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Priority areas for riparian forest restoration in Southeastern Brazil

Áreas prioritárias para a restauração da mata ripária no Sudeste do Brasil

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RESUMO: Projetos de restauração da mata ripária em regiões tropicais são complexos, requerem pesquisa a longo prazo, esforços humanos contínuos e correto uso dos recursos financeiros. Este trabalho apresenta um método para estabelecer prioridades entre as áreas que necessitam de restauração da mata ripária na porção superior da bacia do Rio Pardo, São Paulo, Brasil, através da aplicação de sensoriamento remoto e Sistema de Informação Geográfica. A bacia do Rio Pardo é especialmente importante por ser responsável pelo suprimento de água para uso doméstico e industrial da região de Botucatu. Os resultados indicaram que a restauração da mata ripária deve envolver cerca de 81,27% da área de preservação permanente e deveria ser feita em três fases, direcionando os recursos de acordo com a escala de prioridade.

PALAVRAS-CHAVE: Restauração da mata ripária, Sensoriamento remoto, SIG

ABSTRACT: Riparian forest 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 forest restoration on the upper section of the Pardo River watershed, in São Paulo, Brazil, using remote sensing and GIS techniques. Pardo River watershed is specially 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 a priority scale.

KEYWORDS: Riparian forest restoration, Remote sensing, GIS

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; Miller and Spires, 1978). Conversion of riparian areas to arable land, higher stocking densities on pasture and the wider use of agrochemichals may have contributed to the increased transport of non-point source pollutants to streams (Muscutt et al., 1993). Nutrients and other pollutants from agricultural runoff may cause impact on water quality. Consequently, changes in water quality can affect some aspect of terrestrial, riparian, or in-channel ecosystems.

According to principles of ecological engineering, the most effective way to reduce pollution load is to decrease pollution at the origin (Mitsch and Jorgensen, 1989), since the difficulty in managing water quality problems increases with dilution and distance from the source (Pegram and Bath, 1995). Several practices can reduce soil erosion effects and keep sediment and pollutants away from water bodies. Keeping vegetated buffer zones between upland and watercourses and reservoirs comprises one of these techniques. Riparian buffers function as filters to delay, absorb, or purify contaminated runoff before it enters surface waters. These concepts were previously developed by Tollner et al. (1977), Karr and Schlosser (1978), Vanderholm et al. (1979), Lowrance et al. (1984, 1985, 1986) and have been widely accepted. Establishment and maintenance of riparian buffers have become a common best management practice (BMP) in the United States. In Brazil, the importance of riparian vegetation has been admitted and led to regulation of specific laws. The Brazilian Forestry Code, a group of laws to regulate the occupation and use of the nation's forests, (Law 4771, from 1965, altered by Laws 7803 and 7875, in 1989) established buffer zones of natural vegetation around water bodies. The strategy for establishing the widths of riparian buffers was based mainly upon width or size of the water body (Table 1).

Although the Forestry Code is conservative, monitoring buffer zones is quite difficult in so complex hydrographic systems. Furthermore, before the Laws have been regulated most of the riparian zones in the Southeastern Region had been degraded by agricultural activities (e.g., coffee plantations and sugar cane crops). Nowadays, remnant forest patches and corridors represent only 5% of the São Paulo State area (SOS Mata Atlântica / INPE, 1992). 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 at watershed scale has increased.

Table 1.
Widths of riparian vegetation fixed by the Brazilian Forestry Code
(Larguras para vegetação ripária estabelecidas pelo Código Florestal Brasileiro)

Width or size of the water bodies	Minimum width of natural vegetation around water bodies
Up to 10 m	30 m
From 10 to 50 m	50 m
From 50 to 200 m	100 m
From 200 to 600 m	200 m
Around lakes and natural or artificial reservoirs	30 m in urban areas;
	50 m in rural areas (water bodies up to 20 ha in area);
	100 m in rural areas (water bodies greater than 20 ha in area)
	100 m for hydroelectric powers
Around headwaters, even on intermittent streams	Minimum radius of 50 m

