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EVALUATION OF PROTECTED AREA EXPANSION IN THE CASE OF THE SERRA DOS ÓRGÃOS NATIONAL PARK, RIO DE JANEIRO, BRAZIL

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Abstract – Manmade fragmentation of the Brazilian Atlantic forest poses a serious threat to the biodiversity of the various ecosystems of this unique biome. To counteract this fragmentation process, the Serra dos Órgãos National Park initiated an expansion project aiming at the inclusion of the adjacent Serra da Estrela mountain range into the National Park area. This work analyzes this region from two different points of view to define the most suitable expansion possibility. The protection suitability evaluation assesses the individual landscape patches according to their ecological value. The urbanization suitability evaluation assesses the same landscape patches according to their suitability for future urban growth. To calculate the suitability for protection, as well as urbanization, the method of Multi-Criteria Evaluation (MCE) is applied. The results of the two suitability evaluations are combined and analyzed to identify core areas and conflict zones of the potential expansion area of the National Park.

Keywords – Serra dos Órgãos National Park, protected area expansion, urban growth, suitability analysis, fuzzy sets, multi-criteria evaluation.

INTRODUCTION

To counteract uncontrolled and irregular urban growth, the management of the Serra dos Órgãos National Park started a project to expand the park area along the Serra da Estrela mountain range towards the Tinguá Biological Reserve to raise the protection status of this ecological corridor and prevent further human interference. This corridor is of major importance, as it connects the two protected areas – the Serra dos Órgãos National Park and the Tinguá Biological Reserve (**Figure 1**).

This work contributed to the expansion project by analyzing the region to identify potential areas suitable for being incorporated into the Serra dos Órgãos National Park. The main objective was to evaluate the protection suitability and the urbanization suitability of the landscape patches within the research area to identify potential conflict zones between these two interests. Using this evaluation as a basis, it was possible to define a potential expansion area including patches which are highly suitable for protection and excluding areas which are prone to urbanization.

The protection suitability evaluation was conducted to get insight into the ecological value of the single landscape patches caused by the present vegetation cover and land use type. Based on this information, the landscape patches could be assessed in view of their importance for being incorporated in the expansion area of the Serra dos Órgãos National Park.

The objective of the urbanization suitability evaluation was to identify those zones within the research area, which provide appropriate conditions for future settlement and urban expansion. Hereby, the landscape patches were analyzed according to criteria such as vegetation cover and proximity to infrastructural facilities which make them favorable for settlers. The fragments could then be ranked according to their potential for being urbanized.

Finally, this work aimed to provide the Serra dos Órgãos National Park management with detailed information about the possibilities and limitations of the planned expansion project. A final map and an explicatory report pointed out the potential core expansion area, with landscape patches of high ecological value and the potential conflict zones caused by expanding urbanization. That way, this work contributed to the optimization of the expansion area and its sustainability.

DATA AND METHODS

GIS development

A GIS was developed based on aerial photographs taken in 1999 at a scale of 1:10,000 provided by AMPLA (AMPLA Energia e Serviços SA). The raw GIS data was processed by the cooperative ESTRUTURAR, which was also involved in the expansion project of the Serra dos Órgãos National Park.

Protection suitability evaluation

As a first step, the protection suitability of the single patches of different land use was evaluated. Subsequently, the classes of a land use map were ranked according to their ecological potential. The resulting map allocates a suitability level to each patch within the landscape to assess the possibility of its incorporation into the National Park.

The starting point of the protection suitability evaluation was a land use classification of the research area into 14 different classes. The method chosen for classifying land use can be described as manual digitalization using aerial photographs as a basis. This method was preferred over automate remote sensing classification methods because there had been a previous classification covering most of the research area provided by the cooperative ESTRUTURAR using the latter method. Thus, the land use classification map set only had to be completed and refined. Moreover, the chosen resolution for the raster model of the Multi-Criteria Evaluation (MCE) of 10x10m did not allow for using available Landsat 7 satellite images with a resolution of 30x30m. The 10x10m resolution of the aerial photographs provided by AMPLA was chosen to also identify small land use features such as single houses and small streets.

The single land use classes were grouped into general suitability classes according to their ecological value and their importance for the National Park. For finer differentiation of the 14 land use classes with respect to their protection suitability, the classes within the general groups were further processed applying a method which is common in decision support applications: the Analytical Hierarchy Process (AHP) (Eastman, 1993; Granzol, 2005; Banai-Kashani, 2005).

This procedure is based on the technique of pairwise comparisons developed by Saaty (1977). The purpose of this technique is to rank criteria according to their weight or significance with respect to a specific objective or decision. The AHP breaks down the weighting by comparing only two criteria in pairs at each step of the procedure. In this manner, ratings are provided on a 9-point continuous scale of comparison (**Table 1**).

Table 1 *- AHP 9-point continuous scale*

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very strongly	strongly	moderately	**equally**	moderately	strongly	very strongly	extremely
less important					**more important**			

The eigenvector and the maximal eigenvalue of the comparison matrix are then calculated to get a best-fit of criteria weights. This method quantifies the verbal comparison and assigns a value to each criterion representing its weight. In the Weighted Linear Combination (WLC) concept, this weight value is within a range of 0 to 1; the sum of all criteria weights sum up to 1.

Urbanization suitability evaluation

In the second phase of the project, an urbanization suitability evaluation of the region was conducted. As a starting point, the following question was put: “Where are the areas of potential urban growth according to the present natural and infrastructural conditions?” In order to get quantitative results, five suitability criteria for urban growth were defined: existing land use, slope, proximity to existing settlements, proximity to roads and proximity to rivers. Subsequently, the method of Multi-Criteria Evaluation (MCE) (Malczewski, 1999; Florent et al., 2001) was applied to these criteria to get a map classifying the area of interest into zones of different urbanization suitability.

