A FUZZY LOGIC MODEL FOR ZONE DELINEATION IN A PRESERVATION AREA IN BRAZIL

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Abstract. Territorial planning plays a fundamental role in preservation of areas for ecological conservation and environmental management as well as in providing adequate spaces for visitation and research and prioritizing sustainable relationships between man and nature. The present work exhibits a methodological proposal that allows the standardization of territorial classifications in preservation areas. Based on fuzzy logic, the proposed model observes the particularities of a preservation area; hence, the decision generated in the classification of zones represents the work that is currently being developed in the areas of biology, geography, environmental engineering, among other research groups. The modeling combines the evaluation of the data collected in the field (variables: quantitative and qualitative) with vegetation indices obtained from satellite imagery. Combining this information enables each sampling point to be categorized, thereby generating preservation area zones. The results showed that the methodology can distinguish border areas as transition zones, allowing appropriate management to offer detailed information of the study area. The case study, in which the methodology was applied in a preservation area in southern Brazil, showed that the methodology assists in territorial planning, with a clear indication of what actions have been performed and simple data collection.
Keywords: *environmental preservation, southern Brazil, standardized classification, territorial planning, zone of transition*

Introduction

The recent decades have seen a growing discussion by political authorities and scholars regarding the need to delimit natural areas for conservation and increased coverage and effectiveness of protected areas (Watson et al., 2014). The meaning of sustainability is often debated, which can be conceptualized as the management of resources such that their contribution to human welfare is conserved or improved for the next generations (Kennedy, 2007). Brazil, with its vast territory of more than 8.5 million km² (IBGE, 2019), is responsible for protecting its natural environment, which is a difficult task when facing pressures for the expansion of land use for economic purposes, such as agriculture, pasture, and mining (IBGE, 2015). From 2003 to 2009, Brazil stood out in relation to the expansion of the network of preservation areas (PA). Brazil accounts for 73% of world expansion out of the entire legally protected area of the planet that was established in 2003 (Jenkins and Joppa, 2009).

In Brazil, PAs are called conservation units; hence, the designation to the National System of Nature Conservation Units (SNUC in Portuguese) established in 2000 by federal law aims to ensure that all conservation units represented significant ecological samples from different populations, safeguarding the existing biological patrimony

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(Ministério do Meio Ambiente, 2011; Bernard et al., 2014). In 2002, the Brazilian government established several procedures and criteria for the creation of each PA, establishing its management plan, protection, and supervision actions that must be formalized and implemented. The management plan is a document that works as the identification of the area of preservation, having the zoning definition of a PA observing the particularity of each zone as a fundamental part with adequate management to the territorial ordering, such that the administration of the entire of the area reaches objectives with consistency and effectiveness. Although the legislation deals with zoning, the distinction between legislation and scientific knowledge is still quite high (Azevedo-Santos et al., 2017). The process of how to do this territorial division is guided by documents with a methodological superficial purpose; however, when we looked for this information in the management plans, we observed that zoning occurs in different ways because no methodology standardizes this classification.

In terms of the effectiveness of classification, many questions can still be asked regarding zoning in preservation areas. Liu and Li (2008) highlighted several known problems with the implementation of zoning schemes in China and elsewhere, including the lack of clear regulations on how to structure the spatial arrangement of zones and the lack of guidelines that determine the factors that should be considered since the creation of the PAs (Fendrich et al., 2019).

In study by Lima and Ranieri (2018), zoning can be approached in many ways. Land use planning is done with respect to only one type of zone. The study was done through a documentary analysis using the management plans. Zhang et al. (2013) used the methodology of combining interviews with geographic information systems (GIS) using a multi-criteria decision analysis based on the GIS method to formulate the zoning areas in the national park, with a wise process used to identify the priorities and prior knowledge of the area. Interviews were then conducted for the case study. The study of Vardarman et al. (2018) observed that the invasion of exotic species generated a zoning according to the degree of invasion by making field observations and performing statistical analyses. The main source of data for spatial delimitation of maps was provided by a nature conservation agency in the Czech Republic.

A natural phenomenon related to sustainability can be described in many ways, including visualization, physical models based on the creation or recreation of ecosystems, and conceptual and quantitative models. The last method, where the fuzzy logic theory can be applied, is the most informative for decision makers (Todorov and Marinova, 2011). An eminent factor of the fuzzy logic theory is the ability to capture intuitive concepts in addition to considering the psychological aspects used by humans in their usual reasoning; this has not been represented in traditional models (Zadeh, 1965; Oliveira, 1999; Zimmermann, 2001).

