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Riparian restoration priorities in Southeastern Brazil

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Abstract Riparian restoration projects in the Tropics are complex, demanding long-term research, continuous human efforts and correct use of financial resources. This paper presents an approach to rank priority areas for riparian restoration on the upper section of the Pardo River watershed, in São Paulo, Brazil, using remote sensing and GIS techniques, and to monitor the land use on high priority areas. Pardo River watershed is especially important, since it is the major source of drinking water supply for the region and water for domestic and industrial use within Botucatu and surrounding. Results indicated that riparian restoration should involve 81,27% of the protected area and could be made in three phases, allocating resources according to priority scale.

Keywords: remote sensing, GIS, riparian restoration, Land Use Capability, landscape planning

1 Introduction

It has long been recognized that agricultural activities are the major contributors to non-point source pollution of inland surface and underground water (Doyle et al., 1977). Changes in water quality can affect in some extent, terrestrial, riparian, or in-channel ecosystem. Riparian buffers can reduce soil erosion effects and keep sediment and pollutants away from water bodies since they function as filters to delay, absorb, or purify contaminated runoff before it enters surface waters. In Brazil, the importance of riparian vegetation has been admitted and led to regulation of specific laws. The Brazilian Forestry Code, (Law 4771, from 1965, altered by Laws 7803 and 7875, in 1989) established buffer zones of *natural vegetation* around water bodies. Although the Code is conservative, monitoring buffer zones is quite difficult in so complex hydrographic systems, such as in the Tropics. Furthermore, before the Laws have been regulated most of the riparian zones in the Southeastern Region of Brazil had been degraded by agricultural activities. This fact has led to a great concern about water quality, aquatic ecosystems, habitats and the costs for water treatment. Consequently, the interest on riparian restoration on watershed scale has increased.

Riparian forests in the Tropics are characterized by high diversity of species, ranging from 23 to 247 per hectare (Rodrigues & Nave, 2000), and complex dynamic based on plant/animal interaction through pollination and seed dispersion. Thus, restoration projects are complex, demanding long-term research, continuous human efforts and financial resources, as well. In that way, the objectives of this research were to select priority areas for riparian restoration plan for the upper section of the Pardo River watershed in São Paulo State, Brazil, using remote sensing and GIS techniques, and to monitor the land use on high priority areas. Pardo River watershed is especially important, since it is the major source of drinking water supply for the region and water for domestic and industrial use within Botucatu and surrounding.

2 Materials and method

2.1 Study area

The study area is located in the municipal districts of Pardinho and Botucatu, São Paulo State, Brazil (between 22°59'41" and 23°06'11"S and 48°21'38" and 48°25'20"W), approximately 230 km northwest of São Paulo City.

Natural vegetation includes mesophytic forests, riparian woodlands and, typical *savanna* (cerrado). Average annual rainfall is 1529 mm with the greatest amount of 248 mm in January. Agricultural production consists of row crops and livestock (beef cattle).

2.2 Landsat-5 TM digital image processing

The Landsat TM image used in this study was acquired on June 08, 1997 (orbit 220, point 76, quadrant A), comprising bands TM3 (0,63 to 0,69 μm), TM4 (0,76 to 0,90 μm) and TM5 (1,55 to 1,75 μm). SPRING, software developed by INPE-Brazil, was used to process the image. Initially, the image has been rectified and georeferenced to the Universal Transverse Mercator (UTM) projection, and resampled to a 30 x 30 m pixel. Finally, a classification of the image was performed according to Shimabukuru & Smith (1991). The least-squares mixing models separated the colored composite image in three fraction images of soil, vegetation and shadow. It was used a composition of these three fractions, which provided a great contrast among the different land use classes. Image data was grouped through segmentation technique, which meant that only neighbor regions could be grouped. The minimum mapping unit comprised three pixels or 0,27 ha. The algorithm employed, ISOSEG, allowed classification of the segmented image.

This classification was evaluated by obtaining a classification error matrix and by assessing its accuracy (Lillesand & Kiefer, 1994). This process was performed in IDRISI32 GIS. The error matrix was obtained by the crossing GIS capability, generating a random set of locations to visit on the ground for verification of the true land cover type, according to Eastman (1999). These locations were compared to the classified map, resulting in an error matrix. The size of the sample used in the accuracy assessment was estimated assuming level of confidence of 95%, and desired confidence interval of 0,05.