The first step of the urbanization suitability evaluation was to select the criteria which best represented the landscape suitability for urban expansion. As this project focused on land use aspects, no economic or property-related criteria were chosen. The criteria selection was based on the concepts of widely applied urban growth models such as SLEUTH, SCOPE and the WhatIf? model, which use suitability criteria for the selection of developable sites (Candau, 2002; Clarke, 2005; Jones 2005; Klostermann, 1997). Hereby, suitability ratings are generally determined by proximity to infrastructure and services, topographic conditions, demographic patterns, etc. (Johnston and Shabazian, 2002).

After the literature review, these basic urban growth modeling concepts were adapted to the local conditions of the research area. The major underlying idea was that urban expansion normally develops from existing settlements. In general, this expansion is oriented or influenced by the existence of transport system, rivers and characteristics of the landscape, such as present land use and slope (Johnston and Shabazian, 2002; Varanka, 2006; Clarke, 1998; Wilson et al., 2002). This concept was the starting point for selecting the five criteria of urban expansion suitability:

Existing land cover (Code used within this project: LAND): The assumption was that people prefer to settle on land which requires minimum effort of preparation for housing. For example, grass land is preferred over land covered with dense forest.

Slope (Code: SLOPE): This is one of the most regularly used criteria for settlement suitability in modeling urban growth. The ranges of slope suitability within the research area were defined by adjusting commonly used values to the special situation in the low-developed settlement of the research area.

Proximity to existing settlements (Code: PROXSET): Existing settlements provide better infrastructural, economic and social structures than areas far away from any development. Therefore, the assumption was that urban growth has its starting point at existing settlements.

Proximity to roads (Code: PROXROD): This criteria, also known as road gravity, indicates that urban growth is generally orientated along existing roads due to good accessibility and economic possibilities.

Proximity to rivers (Code: PROXRIV): During the preliminary field trips it was come upon that proximity to rivers plays an important role when settlements in rural Brazilian areas are concerned. Most of the small towns and villages in the research area have poor wastewater collection systems. One of the possibilities chosen by people to get rid of wastewater and garbage is to use rivers as natural sewers. For that reason, proximity to rivers states a settlement advantage and was chosen as a criterion.

The five criteria had to be quantified and combined to get a single urbanization suitability value for each cell within a raster model. This model assigned a probability to each cell, which indicated the likelihood of the cell to be urbanized according to criteria. The cell state (value of urbanization suitability [0-255]) depended on the weighted combination of five of the urbanization suitability criteria.

Before combining the values of the five criteria to one single value, the different measuring units of the criteria (degree, land use type, and distance) had to be standardized. For the criteria standardization fuzzy set, membership functions were applied (except for criterion 1). The gradual suitability representation of the fuzzy method was preferred over sharp suitability classes for all criteria except for criterion 1. Criteria 2 to 5 are of spatial nature and therefore it would have been difficult to set sharp boundaries of suitability classes.

Fuzzy logic is an alternative to traditional Boolean logic developed for modeling human knowledge and consideration in a mathematical way to make computation possible. Applying fuzzy logic, terms like “very steep”, “quite distant” and “extremely unsuitable” can be represented quantitatively and calculated mathematically (Kruse et al, 1994). This method was first introduced to the scientific community when Lofti Zadeh published his essay “Fuzzy sets” (Zadeh, 1965). In contrast to traditional sets (where an element can only be fully contained or not), fuzzy sets can also contain elements partially (Hall et al., 1992). If Boolean logic elements have only the values 0 (not contained) and 1 (contained), fuzzy set elements can also have values in-between 0 and 1. The degree of membership of an element to a fuzzy set is defined by the membership function.

For applying the Weighted Linear Combination method (WLC) to the standardized and quantified criteria, a weighting was necessary. The task was to get a ranking of the criteria representing the significance of each criterion with respect to its influence on the urban expansion. One can think of the hypothetical decision problems of a settler: Should I settle close to the existing settlement or do I prefer proximity to the street? Should I settle on a plane area or do I prefer the steep hill with proximity to the river?

The used weights refer to commonly applied suitability ranges for urban expansion criteria (Yang and Low, 2003; Johnston and Shabazian, 2002; Clarke, 1998). These values, ranging from 0 to 1 and summing up to 1 for all criteria, were adjusted to the situation within the research area through interviews with locals and with geographers of the cooperative ESTRUTURAR (http://www.estruturar.com.br/), and through interpretation of fieldwork data.

The last step was to combine the criteria to get one single suitability value for each pixel. This was achieved by the weighted linear combination of the criteria according to the following formula (Eastman, 1993):

$$S = \sum w_i x_i$$

where:

S = suitability value

w_i = weight of criterion i

x_i = original value of criterion i

To get the maximal potential urban expansion area, a worst case scenario was developed. Thus, four different scenarios were created by changing the weights of the criteria. Then, the highest urbanization suitability value of each cell was taken comparing the four scenarios.

Final integrated analysis

The outcome of the protection suitability evaluation and the urbanization suitability evaluation were combined resulting in a map representing potential core zones of protection and potential conflict zones. The potential core zones of protection are characterized by high protection suitability levels and low urbanization suitability levels. Within the potential conflict zones, the levels of both protection suitability and urbanization suitability are high. A map was generated as a final product, proposing the limits for the extension area considering the following requirements defined by the National Park Management:

- The area should be composed of mainly land use classes which are of high protection value.
- The area should be as distant as possible from human infrastructure such as settlements, roads and supply networks so as to reduce negative disturbance effects.

