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An Approach to Environmental Planning and Sustainable Management of Watersheds and Municipalities in Southeastern Brazil

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Abstract

Diagnosis of fragmentation and landscape sustainability conditions are essential to environmental planning and sustainable management of natural resources. Land use spatial patterns and landscape structural indexes (landscape metrics, Urbanity Index—UI, and Landscape Vulnerability Index—LVI) have been proposed to assess biodiversity conservation and ecological sustainability, provided by impact of land use at Middle Mogi Guaçu watershed and its seventeen municipalities, in 2009. Land use typologies and structural indexes values were obtained based on screen digitizing of LandSat-5 imagery, for 2009. Cluster analysis and Permutational Multivariate Analysis of Variance were used to test the null hypothesis of equal degrees of fragmentation and sustainability conditions among municipalities in 2009, respectively. Land use spatial pattern showed a predominantly human occupation for watershed and its municipalities, with agricultural use as the main pressure factor. Municipalities were aggregated into three clusters related to forest fragmentation: one categorized by fifteen municipalities; the second cluster (municipality of Luiz Antônio) showing the best condition, and the third group (municipality of Araraquara) with extreme fragmentation condition. Landscape metrics related with shape, size, and core areas fragments intensify edge effects, and increase habitat isolation. The watershed showed a low naturalness and an intermediate degree of vulnerability. Ecological sustainability was different among municipalities ($\alpha = 0.05$, $F = 32.65$ and $p = 0.002$), with two municipalities (Analândia and Luiz Antônio) presenting the best conditions. The most committed condition was observed, in municipalities of Rincão and Guatapará. For conservation policies to be effective must focus on the creation of ecological corridors around legally protected areas, besides creation of new legal reserves, with purpose to improve biodiversity conservation and ecological sustainability of Middle Mogi Guaçu watershed and its municipalities.

Keywords

Sustainability Indicators, Landscape Metrics, Conservation Scenarios, Geotechnology

1. Introduction

Land use related activities, mainly to meet demands for natural resources, have resulted in environmental degradation [1]. Factors impacting land use are local and/or regional development actions as well as ecological and structural characteristics of landscape. Decisions related to land use involve trade-offs between meeting human needs and ecosystem health, depending on social values [2].

Landscape sustainability is a process of improving dynamic relationship between ecosystem services and human well-being in a changing landscape [3] and is highly dependent on land use dynamics [4].

The geotechnology is an effective technique for sustainable use planning [5], fragmentation diagnosis [6] [7], and identification of scenarios for biodiversity conservation, based on landscape condition of remaining natural vegetation [8]. Landscape metrics [9] [10] and ecological sustainability indexes [11]-[14] can be used in analysis of landscape management spatial patterns.

These tools also allow the decreasing naturalness or increasing artificiality resulting from anthropic activities, to be monitored in time and space [15], allowing essential information about current and historical conditions and the nature-society interaction to be disseminated to scientific community, general public and decision makers [16].

The watershed approach is recognized as a holistic approach to ecosystem management, disaster risk reduction, and climate change adaptation [17] [18]. Worldwide environmental, socio-economic and political changes are challenging some of foundations on which watershed management has been based for last 20 years. Currently, watershed management is going through an experimentation period, in which old and new practices often coexist and mix in new watershed management programs, design and implementation strategies, and is developed having a different approach. Some of paradigm shifts that are emerging from this experimentation link to parallel changes in other areas of development and conservation [19]-[21], including activities with the focus on beneficiaries [19]. Emphasis on watershed natural resource management is now a part of local socio-economic development processes with involvement and contribution from local people, in a pluralist collaborative process through multi-stakeholder participation, linking social, technical and policy concerns [19] [22] [23].

In this study, we identified scenarios of biodiversity conservation and ecological sustainability for the Middle Mogi Guaçu watershed and its municipalities, in 2009, based on land use spatial pattern, and landscape structural indexes, with the goal to environmental planning and sustainable management of natural resources.

2. Study Area

The study was performed at two scales: Middle Mogi Guaçu watershed limits and the total area of municipalities. The study area is located between geographic coordinates 21˚20 S - 22˚5 S and 47˚16'W - 48˚12'W, equivalent to total territory of municipalities Américo Brasiliense, Analândia, Araraquara, Descalvado, Guatapará, Ibaté, Luiz Antônio, Pirassununga, Porto Ferreira, Rincão, Santa Cruz das Palmeiras, Santa Lucia, Santa Rita do Passa Quatro, Santa Rosa de Viterbo, São Carlos, São Simão, and Tambaú (Figure 1). The climate is Aw type (Köppen, 1931) that characterizes tropical with dry winter (May to October) and a rainy season (November to April). The minimum