Multi-criteria analyses are examples of techniques that consider several perspectives and can integrate several actions in the decision process in a certain complex situation. From the operational point of view, multi-criteria methods have the ability to adapt to problems on several fronts, which can be described as conflicting interests. Although the multi-criteria evaluation technique does not solve the problem, it can help detail the problem, making the complex situation more transparent for decision makers (Munda et al., 1994; Hsueh and Cheng, 2017).

The objective of this study was to develop a quantitative model based on fuzzy logic to delineate the management zones in PA in Brazil. For this purpose, the possible variables (i.e., quantitative and qualitative) must be combined such that the map of the

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area emphasizes its relationship with the surrounding areas. A case study was performed in a PA in southern Brazil to test the efficiency of the model.

Materials and Methods

Preservation area establishment

The establishment of all possible zones for a Brazilian PA covers the following: zone intangible, natural, extensive use, intensive use, historical-cultural, recovery, special use, conflicting use, temporary occupation, indigenous superposition, experimental interference, buffer, and presented in the Methodological Guideline according to the national legislation (IBAMA, 2002; Mazza et al., 2016; Simardi and Souza, 2018).

A PA can be classified in two ways. Some PAs need only a specific element for their classification (e.g., in the case where buildings are identified, the PA is automatically classified as a "zone of special use"). These zones in PAs include zones of special use, zones of conflicting use, zones of temporary occupation, indigenous superposition, and zones where historical/cultural heritage is found (*Fig. 1*).

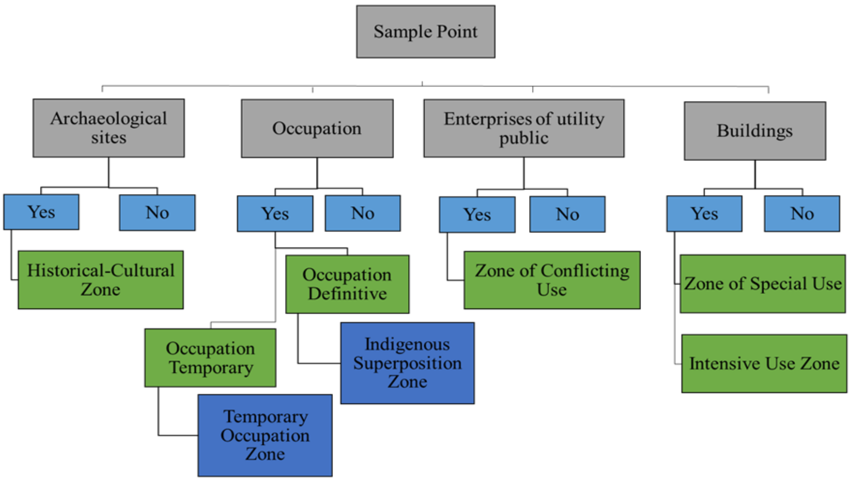

Figure 1. *Scheme for the classification of areas with specific characteristics*

However, such specific elements will not always appear to generate the classification, which makes it necessary to seek the criteria for classifying intangible zone (IZ), natural zone (NZ), extensive use zone (EUZ), and recovery zone (RZ). The classification of this second group of PAs is much more complex and relies on the criteria not always clear for a decision maker.

Study area and data

The study area is the Santa Helena Relevant Ecological Interest Area (ARIE-SH), a 1.515 ha preservation area in the phytogeographic domain of the Atlantic Forest, which, in ecology, is considered a hotspot (Myers et al., 2000). According to the Brazilian legislation, this PA is classified as a Relevant Ecological Interest Area, a permanent category to sustainable use, with characteristics of possessing small areas with little or no human occupation and a singular natural feature with the purpose of protecting local ecosystems.

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ARIE-SH is located in the southern region of Brazil in the municipality of Santa Helena, state of Paraná (*Fig. 2*). It was officially established in 1984 on the banks of the Paraná River at the border between Brazil and Paraguay after the construction of the hydroelectric power plant of Itaipu (Management Plan, 2010).