- The area should be as large and compact as possible to provide sufficient core area and to reduce negative edge effects.
- The contrast between the single patches and their surrounding environment should be as small as possible to stimulate corridor effects between these patches.
- The distance between the patches of the classes with high protection value should be as small as possible to stimulate animal movement and seed dispersal between these patches.
- The limit for the extension area should also represent natural barriers for future urban growth. They should be obvious and visible not only on maps but also in the field (steep hills, rivers, etc.).

RESULTS AND ANALYSIS

Protection suitability evaluation

A land use classification map was provided by the cooperative ESTRUTURAR, and was used as input data for the protection suitability evaluation. This classification map covered about 80% of the research area. The remaining 20% had to be completed by using aerial photographs from AMPLA (**Figure 2**).

The significance of the land use classes for the expansion project had to be evaluated. The single classes were assessed whether they were of interest to the National Park and whether they had an ecological value that justified the incorporation of patches of this class into the expansion area. Four general suitability groups were defined during this process, and the single classes were assigned to one of the following groups:

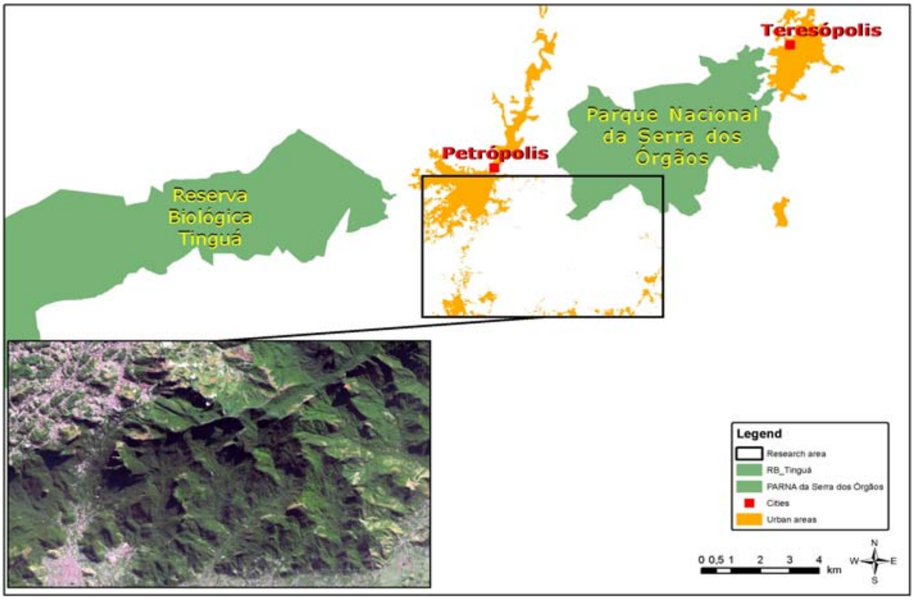

__Figure 1__- The research area of the project: Serra da Estrela

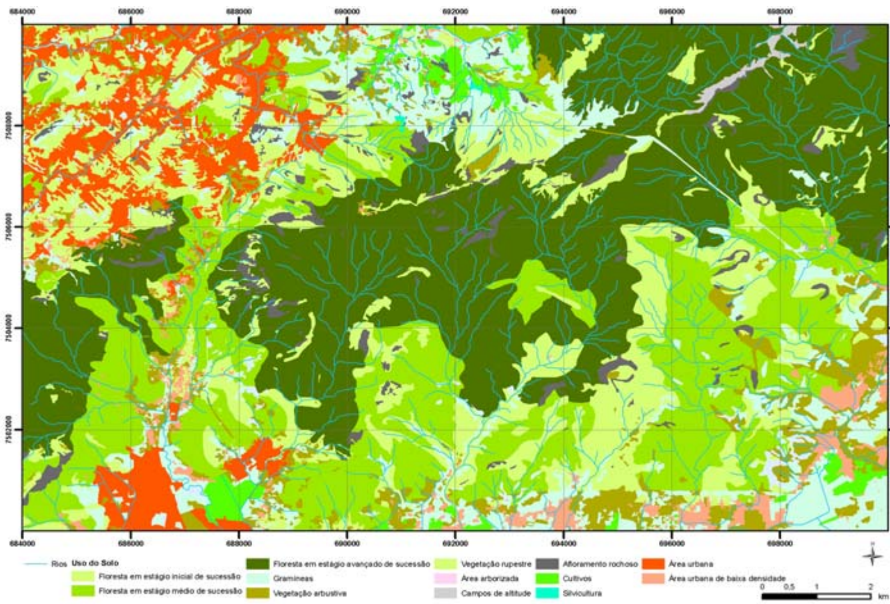

__Figure 2 -__ Land use map of the research area

Suitability Group 1 - High suitability**:** This group contains all classes which are of high suitability for the expansion area. CamAlt and VegRup in general contain high numbers of endemic species, and the protection of these ecosystems is a defined goal for the National Park (IBAMA, unpublished). Forest patches classified as FlorAvan are considered as the most natural and undisturbed form of forest, and they can be found within the region. Due to the abundance of orchids, bromeliales, and asteraceae within even small patches of the class VegRup, the AfloRo class was also classified as highly suitable (**Table 2**).

Suitability Group 2 - Medium suitability: This group contains the forest types FlorMed and FlorInic. Both classes are not of highest priority for the National Park, but still have important values and functions to be considered. If incorporated into the expansion area, they can develop further without being endangered by human disturbance (**Table 3**).

Suitability Group 3 - Low suitability**:** Patches of the classes within this group are either under permanent or periodic human use (Culti, Grami, Silvi), have suffered from human use (SolExp), or have recently been abandoned (VegArb). None of these classes are of high ecological value for the National Park. They may even have a negative influence on other patches due to human activities, and may represent barriers for ecological fluxes of flora and fauna. Yet, they were not considered of no ecological value. If a small patch of this group is surrounded by high-value patches, action-taking for improving the state of this patch could be considered (**Table 4**).