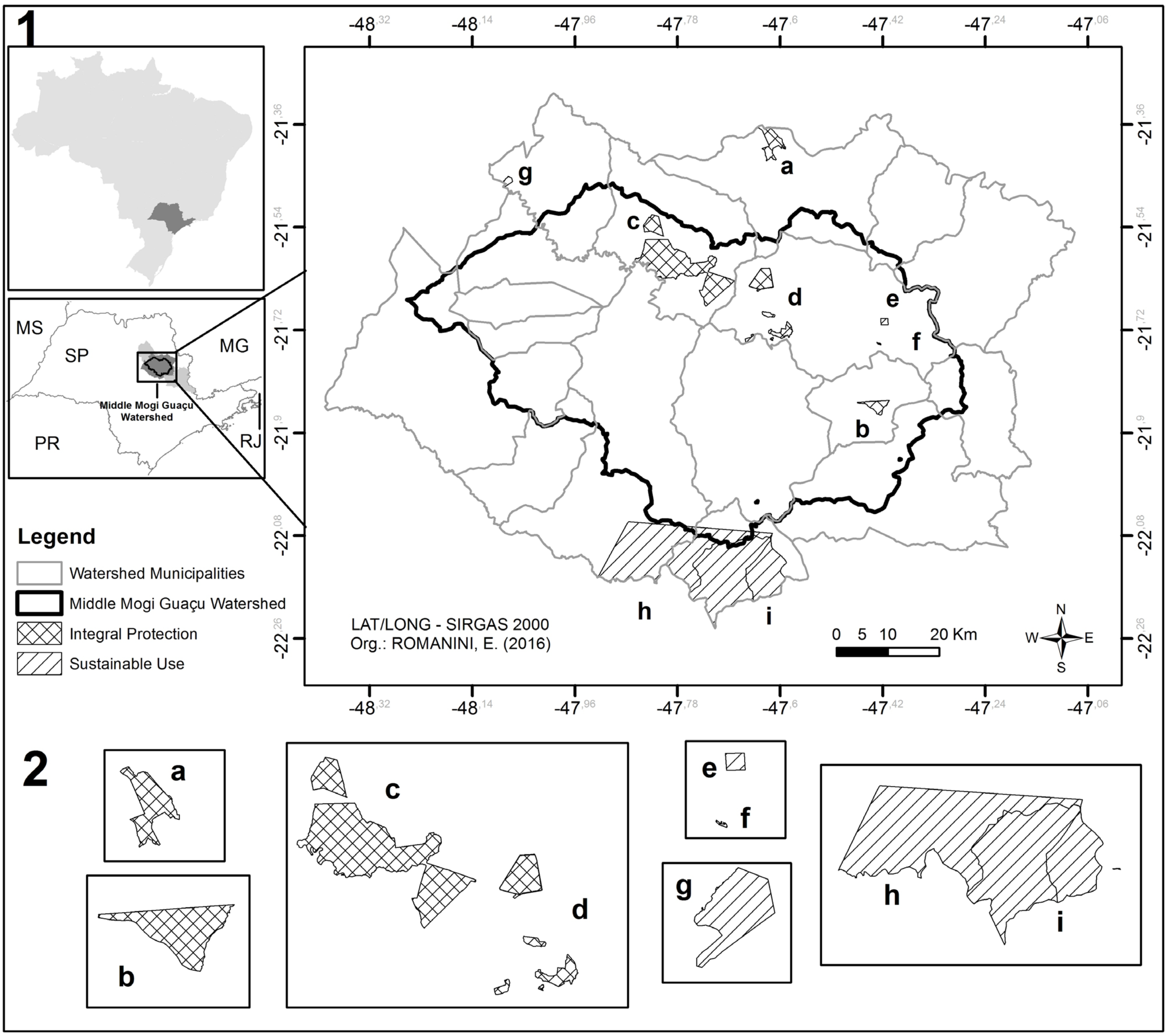

Figure 1. 1. Middle Mogi Guaçu watershed location, highlighting municipality limits. 2. Legally protected areas: I) Integral Protection category (a) Santa Maria Ecological Station, (b) Porto Ferreira State Park, (c) Jataí Ecological Station, (d) Vassununga State Park, and II) Sustainable Use category (e) Area of Relevant Ecological interest of Vassununga, (f) Natural Heritage Private Reserve of Sítio Kon Tiki, (g) Natural Heritage Private Reserve of Toca da Paca, (h) Protected Environmental Area of Piracicaba Juqueri Mirim, and (i) Protected Environmental Area of Corumbataí, Botucatu e Tejupa-Corumbataí perimeter.

temperature is between 18.5˚C and 19˚C, maximum temperature is 23.5˚C and 24˚C. Annual rainfall is 1.100 to 1.700 mm.

The study area is characterized by cerrado vegetation (Brazilian savanna), semi-deciduous forest, and riparian forest [24]. Agricultural activities include sugarcane, citrus, and pasture cultivation [25] as well as *Eucalyptus* spp. and *Pinus* spp. forestries. Agricultural activities are strongly associated with industrial sector, esp. sugar, alcohol, paper, cellulose, vegetable oil, and beverage production [26].

The study area has ten legally protected areas: four areas corresponding to Brazilian integral protection category (Santa Maria Ecological Station, Porto Ferreira State Park, Jataí Ecological Station, and Vassununga State Park) and six to Brazilian sustainable use category (Area of Relevant Ecological Interest of Vassununga, Area of Relevant Ecological Interest of Pé de Gigante, Natural Heritage Private Reserve of SítioKonTiki, Natural Heritage Private Reserve of Toca da Paca, Protected Environmental Area of Piracicaba Juqueri Mirim-Area I, and Protected Environmental Area of Corumbataí, Botucatu e Tejupa-Corumbataí perimeter) (**Figure 1**).

3. Material and Methods

Hydrography and road network data were obtained from Brazilian Institute of Geography and Statistics (IBGE) [27] in a scale of 1:50.000.

Classification and extension areas of land use/land cover were obtained based on screen digitizing of LandSat-5 imagery, sensor TM (path 220, raw 075, obtained for 2009, September 13), with a spatial resolution of 30m, and a multispectral composite of three bands: near-infrared, red and green wavelengths.

Land use/land cover typology were discriminated by criteria of tone, texture and context [28] [29], using manual digitalization of polygon in ArcMap 10.2 software. Each polygon of land use was related to a previously established first level of land use class [30] [31]. The second level detailed the land use and cover typologies in each primary level.

To assess natural vegetation conditions of the Middle Mogi Guaçu watershed and all municipalities, we used 54 landscape metrics in Fragstats 4.2 [32]. We performed principal components analysis (PCA) and Spearman's rank correlation to identify independent components of landscape structure/natural vegetation conditions and to evaluate degree of redundancy among landscape metrics (non-linear and monotonic relationships between landscape metrics). PCA was based on correlation matrix of the metrics (54 patch metrics for 17 municipalities) and was deemed appropriate after examining pairwise scatterplots among metrics. To summarize the results of PCA, we calculated the number of principal component required to account for >95% of variation.

Hierarchical clustering was conducted to identify discrete groups based on dissimilarity matrix of landscape metrics among municipalities. All analyses were performed in R software [33] [34], package vegan and commands decostant (standardize), dist (distance matrix based on Euclidean distance) and hclust (based on average). We examined the dendrogram to identify which metrics were grouping municipalities.

Sustainability assessment conditions in watershed and municipalities level, for 2009, outcome from overlapping Urbanity index (UI) [11] and Landscape Vulnerability Index (LVI) [13] [35] [36].

The UI [11] reflects landscape naturalness and estimates the extension of landscape domination by strongly human-altered systems [14]. It is based on ratio between anthropogenic and natural uses (Equation (1)) [11].

$$UI = \log_{10}\left[(A+U)/(F+W)\right] \quad (1)$$

where U correspond to urban area; A agricultural area; F forest area, and W aquatic and wetland areas. The spatial representation of UI considers the maximum degree of naturalness (UI = 0) and the minimum degree of naturalness (UI = 1), which correspond to predominance of strongly human-altered systems. This index doesn't measure unit.

The LVI indicates the susceptibility of a landscape to environmental impacts, *i.e.*, environmental vulnerability decreases as the ability of the landscape to minimize environmental impacts increases [13] [35] [36]. The LVI values (Equation (2)) were obtained by two metrics, the Vegetation Quality Index (VQI) and the Water Quality Index (WQI).

$$LVI = (VQI + WQI)/2 \quad (2)$$

The VQI was estimated (Equation (3)) from the values of three metrics of vegetation patches: Area (AREA), shape (SHAPE) and distance (DISTANCE) between patches, which were obtained from the land use reclassification;

$$VQI = (AREA + SHAPE + DISTANCE)/3 \quad (3)$$

The WQI describes the susceptibility of water bodies, which is related to distances between water resources and sources of impact represented by different land uses [37]. It is based on the functional curves from the Habitat Quality Index [35] and assumes that land use and cover are related to environmental vulnerability of vegetation and water components.

A higher LVI value (1) reflected lower landscape resilience, and a lower LVI value (zero) reflected higher landscape resilience. This index doesn't measure unit.

Spatial representation of UI and LVI values was obtained based on RASTER VECTOR, AREA, and IMAGE CALCULATOR commands in the IDRISI Selva software [38], and fuzzy logic transformed by a linear function with a minimum value of 0 and a maximum value of 1. This representation considers the maximum degree of naturalness or lower landscape vulnerability with a value of zero, and the minimum degree of naturalness or higher landscape vulnerability with a value of one [37].

We performed descriptive statistical analyses and Permutational Multivariate Analysis of Variance (PERMANOVA) in the R software [33], to test the null hypothesis of equal degrees of sustainability condition between municipalities in 2009 [39]. The PERMANOVA with Euclidean distances and Monte Carlo permutation was performed to 1000 randomly points that were sampled for each municipality, with no overlap, totalizing 17,000 points. The permutation procedure was used to obtain p-values and appropriate distance based on pseudo F-statistic for each factor, and a pair-wise a posteriori comparison of levels (municipalities). The sampling was accomplished with the "dismo" [40] and "raster" [41] packages for R software [33], and PERMANOVA was performed with the "vegan" package.