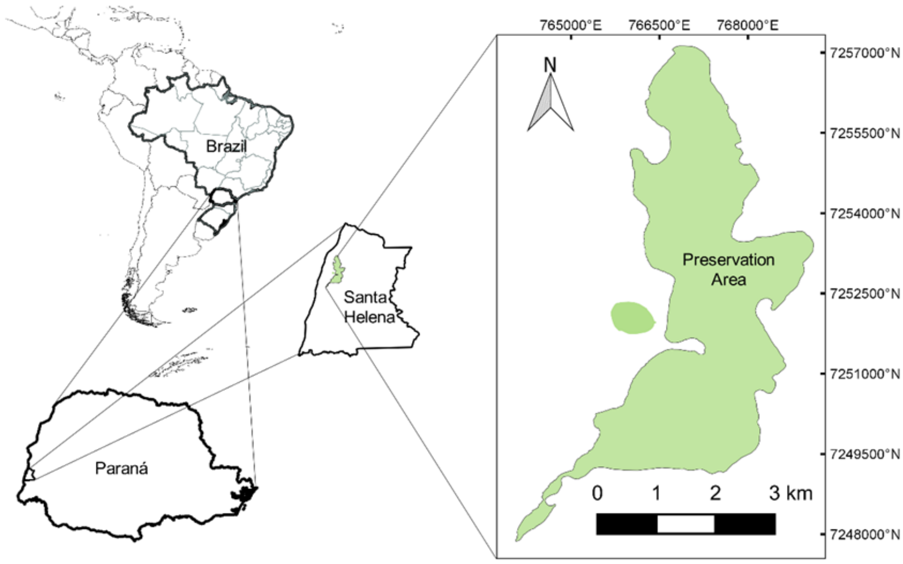

Figure 2. *Location of the Santa Helena Relevant Ecological Interest Area (images projected in the Universal Transverse Mercator (UTM) projection zone 21S and WGS 84 (World Geodetic System 84) ellipsoid)*

At this time, many areas along the river were expropriated, and reforestation with exotic and native trees species took place. Nowadays, the ARIE-SH is covered by a semi-deciduous seasonal forest according to the Brazilian classification of vegetation provided by IBGE (2012) in different stages of ecological succession. The main exotic species present include mango (*Mangifera indica* L.), jambolão or Java plum (*Syzygium cumini* (L.) Skeels), and Japanese raisin tree (*Hovenia dulcis* Thunb.). Meanwhile, the areas, where native species were planted, show a high diversity with several native herbaceous and shrub species, including ferns, growing in the shade sub-forest. The areas, where native species were planted, such as pitanga or Surinam cherry (*Eugenia uniflora* L.) and gabiroba (*Campomanesia xanthocarpa* Mart. ex O. Berg), are the richest in the number of trees species and present an intermediate successional stage.

Fieldwork was performed between March 2018 and June 2018. A total of 87 plots measuring 5×10 m² were sampled using the method proposed by Muller–Dombois and Ellenberg (1974). The location of the plots was selected with a distance of approximately 400 m. During the survey, the circumference at breast height (CBH) parameter was used in reference to the circumference of the trunk at 1.30 m height. Each plot was georeferenced at its center point using a global navigation satellite system (GNSS) (Etrex 30, Garmin, Garmin International, Inc., Kansas City, USA) receiver with a positional accuracy of approximately 5 m. The vegetation data collected in each plot consisted of (a) the number of trees with a CBH greater than or equal to 0.30 m, (b) the diversity of species, that is, how many species have a CBH greater than or equal to 0.30 m, and (c) the regeneration level registered by photography.

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Model structure

The interpretability of the classification systems refers to their ability to express their behavior in a manner that is easily understood by a user (Jim and Mart, 2019). Based on this indication and to find means of facilitating the systematization of the process, a model was developed to propose to classify the sampled areas. The chosen variables were based on vegetation because "the lower degree of degradation of vegetation generally leads to the lower degree of degradation of fauna and soils" (IBAMA, 2002).

The input variables for the study are as follows: vegetation density index, diversity of species, and regeneration index. The expected output variable refers to "zoning," where each investigated point will be associated with a zone. The general approach is to first quantify the linguistic statement then retransmit the quantized logical input and output ratios using mathematical operators (Chen and Pham, 2000).

The fuzzy sets for the input and output variables considering the working hypothesis can be represented in several ways by pertinence functions, the most common being the triangular, trapezoidal, Gaussian, bell-shaped, Z-shaped, and S-shaped functions (Ibrahim, 2004). The pertinence functions chosen to describe the variables in this work exclude the triangular and trapezoidal functions considering that in nature, the behavior changes are not abrupt.