Suitability Group 4 - No suitability**:** The classes of this group are not appropriate for incorporation into the National Park expansion area at all. Their

Table 2 *- Land use classes of the protection suitability group 1*

Suitability Group 1 (SutGrup1): High suitability			
Landuse class (english)	**Landuse class (portuguese)**	**Code**	**ID_Class**
Rock	Afloramento rochoso	AfloRo	1
High-altitude grassland	Campos de Altitude	CamAlt	2
Forest (advanced development stage)	Floresta em estagio avançado de sucessão	FlorAvan	3
Rock vegetation	Vegetação rupestre	VegRup	4

Table 3 *- Land use classes of the protection suitability group 2*

Suitability Group 2 (SutGrup2): Medium suitability			
Landuse class (english)	**Landuse class (portuguese)**	**Code**	**ID_Class**
Forest (initial development stage)	Floresta em estagio inicial de sucessão	FlorInic	6
Forest (medium development stage)	Floresta em estagiobmédio de sucessão	FlorMed	5

Table 4 *- Land use classes of the protection suitability group 3*

Suitability Group 3 (SutGrup3): Low suitability			
Landuse class (english)	**Landuse class (portuguese)**	**Code**	**ID_Class**
Cropland	Cultivos	Cultiv	10
Grassland	Gramíneas	Grami	9
Silviculture	Silvicultura	Silvi	8
Open soil	Solo exposto	SolExp	11
Shrub vegetation	Vegetação arbustiva	VegArb	7

ecological value is considered zero or very low, their disturbance potential for communities of flora and fauna is high and SNUC regulations even prohibit their existence within the limits of National Parks (Senado Federal, 2002) (**Table 5**).

After this first general grouping, the Analytical Hierarchy Process (AHP) was applied in order to get a more refined ranking of the classes. For establishing the pairwise comparison matrix, the classes of the suitability group 1 and suitability group 4 were considered as one class, respectively. To weigh the classes with the 9-point comparison scale values, the following questions were put:

- Which class is of major interest for the expansion project?
- Which class is of minor interest for the expansion project?

After some reconsideration of the single pairs of comparison within the matrix (**Table 6**), a ranking with a reasonable Consistency Ration (CR) of 0.10 – Saaty (1977) recommends a CR value equal or smaller than 0.10 - could be achieved (**Table 7**).

Urbanization suitability evaluation

After the definition of which criteria were relevant for urban expansion, they had to be quantified and standardized. For that reason, a point on a scale from 0 to 255 (0 for not suitable and 255 for utmost suitable) was applied to each criterion. Using such a scale had technical reasons as the GIS software IDRISI, which was applied in this step, requires this scale as input.

***Criterion 1 - Existing land use (LAND)*:** The land use classification map functioned as the input for criterion of existing land use. The relevant question was, which classes are adequate for urban expansion due to the efforts one has to make to prepare the landscape patches of these classes for settling and housing.

In the case of the criterion LAND, a simple ordinal ranking of the classes was developed. Structures considered not at all suitable for housing and settlement

Table 5 *- Land use classes of protection suitability group 4*

Suitability Group 4 (SutGrup4): No suitability			
Landuse class (english)	**Landuse class (portuguese)**	**Code**	**ID_Class**
Street	Estradas	Estrad	12
Urban area	Área urbana	AreUrb	14
Urban area (low density)	Área urbana de baixa densidade	AreUrbBa	13

Table 6 *- Pairwise comparison matrix of land use classes*

	SutGrup1	FlorMed	FlorInic	Cultiv	Grami	Silvi	SolExp	VegArb	SutGrup4
SutGrup1	1								
FlorMed	0.3333	1							
FlorInic	0.1667	0.2500	1						
Cultiv	0.1111	0.1429	0.2000	1					
Grami	0.1111	0.2000	0.2000	3.0000	1				
Silvi	0.1111	0.2000	0.3333	3.0000	3.0000	1			
SolExp	0.1111	0.1429	0.1429	0.5000	0.3333	0.2000	1		
VegArb	0.1667	0.2500	0.3333	5.0000	3.0000	3.0000	5.0000	1	
SutGrup4	0.1111	0.1111	0.1111	0.2000	0.2000	0.2000	0.3333	0.1429	1

Table 7 *- Result of the AHP for protection suitability of land use classes*

Class	**Code**	**Suitability score (Eigenvalue)**	**Suitability score (Ordinal Ranking)**
Rock, High-altitude grassland, Forest (advanced development stage) Rock vegetation	SutGrup1	0.3863	1
Forest (medium development stage)	FlorMed	0.2219	2
Forest (initial development stage)	FlorInic	0.1329	3
Shrub vegetation	VegArb	0.0907	4
Silviculture	Silvi	0.0609	5
Grassland	Grami	0.0425	6
Cropland	Cultiv	0.0293	7
Open soil	SolExp	0.0214	8
Street, Low-density urban area, Urban area	SutGrup4	0.0141	9

Table 8 *- Urbanization suitability ranking of land use classes*

Class	Code	Suitability value (0 - 255)
Rock	AfloRo	0
Rock vegetation	VegRup	0
Forest (advanced development stage)	FlorAvan	32
Forest (medium development stage)	FlorMed	64
Silviculture	Silvi	98
Forest (initial development stage)	FlorInic	130
Shrub vegetation	VegArb	162
Cropland	Cultiv	194
Open soil	SolExp	226
Grassland	Grami	255

are both rocky classes AfloRo and VegRup due to the extremely steep slope of these terrains. The three forest classes FlorAvan, FlorMed and Silvi represent a relatively inappropriate terrain for settlement due to their dense vegetation cover. FlorInc, VegArb and Culti require relatively small effort for clearing. SolExp and Grami got the highest scores as they are practically ready for housing. Grami got the highest score due to better soil stability than SolExp.