4. Results

We identified four classes of land use for the Middle Mogi Guaçu watershed in 2009: 1) natural (forest, Brazilian savanna/cerrado and shrub savanna); 2) anthropogenic agriculture (pasture, annual crop, perennial crop, bare soil, forestry, small properties, and rural infrastructure); 3) anthropogenic non-agricultural (urban areas, mining, industry, and roads); and 4) aquatic ecosystem (river, lakes, reservoirs, and wetlands) (Figure 2).

For the Middle Mogi Guaçu watershed, anthropogenic uses were predominant in 2009 (74.80%). Agricultural land use occupied 71.97% of total area, and was considered the main pressure factor. Sugar cane annual crop corresponds to the predominant

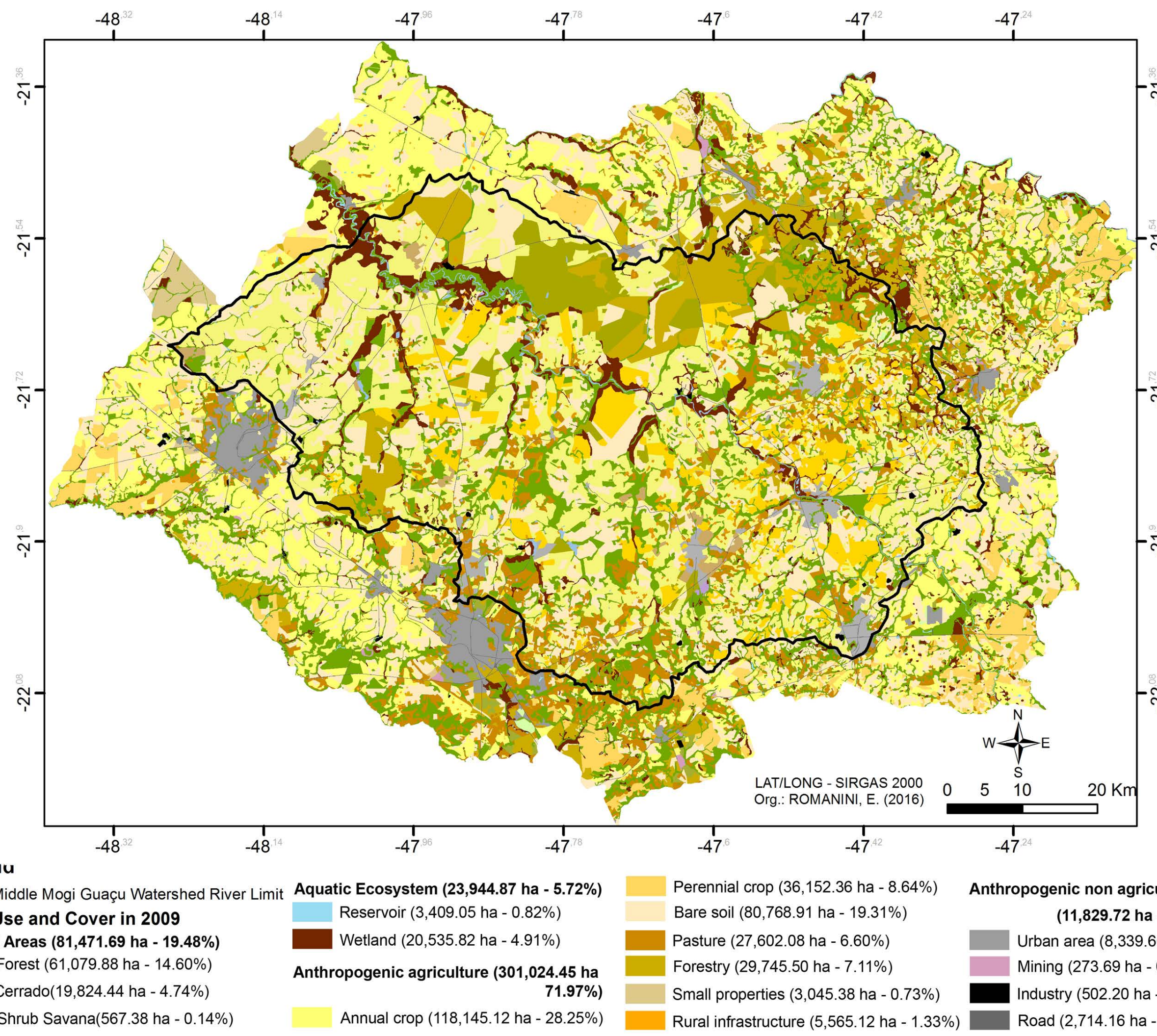

Figure 2. Spatial distribution of land use and cover classes (natural, aquatic, anthropogenic agriculture, and anthropogenic non-agricultural) and area values (ha and %) for the Middle Mogi Guaçu watershed, in 2009.

coverage in agricultural class, equivalent to 28.25% of total watershed area. Anthropogenic non-agricultural use (2.83%) did not represent a significant pressure force in relation to agricultural use (Figure 2). Similarly, anthropic uses (agricultural and non-agricultural) were predominant for all municipalities in the Middle Mogi Guaçu watershed (Figure 3).

Natural areas occupied 19.48% (159,147.27 ha) of the Middle Mogi Guaçu watershed. From this total, only 21,560.61 ha (13.55%) are categorized as integral protection and/or sustainable use legally protected areas (Figure 4).

Aquatic ecosystems occupied 5.72% of total watershed area (Figure 2).

Municipality of Araraquara had the largest anthropogenic agricultural and non-agricultural areas (83.66%), while municipality of Rincão had a minor natural extension area (8.02%) (Figure 3). Municipalities of Luiz Antônio and Analândia exhibited the largest natural extension areas (26.12% and 26.76%, respectively), probably due to presence of legally protected areas within their boundaries (Figure 3 and Figure 4).

Landscape metrics PCA analysis showed a high degree of redundancy. Four principal components accounted for more than 95% of total variance in all landscape metrics. Eight landscape metrics were selected: Number of Patches (NP), Percentage of Landscape occupied by natural vegetation (PLAND), Edge Density (ED), Largest Patch Index (LPI), Fractal Dimension Index (FRAC), Perimeter-Area Ratio (PARA), Core Area (CORE), and Euclidean Nearest-Neighbor Distance (ENN) (Table 1).