Restoration programs should reach structural and functional characteristics close to the original vegetation (Macedo, 1993). Nevertheless, riparian forests in the Tropics are characterized by high diversity of species, ranging from 23 to 247 per hectare (Rodrigues and Nave, 2000), and complex dynamic based on plant/animal interaction through pollination and seed dispersion. Thus, restoration projects are complex, demand long-term research, human and financial resources, as well. Several approaches (Phillips, 1989; Xiang, 1993; Simões, 2001) have been presented as auxiliary on riparian forest restoration programs. Although scientifically based, those methodologies are data consuming, which is unfeasible for application in large areas. In that way, the objectives of this research were to rank areas for riparian forest restoration in relation to their priorities to reach water quality protection for the upper section of the Pardo River watershed in São Paulo, Brazil, using remote sensing, GIS techniques, and Land Use Capability classification.

METHODOLOGY

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. The study area is inserted in the Cuesta back range (beginning of the Western Plateau), with altitudes ranging from 840 to 1009 m. The study area, is about 5336 hectares. Pardo River is the major source of drinking water supply for the region and water for domestic and industrial uses within Botucatu and surrounding.

Soils in the study area are basaltic rock derived and sandy soils, including Oxisols (“Latossolo Roxo”, “Latossolo Vermelho-Escuro”) 58,32%, Ultisoll (“Podzólico Vermelho-Amarelo”) 31,82%, Lithic (“Litólico”) 0,44%, Hydric soils (“Hidromórficos”) 9,42%. Average annual rainfall is 1529 mm with the greatest amount of 248 mm in January.

Natural vegetation includes mesophytic forests, riparian forests, and typical savanna (“cerrado”). Agricultural production consists of row crops and livestock (milk cattle). Cropland and pasture comprise 8,8% and 76,72% of the study area, respectively.

Riparian restoration on this area is specially important due to water quality and ecological perspectives. Runoff is a concern mainly at the beginning of summer season, when the crop soils are unprotected and the tropical air masses present great instability, resulting in rainstorms.

Landsat-5TM digital image processing

The LandsatTM image used in this study was acquired on June 08, 1997 (orbit 220, point 76, quadrant W), comprising bands TM3 (0,63 to 0,69 mm), TM4 (0,76 to 0,90 mm) and TM5 (1,55 to 1,75 mm). SPRING, a computer software designed by INPE-Brazil, was used to process the image so that different land uses, specially natural vegetation patches, could be easily distinguished from the surrounding terrain.

Initially, histogram stretching was applied to each band as well as edge enhancement filtering, in order to visually enhance the information and to generate color composites that could be submitted to the georeferencing procedure. The image had been rectified and georeferenced to the Universal Transverse of Mercator (UTM) projection, and resampled to a 30 x 30 m pixel. Finally, a classification of the image was performed according to Shimabukuru and Smith (1991). The least-squares mixing models generated 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 were 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 available algorithm, ISOSEG, allowed classification of the segmented image.

This classification was evaluated by obtaining a classification error matrix and by assessing its accuracy (Lillesand and Kiefer, 1994). This process was performed in the 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 image, 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.

Development of the buffer around water bodies according to the Brazilian Forestry Code

The hydrography of the study area was digitized from eight topographic maps (1:10.000 scale) produced by the Cartographic Plan of São Paulo State. This large scale allows identifying even headwaters of intermittent streams, as required by the Forestry Code. These data were used to produce a buffered map according to the Brazilian riparian width regulations (Table 1) 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 buffers, it was obtained a buffered map according to Brazilian Forestry Code requirements.

Land use capability map

The Land Use Capability Class method classifies soil units into eight specific categories based on their utility for 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).

As this method takes into account soil types, slope and drainage of the land, fertility, erodibility and rockiness of the soil, it is able to point out the most critical conditions of the study area, which require more effective and immediate management.