Criterion 2 - Slope *(SLOPE)***:** The slope of the terrain was derived from the Digital Elevation Model of the research area. The calculation of the membership function was achieved by applying the FUZZY module provided within the GIS software IDRISI. This module evaluates the possibility that each pixel belongs to the fuzzy set by applying the predefined membership function. In this project, the Sigmoidal ("s-shaped") membership function was chosen, which is perhaps the most commonly used function in fuzzy set theory (Eastman, 1993). As input, the FUZZY module requires the positions (along the X axis) of 4 points governing the shape of the curve. However, in a monotonically decreasing function, as applied here, only two control points are needed to define the fuzzy set membership function:

$$y = \cos^2 \alpha$$

with $\alpha = \frac{(x - \text{point}\, c)}{(\text{point}\, d - \text{point}\, c) * \pi / 2}$ if x < point c, y=1 and if x > point d, y=0

In the case of the criterion SLOPE, the critical points c and d were derived by analyzing existing housing patterns within the research area. Hence, a raster with existing settlements was created and overlaid with the slope raster. Then, the distribution of the settlement area across the slope range of the research area terrain was derived (**Figure 3**).

The diagram shows that the greater part of the settlement area is located on slopes between 0 and 10% steep. The remaining part is more or less linearly decreasing and distributed over the slopes from 10 to 40 %. It was suggested by the National Park management to rather calculate with exaggerated values of suitability for urban expansion to reduce the level of uncertainty when defining the final limits of the extension area:

- c = 15% (meaning a 0 to 15% slope is highly suitable for urban expansion)
- d = 40% (meaning slopes greater than 40% are not suitable for urban expansion)

Criterion 3 - Proximity to settlement (PROXSET): For this criterion, the two urban area classes - ArUrb, ArUrbBa - were applied. The same formula as the fuzzy set membership function was chosen for the criterion SLOPE, however, with different units (m) and different critical points. The major question

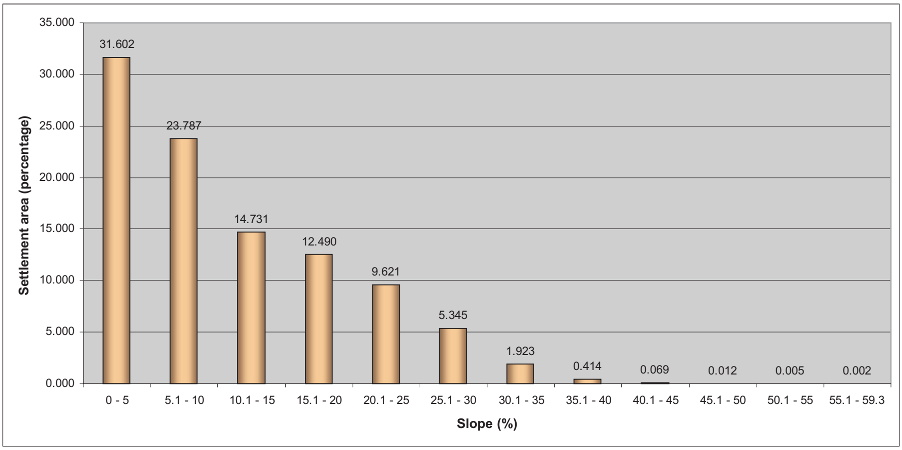

Figure 3 *- Distribution of settlement area over the slope range*

was, until which distance an urban pole has high influence on the decision of people to settle down in its surroundings. During several interviews with locals and with the geographers from ESTRUTURAR, it turned out that the areas with a distance of less than 100m to the next urban pole boundaries are preferred by people to settle down. The main reasons for that are the close access to the urban centre, the advantage of (generally) paved roads, the connection to the storm water drainage system and to electricity, and the social contact. Most people stated a distance of about 1km as the maximum from an urban pole. These distances were once more multiplied by 1.5 to eliminate uncertainties related to the final analysis:

- c = 150m (0 to 150 maximum suitability; value = 255)
- d = 1500m (> 1500m no suitability; value = 0)

Criterion 4 - Proximity to road (PROXROD): Proximity to roads or road gravity, as it is often called, is a major factor for urban growth (Johnston and

Shabazian, 2002; Varanka, 2006; Clarke 1998). Fact is that urban expansion is oriented along existing roads, or may even be stimulated by their existence. As with the PROXSET criterion, the critical points for the fuzzy set membership function were derived from interviews with locals and resident experts. Such as the area within direct influence of roads, the area up to 50m distant from the roads could also be derived. Here, economic opportunities are high, and direct connection to the supply and wastewater network is provided. Within distances up to 500m, the influence of roads is still effective but decreasing. Above this value, roads have no major influence on the people's choice to settle down, and other factors become more important. Thereupon, this is how critical points were defined (again multiplied by 1.5):

- c = 30m (0 to 30m maximum suitability; value = 255)
- d = 500m (> 500m no suitability; value = 0)

Criterion 5 - Proximity to river (PROXRIV): Rivers play an important role for people within the research area, as they provide the functions of wastewater disposal. On its upper parts, rivers also render fresh water supply. As direct influence, a distance from the rivers of a relatively narrow strip of 30m was stated by the locals. Their major consideration is wastewater disposal directly into the river. The river could be used for that purposed up to a distance of 100m, still with decreasing suitability. Further than 100m, the river was no longer decisive regarding wastewater discharge. The critical points for the fuzzy set membership function were defined as follows (original values multiplied by 1.5):