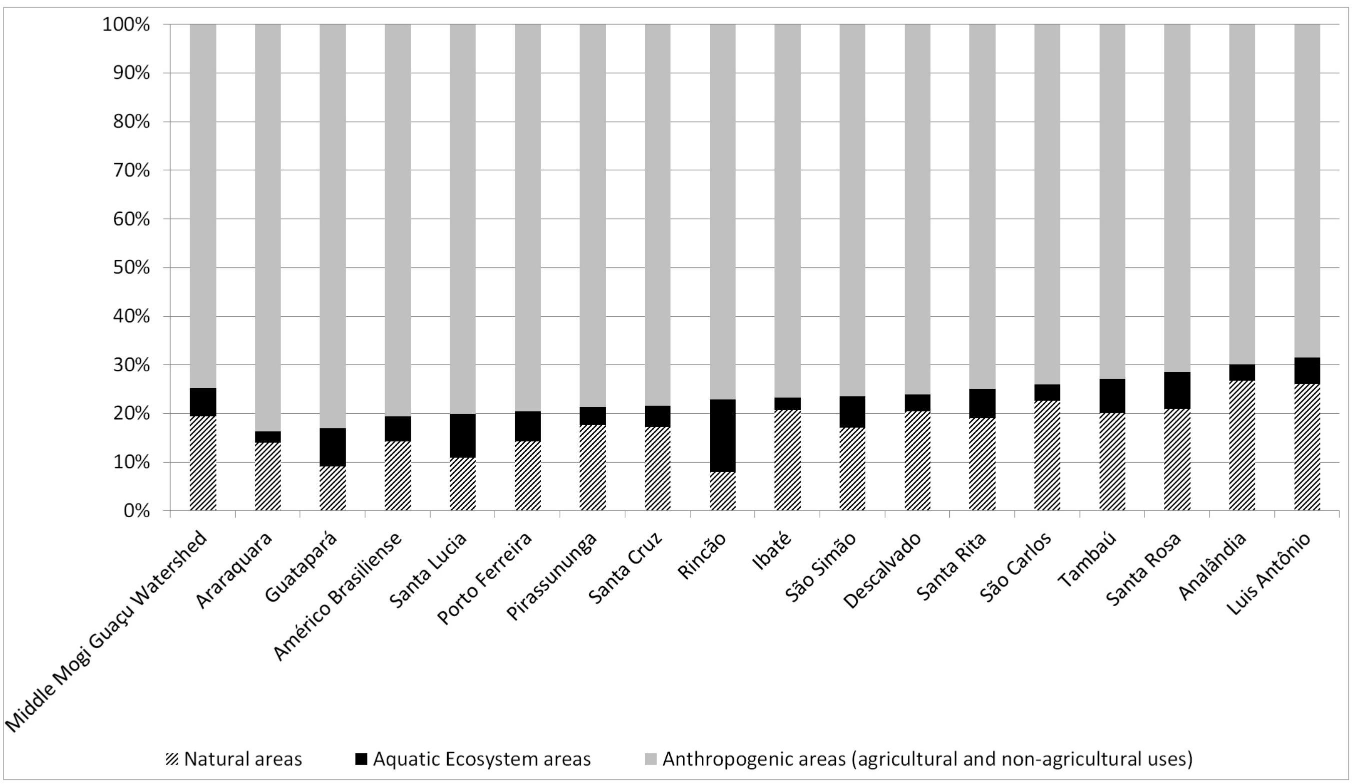

Figure 3. Area values (%) of land use classes (natural, aquatic, and anthropogenic) for the Middle Mogi Guaçu watershed and its municipalities, highlighting the human occupation gradient.

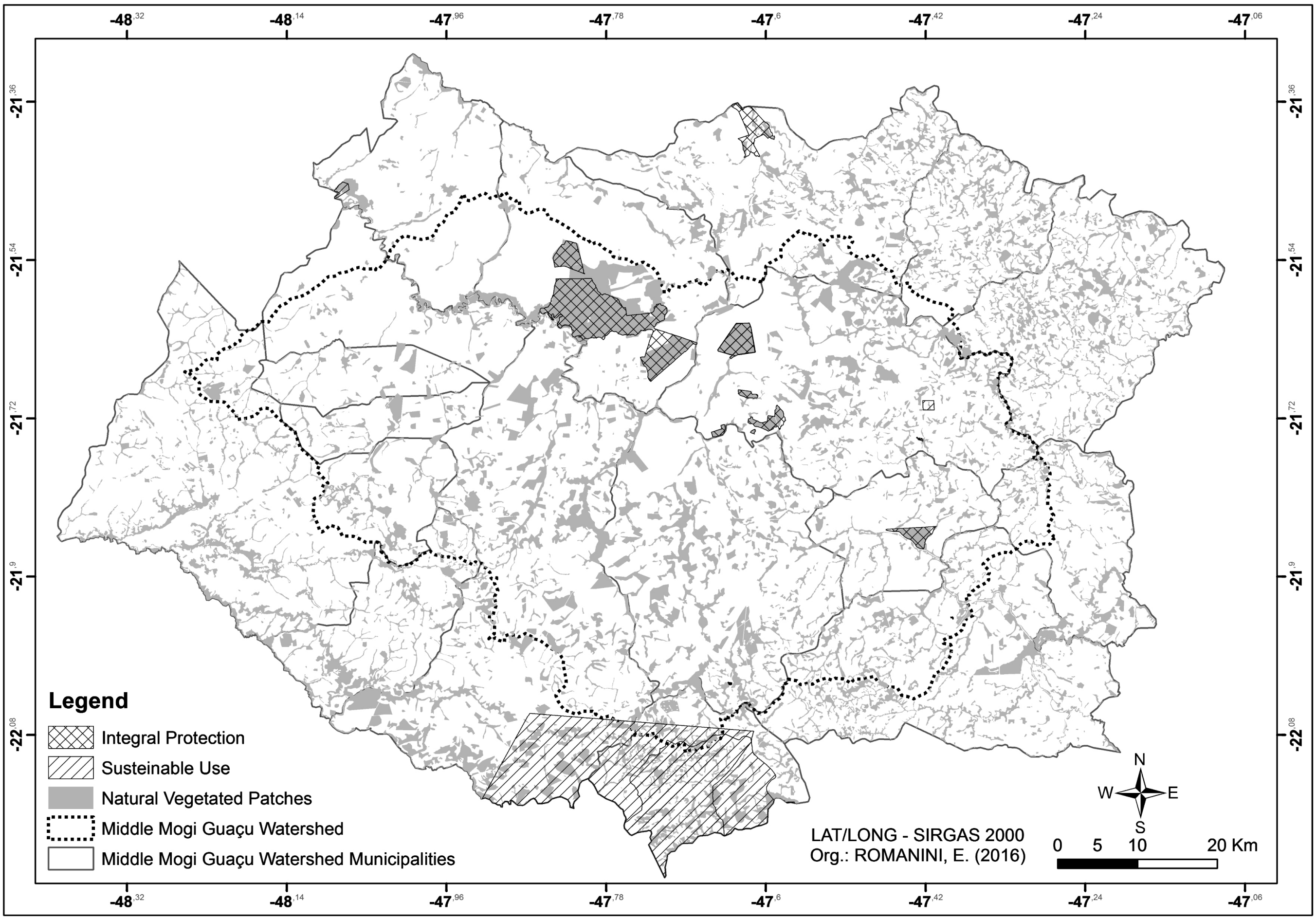

Figure 4. Spatial distribution of natural vegetation in the Middle Mogi Guaçu watershed, in 2009, highlighting the status and localization of different categories of the legally protected areas.

Municipalities were consistently aggregated into clusters based on their relationships to patch metrics. The first was formed by 15 municipalities (Américo Brasiliense, Analândia, Descalvado, Guatapará, Ibaté, Pirassununga, Porto Ferreira, Rincão, Santa Cruz das Palmeiras, Santa Lúcia, Santa Rita do Passa Quatro, Santa Rosa do Viterbo, São Carlos, São Simão, and Tambaú); the second and third were composed by municipalities of Araraquara and Luiz Antônio, respectively. Both of these municipalities were extremely fragmented: the positive end (Luiz Antônio) and the negative end (Araraquara) (Figure 5).