2.3 Development of the hydrographic data layer

The hydrography of the study area was digitized from eight planialtimetric charts (1:10000 scale) produced by the Cartographic Plan of São Paulo State. This large scale allows identifying even headwaters of intermittent streams, as required by the Brazilian Forestry Code. These data were used to produce a buffered map of the Brazilian riparian width regulations for the study area. As the widest stream in the study area is 10-meter wide, it was generated a 30-meter buffer around all streams. All headwaters were digitized on-screen for buffer generation of 50-meter radius. It followed a distance image, reclassified as Boolean to distances up to 50 meters. Combining both images, it was obtained a buffered map according to Brazilian requirements.

2.4 Land Use Capability Map

The Land Use Capability Class method classifies soil units into eight specific categories based on their utility in agricultural use. In the Soil Capability Classification, low values indicate the best soils for agricultural activities without too many restrictions. The suitability decreases as class values increase. Capability classes are divided into subclasses that identify the limiting factor for the soil (e for slope or erosion, s for shallow, stony or droughty, w for wetness and, c for climate).

Ribeiro (1998) presented the Land Use Capability classification in the study area, as a means for land use planning. The map was performed through GIS analysis, based on detailed soil data, 1:10000 scale (Zimback, 1997) and, topographic information derived from 1:10000 topographic maps of the Cartographic Plan of São Paulo State. Land use capability subclasses were obtained through overlay of slope and soil data and a judgment table, according to Lepsch et al., (1991).

2.5 Identification of priority areas for restoration

Land Use Capability classes can be grouped according to their land use intensities. Thus, Group A comprises classes I, II, III, and IV, Group B includes classes V, VI and VII and, Group C, only class VIII. Groups B and C are the most critical in relation to unsuitability for cultivation. They present severe limitations and should be in permanent vegetation. Also the subclasses were ranked according to the criticality of their limiting factors to riparian buffer efficiencies.

As this method takes into account soil types, slope and drainage of the land, fertility, erodibility and rockiness of the soil, and other factors, it is able to point out the most critical conditions of the study area, which require more effective and immediate management. Overlaying Land Use Capability Classes, hydrographic buffers and remotely sensed information allowed identifying riparian areas ranked by priority restoration.

3 Results and discussion

3.1 Image analysis

Resulting classification and field data revealed 6 categories of land use and land covers (**Figure 1**): remnant forest patches and corridors (which includes mesophytic forests, riparian woodlands, secondary forests/meadow), pasture, wetland, water/shadow, croplands and urban area. Similar spectral behavior and spatial proximity between water and shadow did not allow Fig. 01

distinction between them. In the study area, shadow represented forested areas, which reflectance was influenced by relief orientation.

In general, there were a considerable number of correctly classified pixels (**Table 1**). Tab. 01 Accuracy assessment indicated overall Kappa Index of Agreement of 0,82 and total accuracy of 93%. The error matrix comprised 196 classified pixels, 17 in remnant forest patches and corridors, of which 13 were correctly classified, 6 were omitted, 2 were erroneously classified as pasture, and 4 were misclassified as cropland. On the other hand, 4 pixels were included in this category, although they belonged to pasture (3) and cropland (1). In order to assess the accuracy of the classification produced, the omission and inclusion probabilities were evaluated. The probability of correctly classifying a pixel in the category of remnant forest patches and corridors is 68% (producer's accuracy), and the percentage probability of sampling to obtain correctly classified pixels is 76% (consumer's accuracy). The lower percentage was obtained in wetland (67%).