- c = 45m (0 to 45m max. suitability; value = 255)
- d = 150m (> 150m no suitability; value = 09

So as to get just one index for urbanization suitability, the Weighted Linear Combination (WLC) method was applied. Four scenarios were developed, where each criterion was assigned a weight according to its importance for the people's decision to settle down:

$S \quad w_i x_i$ where S = final suitability value

w_i = weight of factor i
x_i = criterion score of factor i

with $\overset{5}{\underset{i\ 1}{}} \quad x_i \quad 1$

The criteria *proximity to existing settlements* (PROXSET), *proximity to roads* (PROXROD) and *slope* (SLOPE) were identified as criteria of greatest importance regarding urban growth. These findings were achieved during conversations with locals, resident geographers, and through reviewing relevant literature (Johnston and Shabazian, 2002; Varanka, 2006; Clarke 1998).

Scenario 1 - Dominance of PROXSET, PROXROD and SLOPE: Within this scenario all of the three major criteria were assigned the same weight of 0.2666. It served as a control scenario for the other scenarios. As for all three major criteria PROXSET, PROXROD and SLOPE, the same percentage of influence on urban growth is assigned.

$$S \quad 0.2666 \quad x_{PROXSET} \quad 0.2666 \quad x_{PROXROD} \quad 0.2666 \quad x_{SLOPE} \quad 0.1 \quad x_{LAND} \quad 0.1 \quad x_{PROXRIV}$$

***Scenario 2 - Dominance of PROXSET*:** Within this scenario the criterion PROXSET was considered as the dominant factor for urban growth. In this scenario, potential urban growth areas are compacted around the settlement zones enclosing the Serra do Mar mountain range.

$$S \quad 0.4 \quad x_{PROXSET} \quad 0.2 \quad x_{PROXROD} \quad 0.2 \quad x_{SLOPE} \quad 0.1 \quad x_{LAND} \quad 0.1 \quad x_{PROXRIV}$$

Scenario 3 - Dominance of PROXROD**:** Within this scenario the criterion PROXROD was considered as the dominant factor for urban growth. The scenario 3 with dominance defined for the PROXROD criterion consequently showed this weighting of the factors by assigning higher probability values to areas close to roads as within the other three scenarios.

$$S \quad 0.2 \quad x_{PROXSET} \quad 0.4 \quad x_{PROXROD} \quad 0.2 \quad x_{SLOPE} \quad 0.1 \quad x_{LAND} \quad 0.1 \quad x_{PROXRIV}$$

Scenario 4 - Dominance of SLOPE**:** Within this scenario the criterion PROXROD was considered as the dominant factor for urban growth. This scenario expressed urban growth tendencies which reach far into the Serra da Estrela mountain range. The high urban growth probabilities of this scenario can be found mainly along the entire river valley of the Serra da Estrela due to relatively flat terrain.

$$S \quad 0.2 \quad x_{PROXSET} \quad 0.2 \quad x_{PROXROD} \quad 0.4 \quad x_{SLOPE} \quad 0.1 \quad x_{LAND} \quad 0.1 \quad x_{PROXRIV}$$

Worst case scenario of urbanization: For the final analysis the findings of the urbanization suitability evaluation were combined to a worst case scenario of a potential urbanization of the research area. The reason for doing so was to reduce the risk of neglecting potential urban growth areas as it might have occurred by taking only one of the scenarios described above. Technically, the worst case scenario was developed by comparing the values of the four scenarios for each pixel and choosing the highest value of these four per pixel. This value entered the worst case scenario as the maximum urbanization suitability value for each pixel (see also **Figure 3**).

Final integrative analysis

The results of the protection suitability evaluation and the urbanization suitability evaluation were combined to one single map for the final integrative analysis of the research area. The goal was to identify the core zone of the expansion area where protection suitability is high and no urban growth can be expected. Furthermore, conflict zones were depicted where the levels of both suitability evaluations were high (**Figure 4**).

The major patch of the Protection Suitability Group 1, reaching from the National Park limit to the road RJ 107, was considered as the maximal potential expansion area. At several points, however, this area is confronted with urban growth tendencies towards the expansion core zone. Within the following three

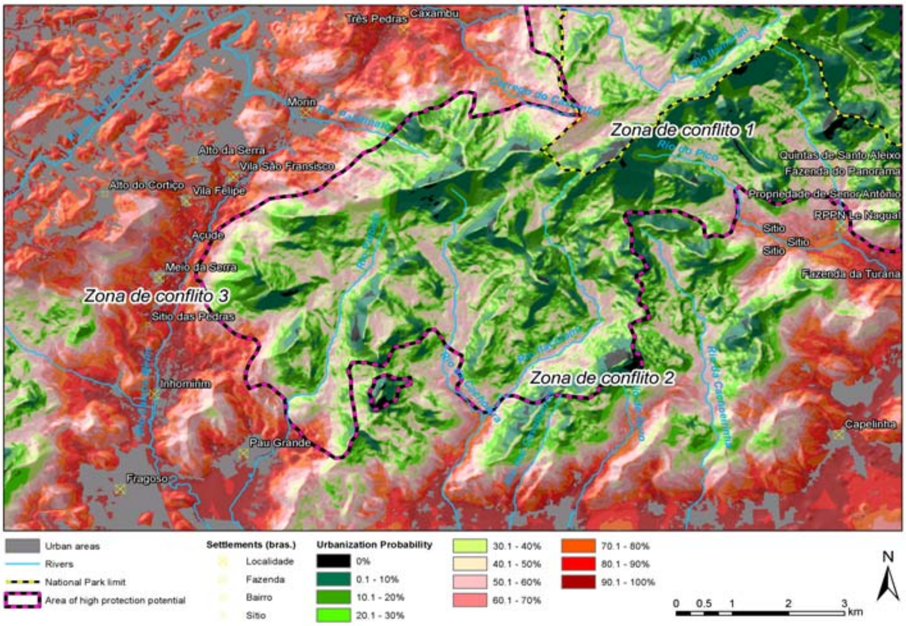

***Figure 4**: Protection core zone and conflict zones*

conflict zones, the expansion effort collides with existing human occupation or with high suitability for future occupation.