The dissimilarity distance between Araraquara and other municipalities (Figure 5) suggests that fragmentation was not similar to other municipalities. The PLAND, NP, PARA_MN, LPI, and CORE_MN metric values (Table 1) demonstrated that municipality of Araraquara has a lower value of natural vegetation, distributed in many fragments with complex shape and low core area. This fragmentation process is more intensive than other municipalities with a predominance of small fragments.

Metric values of LPI, ED and CORE_MN can explain the lower fragmentation in municipality of Luiz Antônio (Table 1), suggesting the presence of large size fragments

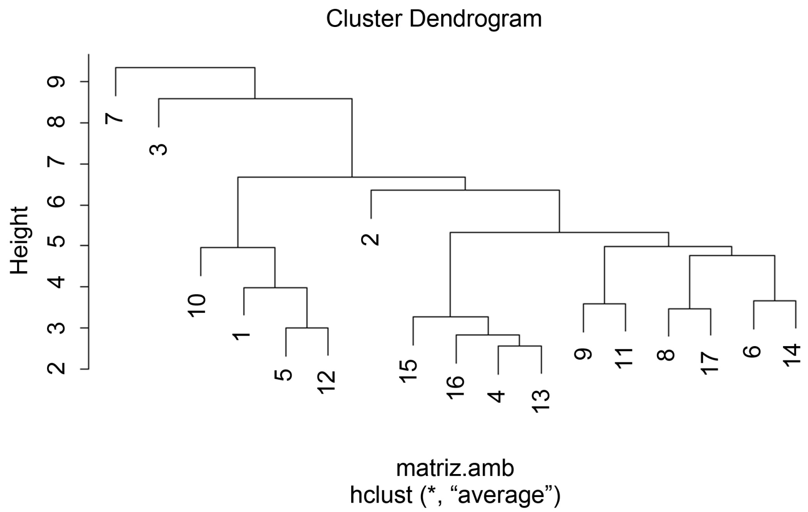

Figure 5. Hierarchical cluster dendrogram (based on Spearman rank) of eight patch metrics for 17 municipalities of the Middle Mogi Guaçu watershed: (1) Américo Brasiliense; (2) Analândia; (3) Araraquara; (4) Descalvado; (5) Guatapará; (6) Ibaté; (7) Luiz Antônio; (8) Pirassununga; (9) Porto Ferreira; (10) Rincão; (11) Santa Cruz das Palmeiras; (12) Santa Lúcia; (13) Santa Rita do Passa Quatro; (14) Santa Rosa do Viterbo; (15) São Carlos; (16) São Simão; (17) Tambaú.

Table 1. Metrics selected for fragmentation comparative analysis condition among municipalities in the Middle Mogi Guaçu watershed, in 2009: Number of Patches (NP), Percentage of Landscape occupied by natural vegetation (PLAND), Edge Density (ED), Largest Patch Index (LPI), Fractal Dimension Index (FRAC), Perimeter-Area Ratio (PARA), Core Area (CORE), and Euclidean Nearest-Neighbor Distance (ENN).

	Municipalities	Landscape metrics							
		PLAND	NP	LPI	ED	FRAC_MN	PARA_MN	CORE_MN	ENN_MN
1	Américo Brasiliense	14.33	49.00	4.15	16.11	1.09	296.39	27.24	332.45
2	Analândia	26.78	82.00	8.74	28.53	1.11	301.62	82.10	175.66
3	Araraquara	14.03	384.00	1.41	19.82	1.09	547.28	25.87	166.82
4	Descalvado	20.41	215.00	2.28	18.90	1.10	278.87	57.44	217.08
5	Guatapará	9.13	83.00	1.95	9.08	1.10	308.65	34.57	337.92
6	Ibaté	20.65	116.00	8.06	25.32	1.10	444.14	37.38	177.84
7	Luiz Antônio	26.11	122.00	16.67	8.94	1.09	397.20	117.66	256.28
8	Pirassununga	17.66	310.00	1.73	25.71	1.11	334.61	28.59	185.25
9	Porto Ferreira	14.22	101.00	2.79	18.10	1.11	327.98	24.66	231.92
10	Rincão	8.03	98.00	2.05	10.09	1.10	373.12	18.08	345.85
11	Santa Cruz das Palmeiras	17.30	118.00	3.72	23.60	1.12	301.97	30.25	190.75
12	Santa Lúcia	10.87	43.00	2.45	12.58	1.09	306.04	28.50	412.71
13	Santa Rita do Passa Quatro	19.03	250.00	2.05	18.44	1.10	321.28	45.43	222.77
14	Santa Rosa do Viterbo	20.93	136.00	2.80	30.25	1.11	309.69	30.54	173.09
15	São Carlos	22.63	350.00	1.69	19.22	1.10	298.53	59.94	212.57
16	São Simão	17.06	191.00	1.81	20.32	1.12	261.05	41.00	249.23
17	Tambaú	20.01	280.00	2.63	30.60	1.12	333.08	27.14	179.44

with high core areas and low edge effects.

Spatial distribution of fragments is an important factor in landscape fragmentation. Increased isolation of fragments makes habitat connection difficult, resulting in lower species richness and composition and negatively impacting plant dispersion and animal movement among sites [42] [43].

Almeida [44] classified the isolation distance between fragments as low (up to 60 m), medium (from 60 to 120 m), high (from 120 to 200 m), and very high (above 200 m). According to this scale [44], all municipalities had high to very high isolation distances in terms of the average of Euclidean distance (ENN_MN) of the natural vegetation patches (**Table 1**). **Figure 4** shows isolation distance, representing the natural vegetation fragments spatial distribution in all Middle Mogi Guaçu watershed municipalities.

The spatial representation of Urban Index (UI) values (**Figure 6**) reflects a condition of low naturalness (majority of UI values above 0.4), associated with urban growth and demand of area for agricultural production, leading to watershed and municipalities anthropization.

The distribution of Landscape Vulnerability Index (LVI) values in the Middle Mogi

