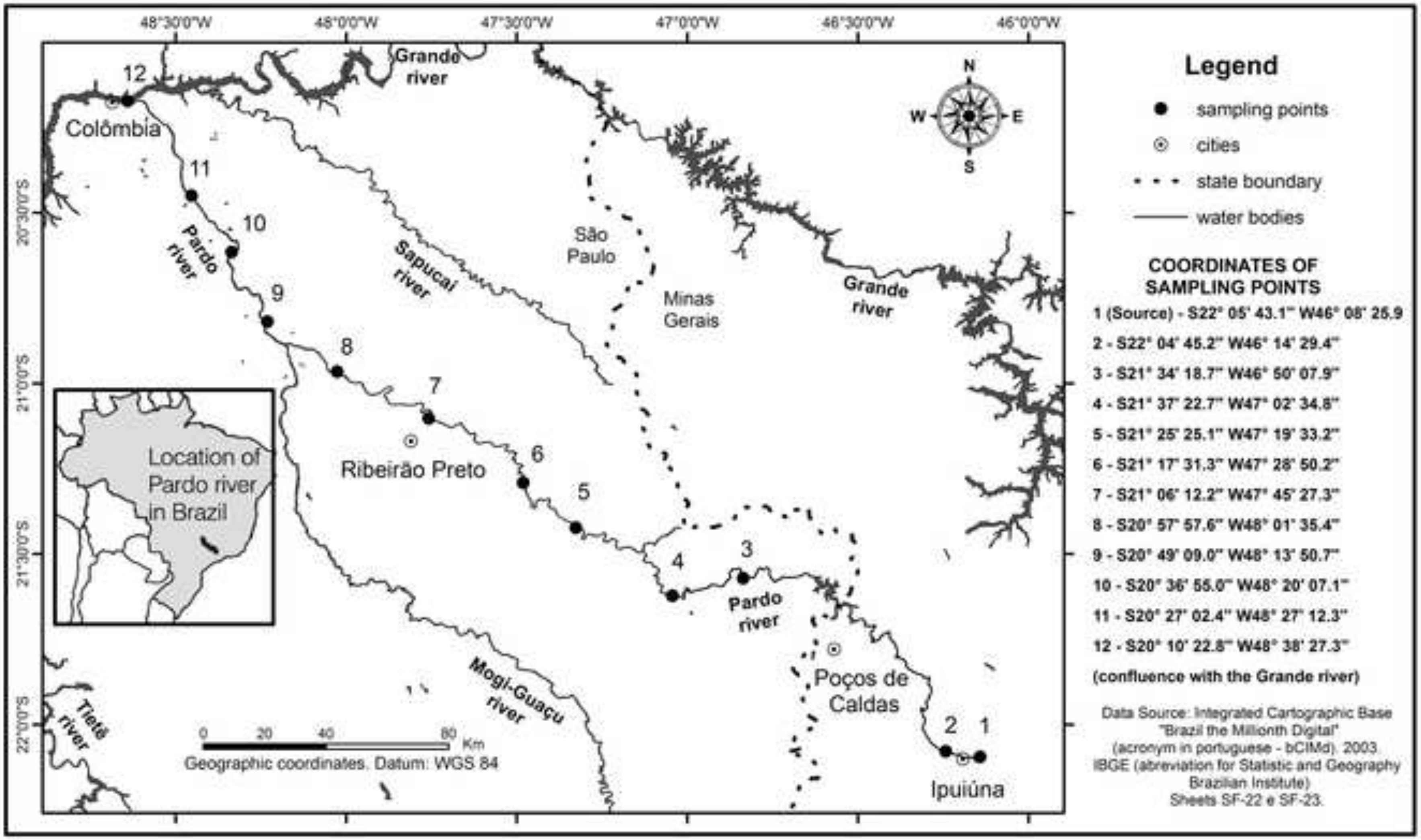
Scores
Excellent
Good
Fair
Poor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21°30'0"S
22°0'0"S
Grande river
Colômbia
Pardo river
Sapucaí river
São Paulo
Minas Gerais
Grande river
Location of Pardo river in Brazil
Ribeirão Preto
Pardo river
Poços de Caldas
Ipuiúna
Mogi-Guaçu river
Tietê river
0 20 40 80 Km
Geographic coordinates. Datum: WGS 84
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W
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Legend
sampling points
cities
state boundary
water bodies
COORDINATES OF SAMPLING POINTS
1 (Source) - S22° 05' 43.1" W46° 08' 26.9
2 - S22° 04' 45.2" W46° 14' 29.4"
3 - S21° 34' 18.7" W46° 50' 07.9"
4 - S21° 37' 22.7" W47° 02' 34.8"
5 - S21° 25' 25.1" W47° 19' 33.2"
6 - S21° 17' 31.3" W47° 28' 50.2"
7 - S21° 06' 12.2" W47° 45' 27.3"
8 - S20° 57' 57.6" W48° 01' 35.4"
9 - S20° 49' 09.0" W48° 13' 50.7"
10 - S20° 36' 55.0" W48° 20' 07.1"
11 - S20° 27' 02.4" W48° 27' 12.3"
12 - S20° 10' 22.8" W48° 38' 27.3"
(confluence with the Grande river)
Data Source: Integrated Cartographic Base
"Brazil the Millionth Digital"
(acronym in portuguese - bCIMd). 2003.
IBGE (abreviation for Statistic and Geography Brazilian Institute)
Sheets SF-22 e SF-23.