The membership function in the "Z" form is presented as follows:

$$f(x,a,b)=\begin{cases}1, & x<a\\ 1-2\left(\dfrac{x-a}{b-a}\right)^2, & a\le x<\dfrac{a+b}{2}\\ 2\left(\dfrac{b-x}{b-a}\right)^2, & \dfrac{a+b}{2}\le x<b\\ 0, & x\ge b\end{cases} \quad \text{(Eq.1)}$$

The membership function in a bell shape is:

$$f(x,a,b,c)=\frac{1}{1+\left|\dfrac{x-c}{a}\right|^{2b}} \quad \text{(Eq.2)}$$

The membership function in the "S" form is presented as:

$$f(x,a,b)=\begin{cases}0, & x<a\\ 2\left(\dfrac{x-a}{b-a}\right)^2, & a\le x<\dfrac{a+b}{2}\\ 1-2\left(\dfrac{x-b}{b-a}\right)^2, & \dfrac{a+b}{2}\le x<b\\ 1, & x\ge b\end{cases} \quad \text{(Eq.3)}$$

Input variable: "Vegetation density index"

The vegetation density index (VDI) is described by the membership function considered in the range of 0 to 10, with the low, medium, and high linguistic denominations (*Fig. 3*). It could have been chosen from 0 to 1 or from 0 to 5 provided that the membership functions were allocated at intervals consistent with its name.

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The membership function with a "low" denomination is a Z-shaped function (*Eq. 1*) with $f(x,1.5,5)$. The term "medium" is described by a bell-shaped function (*Eq. 2*) with $f(x,1.5,3,5)$. Finally, the membership function described by the linguistic term "high" vegetation concentration has an S form (*Eq. 3*) with $f(x,5,8.5)$.

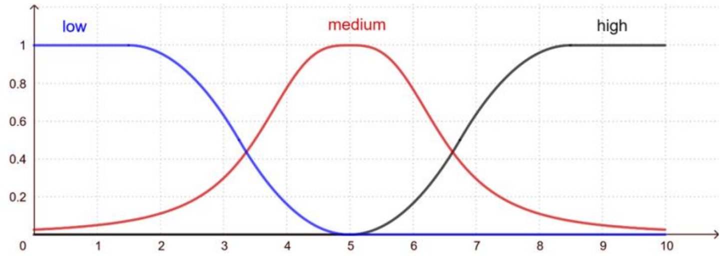

Figure 3. *Membership functions describing the vegetation concentration*

The VDI of the *i*th sampling plot is calculated as follows (*Eq. 4*):

$$VDI_i = \left[\frac{(EVI_i + NT_i)}{\max\limits_{1\le j\le n}\{EVI_j\} + \max\limits_{1\le k\le n}\{NT_k\}} \right] \cdot 10 \quad \text{(Eq.4)}$$

where EVI_i is the result obtained by the index of vegetation between -1 and 1, which can be searched for in the software by georeferenced points; NT_i is the number of trees in the *i*th sampling plot; $\max\limits_{1\le k\le n}\{NT_k\}$ is the maximum number of trees observed among all the sampling plots (k = 1, 2, 3, …, 87); and $\max\limits_{1\le j\le n}\{EVI_j\}$ is the maximum enhanced vegetation index (EVI) observed and calculated for each point sampled in the study area (*j*=1, 2, 3, …, 87).

With regard to remotely mapping disturbances and land use/land cover (LULC), the data from the satellite-based sensors have proven useful for large-area characterization (Atzberger, 2013). The EVI will be used as input in the fuzzy system. The EVI is an "optimized" vegetation index designed to improve the vegetation signal with better sensitivity in regions of high biomass and vegetation monitoring (*Eq. 5*) (Jensen, 2009).

$$EVI = G\frac{\rho_{nir} - \rho_{red}}{(\rho_{nir} + C_1\rho_{red} + C_2\rho_{blue} + L)}, \quad \text{(Eq.5)}$$

where, ρ_{nir} is the reflectance in the near infrared band (0.73 µm); ρ_{red} is the reflectance in the red band (0.66 µm); L is a soil adjustment factor; and C_1 and C_2 are the coefficients describing the use of the blue band for the correction of the red band for atmospheric scattering by aerosols. These coefficients were empirically determined as L = 1, C_1 = 6, C_2 = 7.5, and G (gain factor) = 2.5 (USGS, 2017). The Landsat 8 images used in this work were accessed by the United States Geological Survey (USGS) search platform in March 8, 2018.

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Input variable: "Diversity of species"

Data collection was designed to survey the variety and quantity of the plant species present on the site. The methodological guideline states that areas with the greatest number of species found should integrate the zones of greater degree of protection, such as the intangible and natural zones. For the variable "diversity of species," the membership function with a "low" qualification is a function in Z form with $f(x,1.5,5)$. The linguistic term "medium" is described by the bell-shaped function $f(x,1.5,3,5)$, while the term "high" is described by the S-shaped function with $f(x,5,8.5)$.