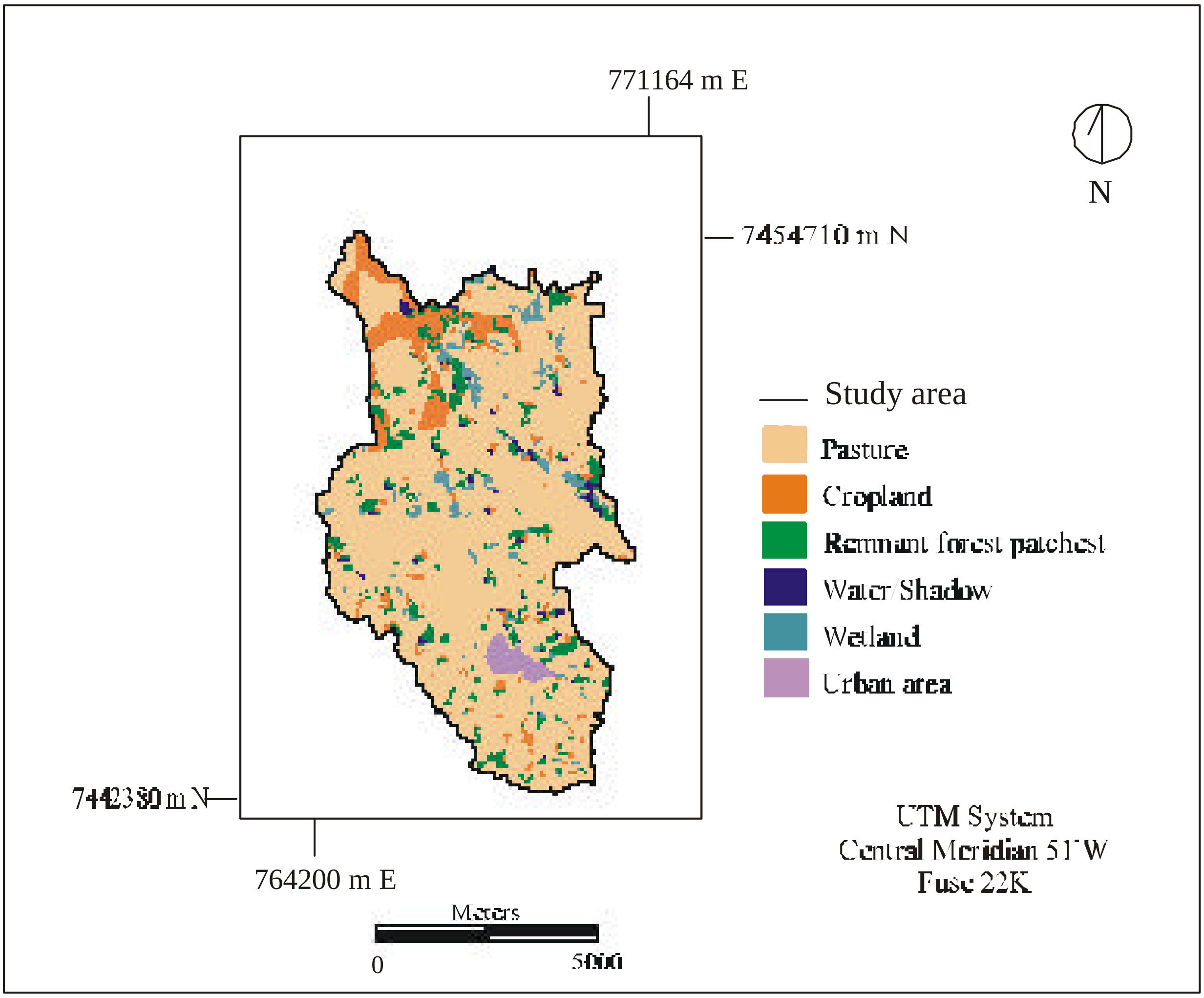

Figure 1 – Land cover classification of the upper section of Pardo River watershed

Table 1- Error matrix and accuracy indicators

	P	C	RF	W/S	W	Total	Errors of Commission	Consumer's accuracy
P	**143**	1	2	1	4	151	0,05	0,95
C	0	**9**	4	0	0	13	0,31	0,69
RF	3	1	**13**	0	0	15	0,27	0,73
W/S	1	0	0	**9**	0	12	0,08	0,92
W	1	0	0	0	**8**	9	0,11	0,89
Total	148	11	19	10	12	**196**		
Errors of Omission	0,03	0,18	0,32	0,10	0,33		**0,07**	
Producer's accuracy	0,97	0,82	0,68	0,90	0,67			

P = pasture, C = cropland, RF = remnant forest patches and corridors, W/S = water/shadow, W = wetland. Total accuracy = ((143 + 9 + 13 + 9 + 8)/196)*100 = 93%.

3.2 Priority areas for riparian restoration

Analysis in GIS allowed to compute the total area protected by Brazilian Laws in the study area. About 811,93 ha should be simply untouched according to the legislation. Those areas are known as *Areas of Permanent Preservation* (APP's) and can not be touched or even managed without pertinent permission. However, an analysis of the results reveals that few riparian woodlands are distributed along the drainage network. Predominant land use on this protected area is pasture (72,96%), followed by remnant forest patches and corridors, wetlands and, water/shadow, summing 18,75% (**Table 2**). Tab. 02