Table 1 Rapid Assessment Protocol parameters and descriptions of hydromorphological characteristics depending on the integrity category

Parameters	Excellent	Good	Fair	Poor
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Substrates and/or habitats available	Multiple types and sizes of substrates favorable to benthic fauna colonization and shelter for aquatic organisms.	More than 50% of the rated stretch presents suitable substrates for colonization, such as submerged branches or rocks.	Between 21 and 30% the merged stretch has stable habitats suitable for colonization.	Over 80% of the stretch was rated with monotonous habitats or with little diversification.
Speed/depth regimes	Presence of fast/shallow, fast/deep, slow/shallow, slow/deep regimes.	Presence of three schemes, with mandatory presence of the fast/shallow regime.	Presence of two types of regimes.	Prevalence of only one type of regime, usually slow/deep.
Sediment deposition	Small sediment banks are visible, but not enough to affect the normal course of the river.	Presence of gravel, sand or fine sediment in the newly formed islands. Wells in the deposition of sediment are small.	Moderate deposition of gravel, sand or fine sediment islands in formation.	The natural river course is actually affected by the sediment deposition.
Channel flow status	Water reaches the lower base on both sides and there is a minimal amount of exposed substrates.	Water fills more than 75% of the channel and less than 25% of substrates are exposed.	Water fills between 25 and 75% of the channel and most of the substrates are exposed.	Very little water in the channel, most of standing water in wells.
Channel alterations	Absence or minimal presence of small pipes and dredging. The stream follows natural pattern.	Presence of a pipe, usually in the area to support bridges, but with no recent plumbing.	Presence of landfills and dams on both sides.	Margins coated with cement and the stream is channeled.
Channel sinuosity	Curves are evident in the stretch evaluated, providing an increase in diversity of habitats.	The sinuosity of the channel is not very evident, curves can be seen far and diversification of habitats for the local biota.	The stretch presents a few curves and monotonous habitats, with few available sites for biota.	The stretch is straight, and if was made from a human action to assign a lower score.
Margins stability	Stable margins, no or minimal evidence of erosion or failed banks; little potential for future problems.	Margins moderately stable, with the presence of areas of erosion of the banks themselves have eroded.	Between 30 to 60% of the length of the margins is eroded and has potential for erosion during floods.	Unstable banks and many eroded areas. Erosion is common along the straight section and curved.
Protection of the margins by vegetation	Over 90% of the surface and immediate margins riparian zone is preserved, i.e., no built-up areas, cultivation areas or pasture.	70 to 90% of the marginal surface is preserved, and there were no great discontinuities. Minimal evidence of crop fields or pastures.	Mixture of places where the soil is covered and where there is no presence of vegetation.	There is an obvious discontinuity of the surrounding vegetation which is practically nonexistent.
Nearby vegetation status of protection	Surrounding vegetation isn't composed of agriculture, exotic species. No signs of degradation caused by human activities.	Vegetation was apparently little altered by human action, and is well preserved. Minimal evidence of negative impact on conservation.	Vegetation consists of exotic species and there is little vegetation preserved. There is human impact.	There is no vegetation and soil is exposed to natural weathering. Deforestation is evident.
Floating solid materials	No observed recyclable solid waste in any place in the stretch analyzed.	Minimum amount of recyclable waste consisting of paper, wood or derivatives, which are naturally degraded.	Mixture of waste naturally degraded and a small quantity of plastic, metal or glass.	Materials such as plastic, metal, glass and styrofoam on the banks or in the river water.