***Conflict zone 1 - Bottleneck along the National Park limit*:** The urban growth along the rivers Rio do Pico, Rio das Pedras Negras and Córrego do Caxambu narrows down the connection zone of the actual National Park area and the expansion area of the Serra da Estrela. Trespassing animals could be affected negatively through disturbance caused by artificial light and sound, and domestic animals. This is especially true for big mammals, for instance, the Woolly Spider Monkey (Brachyteles arachnoids), which is frequently spotted within this area, and needs wide areas of undisturbed habitat. Along the river Rio Pedras Negras there could be identified 26 properties from the RPPN El Nagual located in the direction of the National Park. Some of these properties are weekend cottages; the majority of these properties, however, are utilized for small-scale agriculture producing for self-supply or for the markets in nearby settlements. The area along the river Córrego do Caxambu is dominated by agriculture. No roads reach far into the Serra as it appears on the aerial photos and satellite images. Most of these transportation routes are small trails used either by farmers or for reaching the transmission line for maintenance purposes.

Conflict zone 2 - River valleys along the road "Antônio Além Bergara": Especially along the rivers Rio da Cachoeira and Rio Itacolomí, but also along the rivers Rio do Ouro and Rio da Cachoeirinha, irregular housing and small-scale agriculture is reaching far into the Serra da Estrela. In the case of the rivers Rio do Ouro and Rio da Cachoeirinha, these occupation tendencies do not affect the expansion area of the National Park directly. The proposed expansion area is protected by mountains northwest of these rivers. It is more likely that further urbanization occurs in northern and northeastern direction without reaching into the expansion area. Yet, indirect effects of this development (hunting, irregular agriculture, domestic animals, plant extraction, artificial light, noise, etc.) must be considered in the future. Although not easily accessible due to unpaved roads in bad and irregular conditions, settlements reach far into the Serra da Estrela along the rivers. Houses and agricultural fields, which are too small for recognition during remote sensing, were spotted within the potential expansion area of the National Park.

Conflict zone 3 - Estrada da Serra da Estrela (RJ 107)**:** This area does not represent a conflict zone for the actual expansion project, but if long-term planning is considered, the area along the road RJ 107 (Estrada da Serra da Estrela) is of major importance. This road, with its adjacent settlements, is located between the Serra dos Órgãos National Park and the Tinguá Biological Reserve, and represents an ecological barrier. At the same time, this area is another bottleneck of the ecological corridor between these two protection units, narrowed by the outskirts of Petrópolis in the North and the settlements Inhomirim, Fragoso and Pau Grande in the South. Both of these urban areas show tendencies for growing further into the forests along the Estrada da Serra da Estrela.

FINAL PROPOSAL FOR THE EXPANSION AREA

For the final proposal of the expansion area of the Serra dos Órgãos National Park, the findings of the protection suitability evaluation, the urbanization suitability evaluation and the final integrative analysis were combined to define the limits of the preliminary expansion area. During this phase the requirements defined previously were considered as overall guidelines for delimitating the expansion area:

The area should be composed mainly of the land use classes which are of high protection value: As **Figure 5** shows, the expansion area covers the largest part (80%) of landscape patches of land use classes, which were assigned to the suitability group with the highest protection potential. Another 18% are covered with patches of the suitability group 2. These two suitability groups combined represent almost 98% of the proposed expansion area.

The area should be as distant as possible from human infrastructure such as settlements, roads and supply networks so as to reduce negative disturbance effects: **Figure 6** shows that this requirement cannot be met in all parts of the proposed expansion area. In the region of the outskirts of Petrópolis and in the southern part of the research area, mainly, the expansion area reaches relatively close to existing urban areas. As examined during the urbanization suitability evaluation, these settlements have a considerable potential for urban growth towards Serra da Estrela, and therefore may cause future conflicts. In this region, special emphasis has to be put on choosing obvious limits for the expansion area.

*The area should be as large and compact as possible to provide sufficient core area and to reduce negative edge effects***:** The main part of the expansion area is of considerable size and has a very compact shape reaching almost the ideal shape (square or circle) for reducing the proportion of edge (McGarigal and Marks, 1995). Thereby, forest edge effects like differences in wind and light intensity and quality that alter microclimate, as well as disturbance rates,