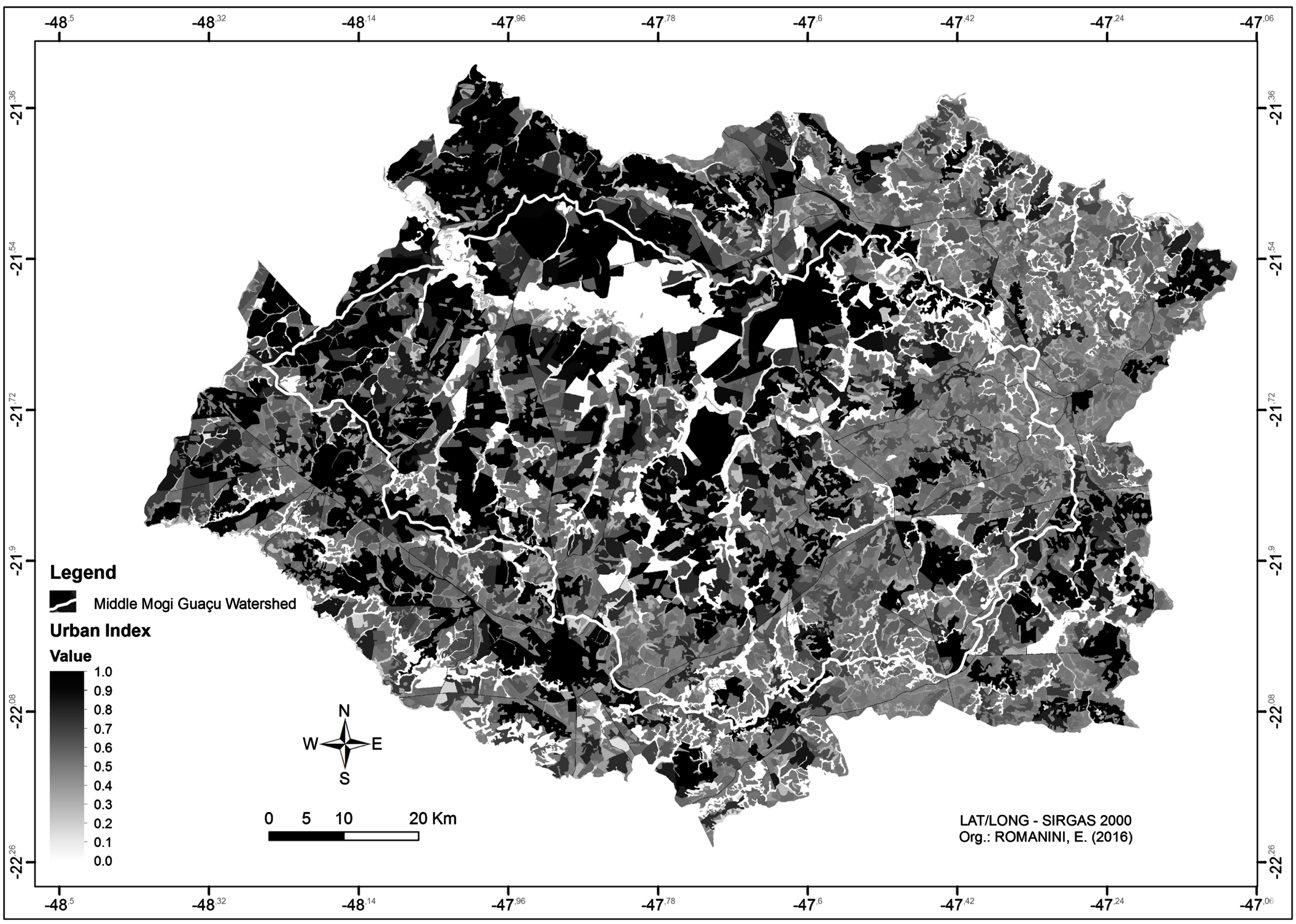

Figure 6. Spatial representation of Urban Index (UI) values relative to the Middle Mogi Guaçu watershed and its municipalities.

Guaçu watershed and its municipalities reflect the degree of susceptibility in relation to landscape capacity to absorb environmental impacts (resilience), showing intermediate vulnerability due to the predominance between 0.2 and 0.6 of LVI values (Figure 7).

The UI and LVI median values and interquartile intervals were irregular for all study areas. In municipalities of Analândia and Luiz Antônio, index value distribution was closer to a situation of high naturalness (low UI values), and low vulnerability (low LVI values), suggesting a better sustainability condition for these municipalities (Figure 8).

Overlaying UI and LVI values enable us to identify favorable conditions for biodiversity conservation and ecological sustainability scenarios (Figure 9), related to UI and LVI values ≤ 0.3, corresponding to higher naturalness and higher capacity (resilience) to absorb impacts. In contrast, UI and LVI values ≥ 0.7 corresponding to lower naturalness and higher vulnerability, indicating the ecological sustainability commitment [37].

The null hypothesis of equal conditions of ecological sustainability among municipalities in the Middle Mogi Guaçu watershed was rejected ($\alpha = 0.05$, F = 32.65, p = 0.002).

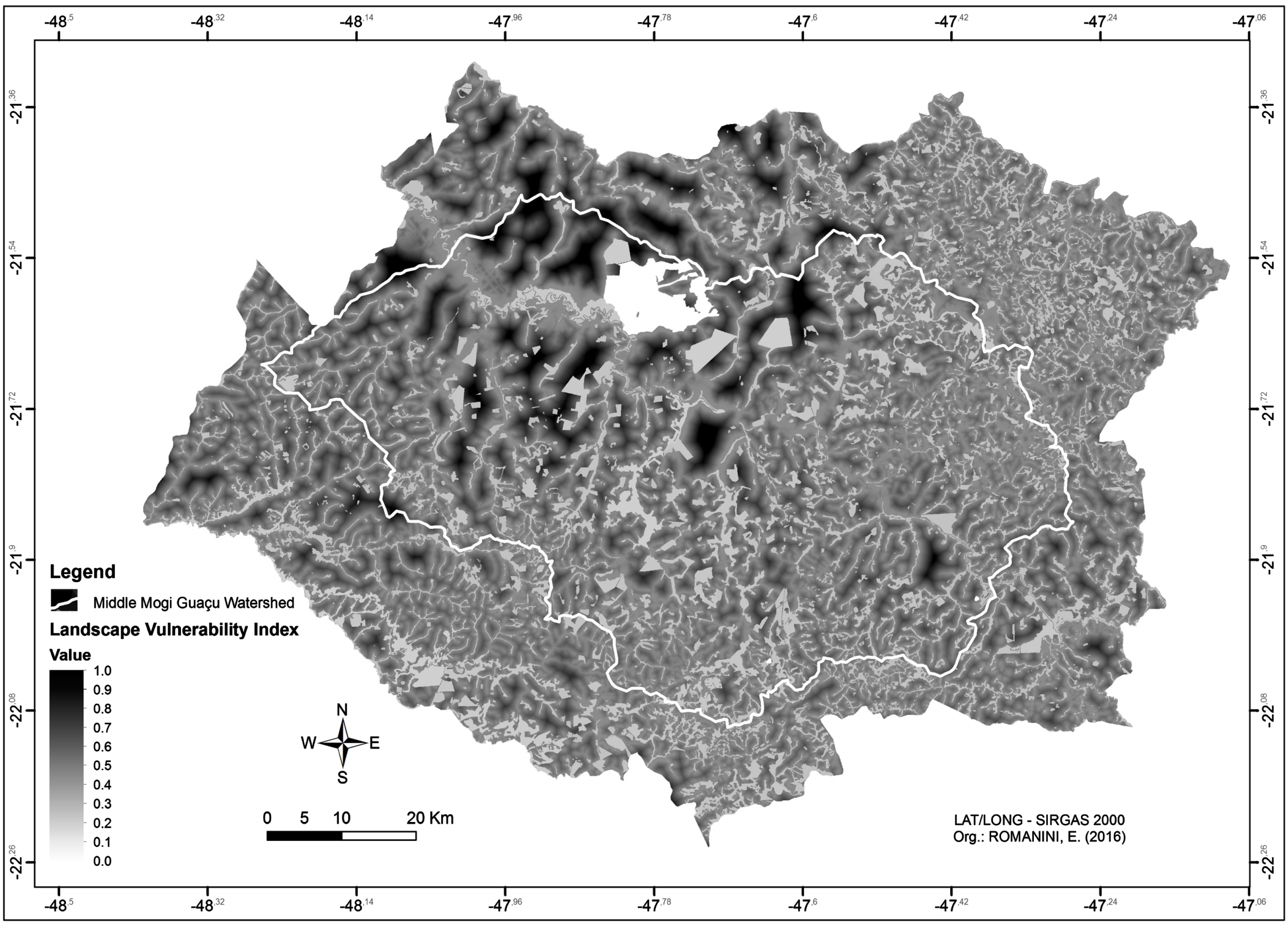

Figure 7. Spatial representation of Landscape Vulnerability Index (LVI) values relative to the Middle Mogi Guaçu watershed and its municipalities.