*Adapted from Rodrigues & Castro (2008).

Table 2 Permanent Protection Area characteristics along the Pardo River, Brazil, 2011-2012.

Sampling Stretch	Nearby cities	Width (m)	PPA characteristics (m) (upstream/downstream)		BFC standards (m)*
			Left	Right	
1 (source)	Ipuiúna, MG	1.5	PPA < 50	PPA < 50	50
2	Ipuiúna, MG/Santa Rita de Caldas, MG	5	PPA < 30	PPA < 30	30
3	São José do Rio Pardo, SP/ Caconde, SP	70	PPA < 100	PPA < 100	100
4	Mococa, SP/Casa Branca, SP	50	PPA < 100	PPA > 100	100
5	Cajuru, SP/Santa Rosa de Viterbo, SP	100	PPA < 100	PPA > 100	100
6	Serrana, SP/Santa Cruz da Esperança, SP	110	PPA < 100	PPA < 100	100
7	Ribeirão Preto, SP	150	PPA < 100	PPA < 100	100
8	Pontal, SP/Cândia, SP	250	PPA < 200	PPA < 200	200
9	Viradouro, SP/ Morro Agudo, SP	300	PPA < 200	PPA < 200	200
10	Jaborandi, SP/Colina, SP	200	PPA < 200	PPA < 200	200
11	Barretos, SP/Guaíra, SP	300	PPA < 200	PPA < 200	200
12 (mouth)	Colômbia, SP	400	PPA < 200	PPA < 200	200

*Brazilian Forest Code standards for source, the PPA should have minimum radius of 50 m around it. For watercourses 50-200 m wide, the minimum PPA is 100 m. For watercourses 200-600 m wide, the minimum PPA is 200 m.

Table 3 Median values of physicochemical parameters according to the season in the Pardo River, Brazil, 2011-2012.

	Stretch	pH	Temperature (°C)	Dissolved oxygen ($mg.L^{-1}$)	Electrical conductivity (μS)	Turbidity (NTU)
Rainy season	1	5.0	19.0	7.4	14.3	0.3
	2	5.3	20.0	7.0	32.2	40.6
	3	5.6	23.2	6.9	47.8	43.0
	4	6.0	24.3	7.1	55.4	29.9
	5	6.3	25.0	7.4	60.3	40.9
	6	5.9	23.9	5.9	55.5	63.0
	7	6.2	24.7	5.6	53.8	52.7
	8	6.5	25.8	6.5	60.0	33.8
	9	6.6	26.2	6.7	61.2	39.8
	10	6.8	26.0	6.5	60.1	37.8
	11	6.5	26.0	7.2	60.3	41.3
	12	6.5	26.4	3.9	59.4	32.2
	Stretch	pH	Temperature (°C)	Dissolved oxygen ($mg.L^{-1}$)	Electrical conductivity (μS)	Turbidity (NTU)
Dry season	1	5.6	18.6	7.5	12.6	0.1
	2	6.2	16.9	7.6	30.7	19.3
	3	6.3	18.8	8.2	44.7	2.7
	4	6.1	20.0	8.1	49.2	2.5
	5	6.4	19.7	7.2	55.7	5.6
	6	6.3	20.1	8.2	56.1	5.7
	7	6.4	20.1	7.1	57.7	6.0
	8	6.3	20.3	7.2	58.3	8.0
	9	6.1	20.3	7.7	61.6	8.3
	10	6.3	20.1	8.2	64.5	9.2
	11	6.5	19.8	8.5	62.3	9.6
	12	6.0	20.2	5.0	59.0	8.7
CONAMA (2005)		6.0-9.0	-	5.0	-	100