The diversity of tree species at the *i*th sampling plot, DTE_i was calculated using the following formula:

$$DTE_i = \left(\frac{NE_i}{\max\limits_{1\le l\le n}\{NE_l\}}\right)\cdot 10 \quad \text{(Eq.6)}$$

where NE_i is the number of tree species observed in the *i*th sampling plot, and $\max\limits_{1\le l\le n}\{NE_l\}$ is the maximum number of tree species found among all sampling plots. The output was multiplied by 10 to scale the values between 0 and 10.

Input variable: "Regeneration index"

The input variable "regeneration index (RI)" is the variable considered in the characterization of zoning because it is a reforestation area. The classification of regeneration provides information that will be considered in the model. The linguistic denominations in the variable regeneration were low, medium, and high (*Fig. 3*).

To distinguish between terms, an area with a mean vegetation that did not enter the sample was considered as high regeneration because it did not complete the 0.30 m diameter that was considered. The term linguistic medium regeneration considered areas with a low and sparse vegetation, among others. The term "low regeneration" was used in places without vegetation in the sub-forest layer.

The membership function with the "low" qualification is a function in Z form (*Eq. 1*) with $f(x,1,5)$. The function with the "medium" qualification is expressed by the bell-shaped function with $f(x,1.5,1.5,5)$. Meanwhile, the function with the "high" qualification is expressed by the function with an S form with $f(x,5,9)$.

Output variable: "Zoning"

The output variable "zoning" has four membership functions: IZ, NZ, EUZ, and RZ (*Fig. 4*).

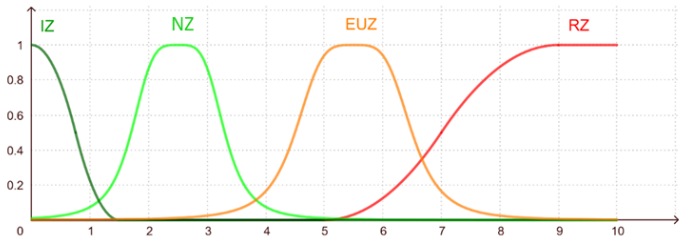

Figure 4. *Membership function of the output variable "zoning"*

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The membership function that represents IZ is a function in the Z shape with $f(x, 0, 1.5)$. The membership function for NZ is associated with the bell-shaped function with $f(x, 0.8, 2, 2.5)$. The EUZ is also associated with the bell-shaped function with $f(x, 1, 2, 5.5)$. Finally, the membership function that describes RZ is a function in the S shape with $f(x, 5, 9)$.

Base rule

This phase is the construction of the base rule that directly interferes with the result, which is still subjective and handmade (Rezende, 2005). Many efforts have been made to systematize or even automate the process of acquiring knowledge. In fuzzy systems, the semantics formed by the operators play a deterministic role.

The base rule is a statement of fuzzy rules in the form of if–then. A general approach would be to first quantify the linguistic statement then retransmit the quantized logical input and output ratios using the mathematical operators (Chen and Pham, 2000). In this work, the operator "and" will be used with the Mamdani controller defined as $I_c(x, \mu(x)) = \min\{x, \mu(x)\}$ (Zimmermann, 2001). The operator "and" is used with Mamdani (*Fig. 5*) when listing the input variables.

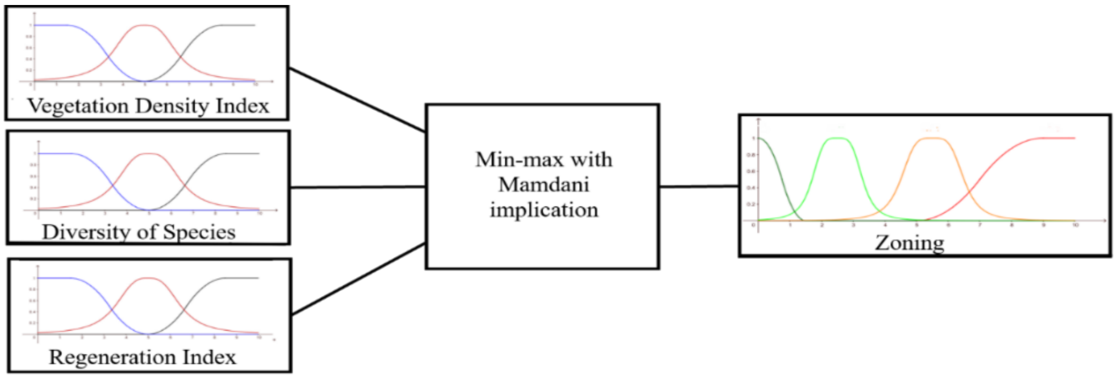

Figure 5. *Fuzzy system scheme for the proposed model*

The base rule in the proposed model will combine the input variables according to its attributes, thereby obtaining 27 rules (*Table 1*).