Ribeiro (1998) presented the Land Use Capability classification for the study area as a means for land use planning. The map was performed through GIS analysis, based on detailed soil data, 1:10.000 scale (Zimback, 1997) and, topographic information derived from 1:10.000 topographic maps of the Cartographic Plan of São Paulo State. Land use capability classes were obtained through overlay of slope and soil data and a judgment table, according to the Brazilian adaptation for the American System of Land Classification (Lepsch et al., 1991).

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.

Priority areas for restoration could be ranked according to the Land Use Capability Groups. In that way, Groups A, B and C can represent low, moderate and high priorities, respectively.

Overlaying Land Use Capability Classes, hydrographic buffers and remotely sensed information allowed identifying riparian areas ranked by priority for restoration.

RESULTS AND DISCUSSION

Image analysis

Field data revealed 6 categories of land use and land covers (Figure 1, Table 2): remnant forest patches and corridors (which includes mesophytic forests, riparian forest, secondary forests/meadow), pasture, wetland, water/reservoir, cropland and urban area. Similar spectral behavior and spatial proximity between water and shadow did not allow distinction between them. In the study area, shadow represented forested areas, which reflectance was influenced by relief orientation. So, it was generated an aspect image which allowed distinction between those categories. Finally, shadow was reclassified as forest patch.

In general, there were a considerable number of correctly classified pixels (Table 3). Accuracy assessment indicated overall Kappa Index of Agreement of 0,89 and total accuracy of 91%. The error matrix comprised 198 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%).

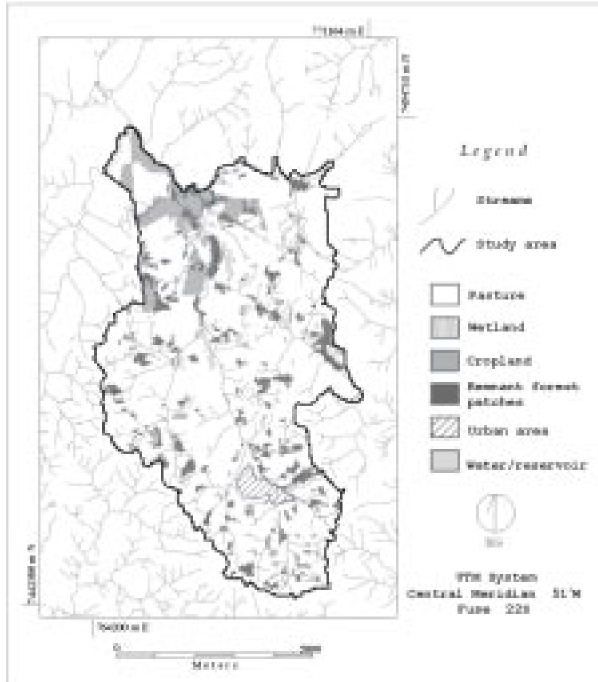

Figure 1.
Land cover classification of the upper section of Pardo River watershed
(Classificação de cobertura vegetal na seção superior da Bacia do Rio Pardo)

Table 2.
Land use and land cover categories and their areas and proportions in relation to the total study area
(Categorias de uso da terra e cobertura vegetal e suas áreas e proporções em relação à área total estudada)

Land use/cover category	Area (ha)	Proportion (%)
Remnant forest patches and corridors	471,28	7,75
Pasture	4090,92	76,72
Wetland	203,85	3,81
Water/reservoir	17,18	1,36
Croplands	474,11	8,88
Urban area	78,85	1,48
Total	5336,19	100,00

Table 3.
Error matrix and accuracy indicators
(Matriz de erros e indicadores de exatidão)

	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	17	0,24	0,76
W/R	1	0	0	**7**	0	8	0,125	0,875
W	1	0	0	0	**8**	9	0,11	0,89
Total	148	11	19	8	12	**198**		
Errors of Omission	0,03	0,18	0,32	0,125	0,33		**0,12**	
Producer's accuracy	0,97	0,82	0,68	0,875	0,67			

P = pasture, C = cropland, RF = remnant forest patches and corridors, W/S = water/shadow, W = wetland.
Total accuracy = ((143 + 9 + 13 + 7 + 8)/198)*100 = 91%.