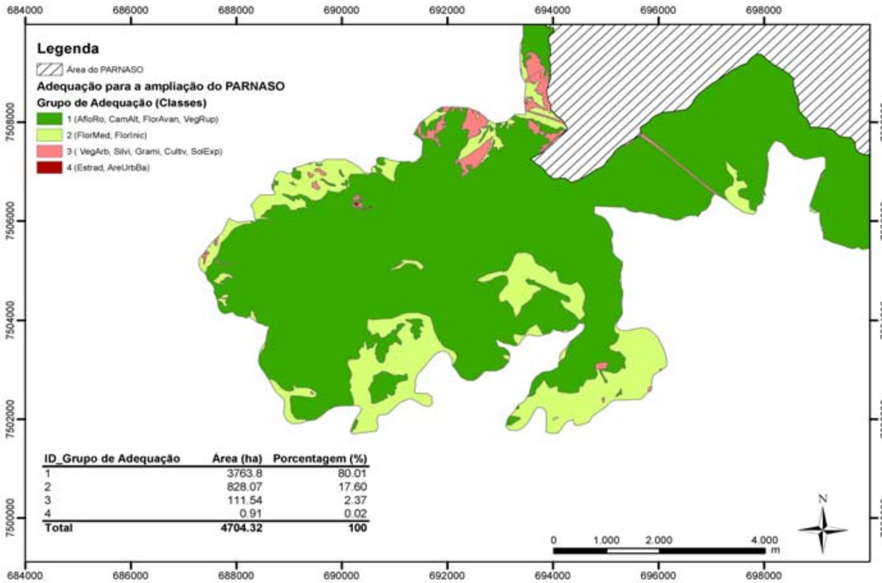

Figure 5 *- Protection suitability of landscape patches of the expansion area*

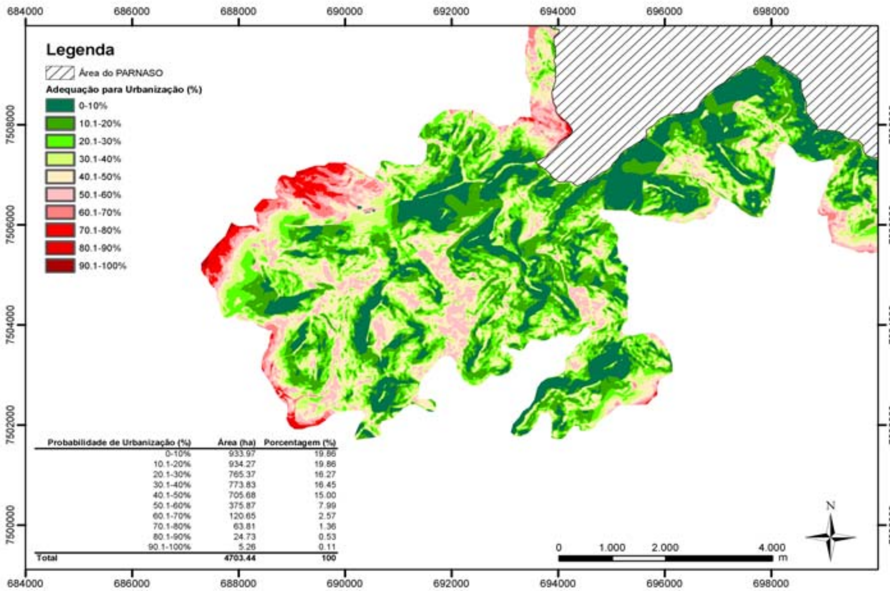

Figure 6 *- Probability of urbanization within the expansion area*

can be reduced.

The contrast between the single patches and their surrounding environment should be as small as possible to stimulate corridor effects between these patches: As stated before, almost 98% of the proposed expansion area is composed of natural resp. semi-natural vegetation representing a matrix of patches of different ecosystems. Since the major part of this 98% is composed of classes of primeval land cover, the contrast of ecological attributes that are relevant to organisms or process does not restrict flora and fauna.

The limits for the extension area should represent natural barriers for future urban growth. At the same time they should be obvious and visible not only on maps but also in the field: This guideline could not be followed at each point of the limit of the expansion area. In general, the limit passes along hills, which represent natural obstacles for urban growth. At several points, however, the limitation has to cross river valleys – potential zones of conflict with urbanization activities. In these regions, especially, educational projects with the local population could help heighten people's awareness of the Serra dos Órgãos National Park and its importance both in a local and in a regional nature conservation context.

CONCLUSIONS

This project contributed to the expansion project initiated by the management of the Serra dos Órgãos National Park. It focused on the Serra da Estrela mountain range, which represents the last still existing connection between the Serra dos Órgãos National Park and the Tinguá Biological Reserve. The goals were to provide the National Park management with a working basis for subsequent project phases, to analyze the Serra da Estrela regarding the ecological potential of its landscape fragments and the suitability for urban growth, and finally, to define a preliminary expansion area based on this analysis.

As a working basis, a Geographic Information System was developed by processing and incorporating existing data, and by creating new information about the National Park and its surroundings. The protection suitability evaluation led to insights about the ecological potential of the landscape fragments of the Serra da Estrela. The urbanization suitability evaluation pointed out the urban growth tendencies of existing settlements towards the Serra da Estrela. The findings of both evaluations were combined and analyzed to identify core zones (where no urbanization can be expected) and conflict zones (where both protection and urbanization suitability is high) within the expansion area. Finally, an expansion area was delimitated including as many core zones as possible and excluding the potential conflict zones for the most part of the research area.

The methods of Geographic Information Systems (GIS) and Spatial Decision Support Systems (SDSS) applied during this work resulted in an informative insight into the characteristics of the research area regarding its potential for protection and urbanization. Though very time-consuming, these methods guaranteed high data accuracy and consistency, important for further project phases, where legal aspects and landownership could play a major role.

The modeling technique of the Multi Criteria Evaluation (MCE), used for the suitability evaluations, turned out to be highly practical. No all-embracing model was required which included all aspects and factors of the complex phenomenon of urban growth. Due to limited time and resources, a rather straightforward approach was chosen by evaluating the urban growth within the research area based on five major criteria. In combination with the findings of the protection suitability evaluation, the urban growth model led to a consistent proposal for the expansion area within the Serra da Estrela.

With the application of FUZZY SETS, the extent of uncertainty was reduced. Instead of relying on "hard" data sets and decision rules of traditional GIS, the analysis was dominated by "soft decisions", expressed in probabilities, whether the phenomenon under consideration occurs or not. It is assumed that the reality of natural characteristics and processes could be modeled more realistically with this method.

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