Table 1. *Rules for zoning delineation*

nº	***Input variables***					***Output variables***	
	If vegetation concentration	**and**	**if** species diversity	**and**	**if** regeneration	**then**	zoning
1	low	and	low	and	Low	then	RZ
2	medium	and	low	and	Low	then	RZ
…							
10	low	and	medium	and	Low	then	RZ
11	medium	and	medium	and	Low	then	EUZ
…							
26	medium	and	high	and	High	then	NZ
27	high	and	high	and	High	then	IZ

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Fuzzy inference

The information regarding the RI were observed for each sample point. VDI_i and DTE_i were also calculated according to (*Eq. 4*) and (*Eq. 6*), respectively. The input value in the fuzzy system will be a point with three coordinates, which generates a real number as a result, using the gravity center defuzzification method (GCD) (Gomide and Gudwin, 1994; Zimmermann, 2001) (*Eq. 7*):

$$GCD = \frac{\int_a^b x\mu(x)dx}{\int_a^b \mu(x)dx}. \quad \text{(Eq.7)}$$

In the GCD, [a, b] is the range of coverage of the membership functions, which in this case is [0,10]. Considering the area formed by the contribution of all the rules, (*Eq. 7*) considers the degree of pertinence (weight) of each point inserted in the model, consequently obtaining a real number as a result. This method returns the point representing the center of the area (or gravity) under the curve formed by the output membership function. The sampled point was classified according to the zone established depending on the GCD output value (*Table 2*).

Table 2. *Zoning classification according to the GCD range*

Zone	GCD range
Intangible	0 to 1.5
Natural	0 to 5.0
Extensive Use	2.0 to 9.0
Recovery	5.0 to 10.0

Each sampled point will be at the intersection of two fuzzy sets representing the zoning. The set for which the point has the highest degree of pertinence will be considered in their classification. If this point is exactly at the intersection point of the pertinence functions, this point will be classified in the most restrictive zone.

Interpolation

The inverse distance weighted (IDW) interpolation method (*Eq. 8*) (Shepard, 1968) was used to generate the thematic maps with the results of the case study applied to the model proposed in this work. Several powers were tested (i.e., 1, 2, 3, 4, 5, and 10). The one with the lowest mean error in the cross-validation was chosen.

$$X_p = \frac{\sum_{i=1}^{n} \frac{1}{d_i^{\,p}} \cdot X_i}{\sum_{i=1}^{n} \frac{1}{d_i^{\,p}}} \quad \text{(Eq.8)}$$

where, X_p is the interpolated variable; X_i is the value of the variable for the *i*th neighbor; d_i is the Euclidean distance between the *i*th neighborhood point and the sampled point; and p is the power of the distance.

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Results

The model presented an efficacy in classification, coherence between the surrounding areas, and in describing the area as observed in the fieldwork in conformity to the area documents (Management Plan, 2010). The results obtained using the model for zoning delineation in ARIE-SH allows classifying the 87 sampled points in the area in accordance to the PA defined by IBAMA (2002). The samples were classified in the range of 0.51 to 8.29 in accordance with the proposed methodology with an average of 4.70 and a CV of 0.43. The average parameters permeated the area as an “Extensive Use Zone.” The IDW (power 2) interpolated thematic map (*Fig. 6a*) represents the area divided in four zones (*Table 3*). The transition areas between the zones (i.e., IZ and NZ, NZ and EUZ, and EUZ and RZ) were created by observing the coverage range (*Table 2*) of each pertinence function for the output variable (zoning) (*Fig. 6b*). The values obtained in these intervals were considered as transition regions, which may belong to zones with different degrees of pertinence (*Table 4*).