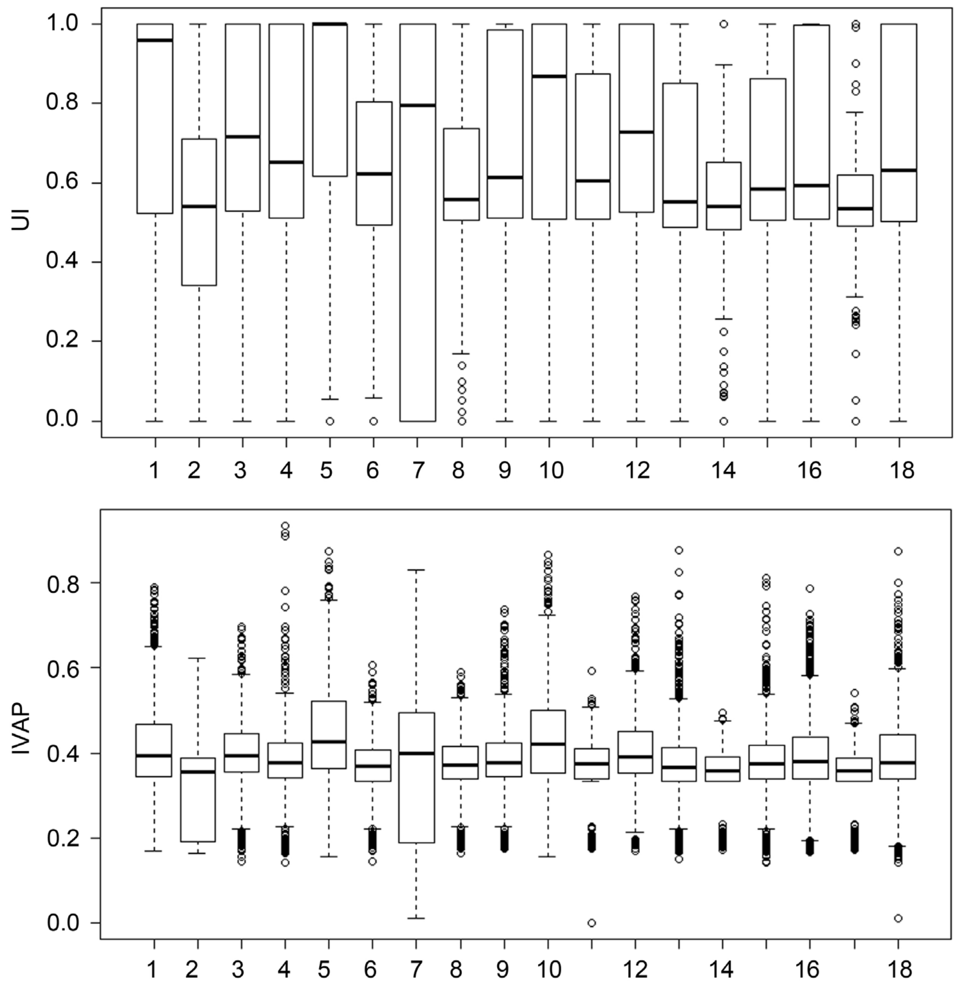

Figure 8. Boxplots of Urbanity Index (UI) and Landscape Vulnerability Index (LVI) for Middle Mogi Guaçu watershed and its municipalities in 2009: (1) Américo Brasiliense; (2) Analândia; (3) Araraquara; (4) Descalvado; (5) Guatapará; (6) Ibaté; (7) Luiz Antônio; (8) Pirassununga; (9) Porto Ferreira; (10) Rincão; (11) Santa Cruz das Palmeiras; (12) Santa Lúcia; (13) Santa Rita do Passa Quatro; (14) Santa Rosa do Viterbo; (15) São Carlos; (16) São Simão; (17) Tambaú; (18) Middle Mogi Guaçu Watershed River.

The pair-wise posteriori comparison among seventeen municipalities (Table 2) indicated that ecological sustainability conditions are similar between municipalities of Descalvado-Santa Cruz das Palmeiras-Luiz Antônio; Porto Ferreira-São Carlos-Luiz Antônio; and São Carlos-Pirassununga-Santa Rita do Passa Quatro. These similarities maybe are associated with presence of scenarios with less committed ecological sustainability and favorable areas to biodiversity conservation. The municipalities of Rincão and Guatapará are those had greater ecological sustainability commitment.

5. Discussion

The Middle Mogi Guaçu watershed is an example of the negative impact of anthropogenic land use (agricultural and non-agricultural uses).