Table 4.
Land use on protected areas
(Uso da terra em áreas de preservação)

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/reservoir	23,43	2,89
Croplands	62,48	7,69
Urban area	4,87	0,60
Total	811,93	100,00

Table 5.
Land use capability subclasses on protected areas
(Subclasses de capacidade de uso das terras em áreas de preservação)

	Total Areas per Class		Areas which should be restored	
Class	Area (ha)	Proportion of the total area (%)	Area (ha)	Proportion of the total area per class(%)
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

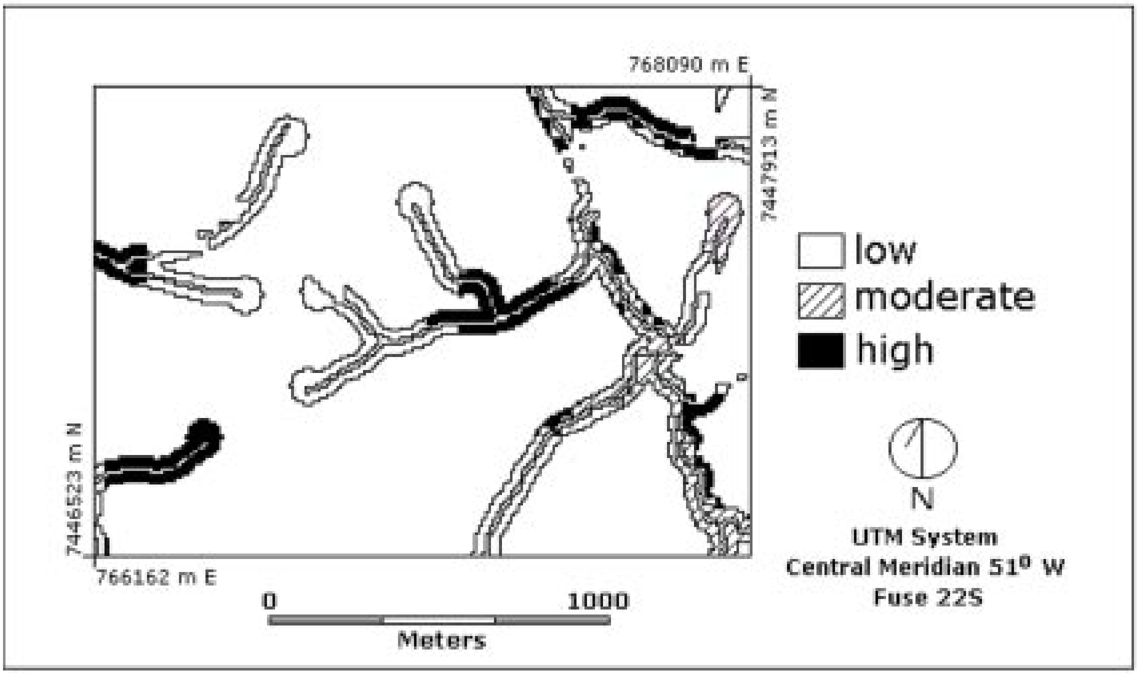

Figure 2.
Detail of priority areas for riparian restoration (portion of the study area)
(Detalhe de áreas prioritárias para restauração ripária, porção da área de estudo)

Priority areas for riparian forest restoration

Analysis in GIS allowed to compute the total area protected by the 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 revealed that riparian forests are poorly distributed along the drainage network. According to Table 4, excluding areas where land use is according to the requirements (remnant forest patches and corridors, 10,88%, wetland, 4,98% and, water/reservoir, 2,89%), about 659,82 ha (81,27%) of riparian areas need restoration. Predominant land use on this protected area is pasture (72,96%), followed by remnant forest patches and corridors, wetlands and, water/reservoir summing 18,75%.

Results also indicated absence of classes I and VIII on 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).

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 5). 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.

CONCLUSIONS

The priorities ranked for a restoration plan 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. The integration of GIS and remote sensing data provided a framework for determining priorities for riparian forest restoration. Areas that lack the filtering function of riparian vegetation have been identified. 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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