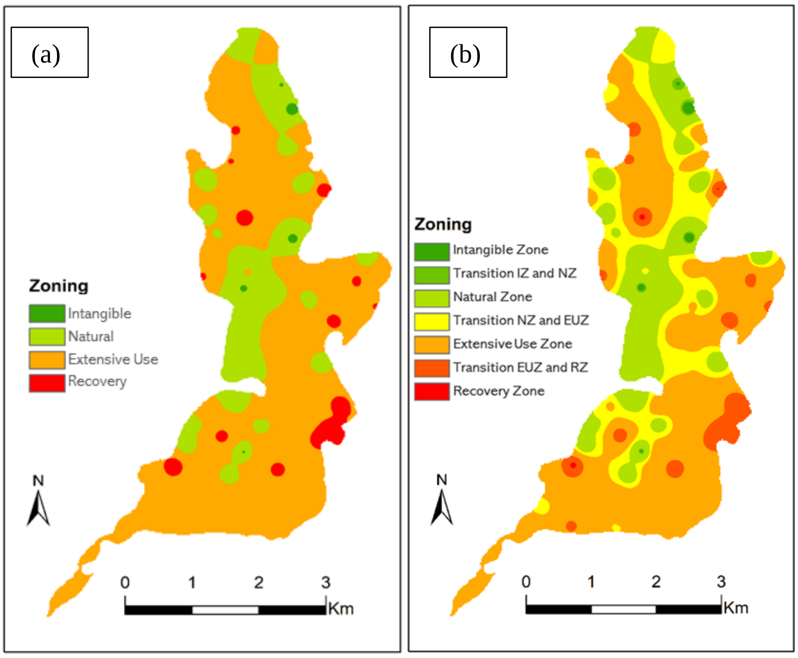

Figure 6. *Zoning map of the area with the proposed methodology: (a) area divided in four zones and (b) area considering the regions of transition between one zone and another*

Table 3. *Area of each zone considering the PA classification (IBAMA, 2002)*

Zone	Area (ha)	Area (%)
Intangible IZ	2.47	0.16
Natural NZ	339.63	22.41
Extensive Use EUZ	1123.2	74.09
Recovery RZ	50.60	3.34

The cross-validation performed for the PA classification produced a correlation coefficient of 0.2429, which was evaluated as poor (values under 0.5), moderate to good

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(values from 0.50 to 0.75), and excellent (values above 0.75). The root mean square error (RMSE) was 1.99. The mean error (ME) was 0.0136 (*Fig. 7*).

Approximately 74.09% of the area extension belonged to the Extensive Use Zone, 0.16% to the Intangible Zone, 22.41% to the Natural Zone, and 3.34% to the Recovery Zone (*Table 3*). When zoning was distributed, including the transition areas, a more detailed understanding of the area can be achieved (*Table 4*). The natural zone that occupied 22.41% of the original map was reduced to 21.91%, but allowed the observation of a larger area (19.25%) that can be classified as a transition area between NZ and EUZ. This result indicated that this area can receive an adequate management to integrate the Natural Zone in the future.

Table 4. *Area of each zone considering the transition zone for PA*

Zone	Area (ha)	Area (%)
Intangible IZ	2.47	0.16
Transition IZ and NZ	7.55	0.5
Natural NZ	332.07	21.91
Transition NZ and EUZ	291.87	19.25
Extensive Use EUZ	831.32	54.84
Transition EUZ and RZ	50.60	3.34
Recovery RZ	0	0

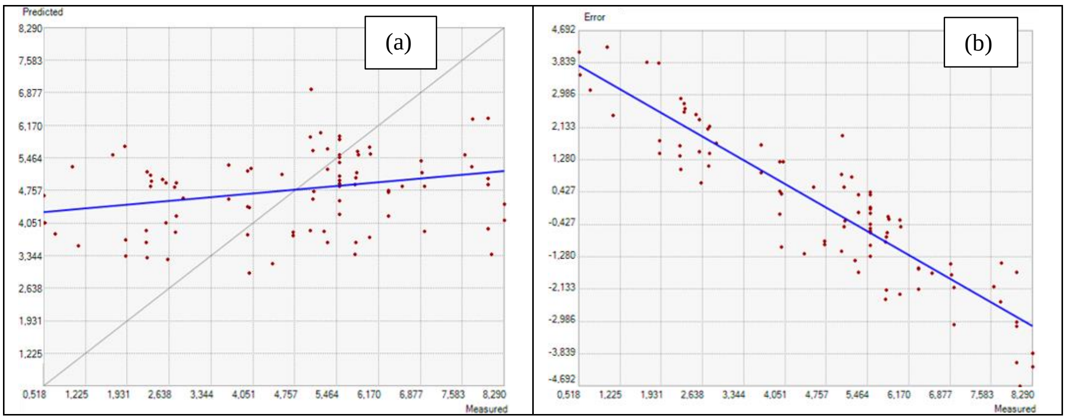

Figure 7. *Adjustment of the points evaluated in the interpolation: (a) fit for the interpolated data with a regression equation of 0.114 x + 4.23 and (b) error in the prediction with a regression equation of −0.885 x + 4.23*