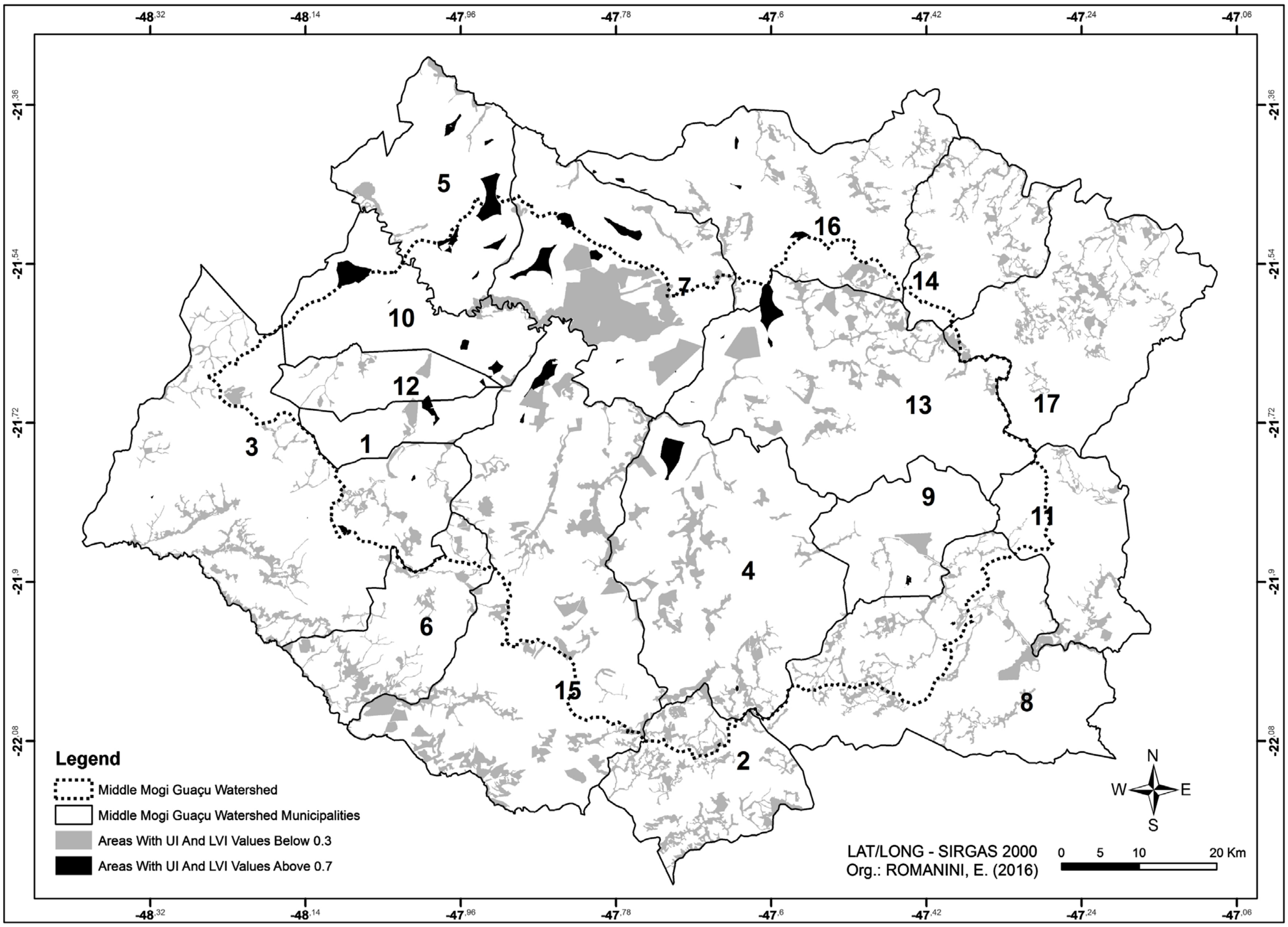

Figure 9. Biodiversity conservation and ecological sustainability scenarios resulting from Urbanity Index (UI) and Landscape Vulnerability Index (LVI) values for Mogi Guaçu Watershed and its municipalities: (1) Américo Brasiliense; (2) Analândia; (3) Araraquara; (4) Descalvado; (5) Guatapará; (6) Ibaté; (7) Luiz Antônio; (8) Pirassununga; (9) Porto Ferreira; (10) Rincão; (11) Santa Cruz das Palmeiras; (12) Santa Lúcia; (13) Santa Rita do Passa Quatro; (14) Santa Rosa do Viterbo; (15) São Carlos; (16) São Simão; (17) Tambaú.

Land use significantly started to change in the late 17th century due to a rise in population; the main land use types were coffee, timber, and sugarcane cultivation [45]. These changes significantly contributed to a decrease in floristic composition [46].

In Brazil, sugarcane is one of the main agricultural products and has been exported since the 18th century [47]. Currently, Brazil is the largest sugarcane producer in the world [48], with 7,531,000 ha of cultivated area [49]. The State of São Paulo accounts for more than 50% of the national sugarcane production [47] [50], occupying 4,809,200 ha in the 2009-2010 harvest [49]. The Middle Mogi Guaçu watershed municipalities produce about 7.14% [49] of the total sugarcane crop in the state of São Paulo.

Analysis of land use changes related to sugarcane cultivation (collected between 2008 and 2009) showed that this crop expansion almost exclusively affected pasture (56.5%) and annual crops (40.2%) [48]. Human-induced land use changes for agricultural purposes, as observed in Middle Mogi Guaçu watershed and its municipalities, lead to

Table 2. Pairwise a posteriori comparisons of urbanity index (UI), landscape vulnerability index (LVI) to seventeen municipalities in the Middle Mogi Guaçu watershed, in 2009, using a and Permutational Multivariate Analysis of Variance (PERMANOVA), where (1) Américo Brasiliense; (2) Analândia; (3) Araraquara; (4) Descalvado; (5) Guatapará; (6) Ibaté; (7) Luiz Antônio; (8) Pirassununga; (9) Porto Ferreira; (10) Rincão; (11) Santa Cruz das Palmeiras; (12) Santa Lúcia; (13) Santa Rita do Passa Quatro; (14) Santa Rosa do Viterbo; (15) São Carlos; (16) São Simão; (17) Tambaú.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	0.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	0.021	0.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	0.002	0.002	0.002	-	-	-	-	-	-	-	-	-	-	-	-	-
5	0.002	0.002	0.002	0.002	-	-	-	-	-	-	-	-	-	-	-	-
6	0.002	0.002	0.002	0.002	0.002	-	-	-	-	-	-	-	-	-	-	-
7	0.002	0.002	0.002	0.235*	0.002	0.011	-	-	-	-	-	-	-	-	-	-
8	0.002	0.002	0.002	0.002	0.002	0.002	0.002	-	-	-	-	-	-	-	-	-
9	0.002	0.002	0.002	0.009	0.002	0.002	0.526*	0.002	-	-	-	-	-	-	-	-
10	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	-	-	-	-	-	-	-
11	0.002	0.002	0.002	0.282*	0.002	0.009	0.213*	0.002	0.002	0.002	-	-	-	-	-	-
12	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	-	-	-	-	-
13	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.92*	0.005	0.002	0.002	0.002	-	-	-	-
14	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	-	-	-
15	0.002	0.002	0.002	0.002	0.002	0.002	0.064*	0.580*	0.015	0.002	0.005	0.002	0.534*	0.002	-	-
16	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	-
17	0.002	0.007	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.202	0.002	0.002

*non-significative with p > 0.05, based on p-values after 4999 Monte Carlo permutations.

decrease in the regional sustainability potential, due to loss of natural capital and environmental functions that determine environmental quality for economic and social development.

The monitoring of naturalness dynamics of a landscape, in time and space can provide essential information about current and historical conditions and nature-society interactions, which can be disseminated through scientific community, general public and decision makers.

The conversion of natural areas to agricultural land quite often results in habitat fragmentation and decreased patch number and size [51]. Landscape fragmentation can be considered as one of the main driver forces in landscape dynamics [52].

The Middle Mogi Guaçu watershed and its municipalities are mainly composed by patches of natural areas with shape, size and quantity of core area which enhance edge effect. Besides that, the fragments spatial distribution increases isolation among habitats. Forest fragmentation in this area shows two extremes: the highly fragmented municipality of Araraquara (small patches and large edge effects), and municipalitiy of Luiz Antônio, with larger fragments and smaller edge effects. It should be emphasized that small fragments are also important, especially in the vicinity of large natural vegetation areas, acting as stepping-stones [8] [44] [53].

The biodiversity conservation scenarios of Middle Mogi Guaçu watershed and its municipalities, based on UI and LVI values and fragmentation process analysis, showed direct (land use) and indirect (population growth, policies for agricultural and forestry expansion associated to the demand for food and fuel) driver forces for decreased biodiversity and ecological sustainability. Scenarios of less committed ecological sustainability and favorable biodiversity were mainly represented in municipalities with legally protected areas (Integral Protection and Sustainable Use status) in their territories. The municipalities with greater commitment to ecological sustainability were occupied by sugar cane crops.

Sugarcane has a high economic return and can be used in food industry and as an alternative energy source. Therefore, the large-scale production of ethanol has positive socioeconomic effects and contributes to the development of host municipalities and neighboring municipalities due to spatial and temporal effects [54]. It is also of large social importance, generating about one million direct jobs in agricultural and industrial sectors [50] [55].

Several studies indicate that a critical threshold of 30% can be considered as the lower limit of vegetation amount that a cultural landscape must present to maintain a balance between biodiversity conservation and economic factors [56]-[59]. In the Middle Mogi Guaçu watershed and its municipalities, the amount of natural area is below this critical threshold.

Legally protected areas are important for biodiversity conservation and maintenance of cultural values associated with environmental protection [26], contributing to ecological sustainability. However, even in municipalities with protected areas throughout their territories, environmental quality may be compromised. For conservation policies to be effective, they must focus on ecological corridors around legally protected area, and new legal reserves creation, with the purpose to improve biodiversity and ecological sustainability of the Middle Mogi Guaçu watershed and its municipalities.

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