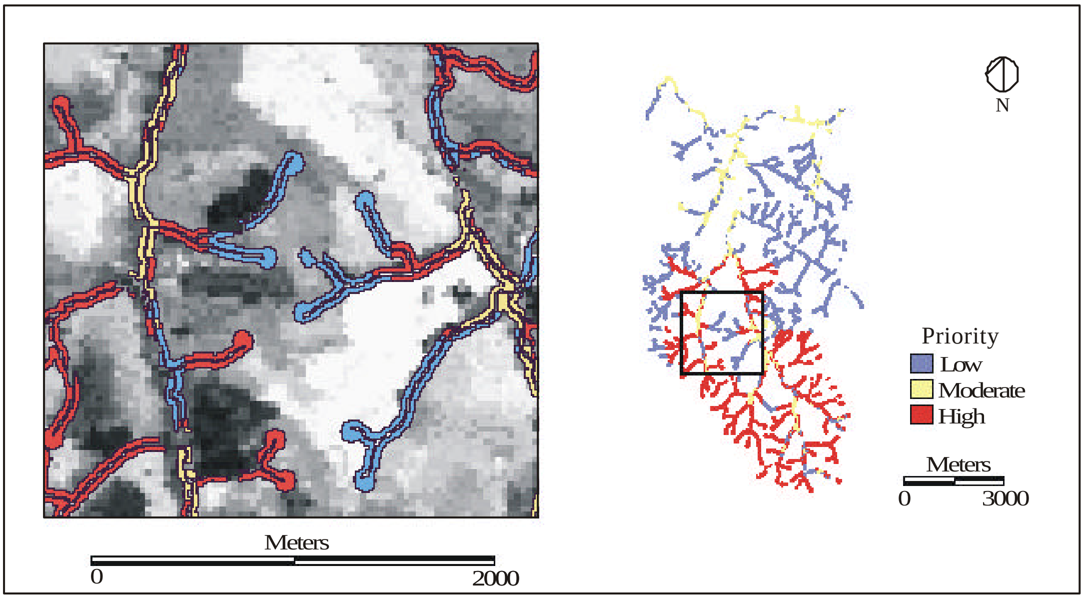

Figure 2 – Priority areas for riparian restoration overlaid on band 5 of the TM (portion of the study area)

Table 2 - Land use on protected areas

Land use/cover category	Area (ha)	Proportion (%)
Remnant forest patches and corridors	88,33	10,88
Pasture	592,36	72,96
Wetland	40,46	4,98
Water/shadow	23,43	2,89
Croplands	62,48	7,69
Urban area	4,87	0,60
Total	811,93	100,00

Results indicate absence of classes I and VIII on the protected areas. Consequently, Land Use Capability subclasses can be regrouped in three groups: A (class II, III and IV), B (classes V, VI) and, C (class VII). Excluding areas where land use is according to the requirements, about 659,82 ha (81,27%) of riparian areas need restoration. Figure 2 shows areas for riparian restoration according to priorities. About 246,95 ha of high priority areas need immediate restoration, which represents 37,43% of the entire protected area (**Table 3**). The riparian rehabilitation program should start in those areas. The subsequent areas should include 84,49 ha (12,81% of the protected area) and, a third step should encompasses the remnant area of 328,37 ha.

Fig. 02

Table 3 - Land use capability subclasses on protected areas

	Total Areas per Class		Areas which should be restored	
Class	Area (ha)	Proportion of the total area (%)	Area (ha)	Proportion of the total area (%)
IIe	107,72	13,27	89,27	13,53
IIe, s	50,86	6,26	41,73	6,32
IIIe	159,72	19,67	137,77	20,88
IIIa	49,55	6,10	38,43	5,82
IVe	28,44	3,50	21,18	3,21
Va	5,66	0,70	3,43	0,52
VIe	115,60	14,24	81,06	12,29
VIIe	294,38	36,26	246,95	37,43
Total	811,93	100,00	659,82	100,00

4 Conclusions

The riparian restoration plan needed on this study comprises 81,27% of the protected area. The integration of GIS and remote sensing data provided a framework to structure a restoration plan in several phases, allocating resources according to priorities. Areas that lack the filtering function of riparian vegetation have been identified. The priorities ranked by this methodology reflect the hydrological and topographical conditions and erodibility of the soils, indicating the most critical in relation mainly to water quality protection perspective. Limiting factors pointed out by the Land Use Capability map are susceptibility to sheet and rill erosion, slope, soil depth or wetness. Those factors also influence riparian buffer function for water quality protection.

Despite of difficulties on riparian restoration, water resources managers and Brazilian legislation have recognized the role of riparian buffers in mitigating or controlling diffuse source pollution and their importance for keeping biodiversity. Efforts in such way should be taken to guarantee better environmental conditions.

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