Discussion

The model presents allows decision makers to classify the PA in a reasonable zoning scheme and enables it to be adjusted to any biome by observing the input variables. This classification generates reliability to the process that becomes standardized. Our model was able to describe the study area using quantitative (i.e., VDI and diversity of tree species) and qualitative (regeneration) variables because of the fuzzy logic that allows us to describe the variable flexibility; hence, it has been used to model landscapes and in different ecological and environmental studies (Sheehan and Gough, 2016).

In the case of a complex system (e.g., natural reserves), we have a model generating several zones based on measurable variables that present ease in the field work, not

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generating great distortions according to the specialist who will reproduce the zoning. Moilanen et al. (2009) argued that a major limitation in land-use planning when made by software is the inability to consider different zone types.

Our work differed from that of Lima and Ranieri (2018) because it studied documentary based only on one type of zone with specific characteristics. Zhang et al. (2013) presented a similarity in the sense of combining methodologies (e.g., GIS and multi-criterion analysis), although they used previous knowledge, which is difficult for research in Brazil because many units do not have the minimum mandatory document that is the management plan. Vardarman et al. (2018) developed a method of zoning by observing biological factors like the invasion of exotic species resembling the variable regeneration treated in this model. It is difficult within the context of conservation to say which methodology is the best because each area has its particularity. The variables are chosen according to specificity of the area, making it difficult to compare approaches. Territorial zoning is undeniably difficult, even with its limitations, yet it reduces the external impact on the area (Bruggeman et al., 2015).

The high variation of the model classification occurred because during reforestation in the case study area, the natural distribution of the species was not observed. The area was divided in fields, where in some cases, a single species or a combination of two or three species were planted without criterion. Therefore, the interpolation method cannot understand the characteristic of the area that is extremely particular. In areas where the vegetation change is not as abrupt as natural areas, this variation tends to be very small because the neighborhood of the studied site will have similar characteristics.

The model proposed herein showed that zoning classification can be done in a standardized and simplified manner, as suggested by Lin and Li (2016), because traditional models are complex to use and interpret.

In the case of zoning, this classification may encounter different interests with different stakeholders perceiving different versions of the same problem. In this context, the implantation of an ecological park, for example, can have a double understanding. Those interested in installing the park may want to enter the natural areas, which contradicts the conservationist interests of maintaining the intangibility of a core area. In this sense, approaches that consider transition zones present more information for decision makers, and can be interpreted as a buffer for the possible damages on the intangible and natural areas, that is, work as attenuating human intervention, for example (Liu and Li, 2008).

Zoning is indispensable in decision making in a conservation area, and studies of possible reproduction and understanding are valued (Cook et al., 2012). The obtained results allowed for an adequate management of each class according to its peculiarity. When transition areas are included in the classification, the knowledge of their size and location can contribute to the management of the area, thereby allowing greater care with areas that already belong to a more restrictive level, but with a small degree of pertinence.

Many preservation areas in Brazil still do not have a management plan even with numerous documents and studies that confirm the importance of zoning. The management plan has been defined since 1979 and is a mandatory document since 2002, and an integral part of this document is zoning. The preservation areas that have this territorial order do not explain the methodology to generate the territorial classification (Ministério do Meio Ambiente, 2011).

Liu and Li (2008) argued that problems with the implementation of zoning schemes in China and elsewhere include the lack of clear regulations on how to structure the spatial arrangement of zones and the lack of guidelines that determine what factors should be

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considered. Many variables are treated and considered in Brazilian laws that define zoning in preservation areas; however, we chose to deal with vegetation because if vegetation is not in a favorable state, the fauna will also not find survival conditions. The choice permitted the use of classic vegetation indexes in the literature, such as EVI, which made the model very practical. Lin et al. (2018) compared the performance of some strategies used to evaluate areas that should be retained. The authors pointed out that unfortunately, selecting the most appropriate model is often difficult because of limited data and knowledge.

However, one of the advantages of the methodology proposed herein is the standardization in the territorial planning of preservation areas in the Atlantic Forest, and the particularity of each study area may be adequate. If an area has potential for visitation, a human intervention variable can be included. If the study area is another type, the rules of this model can be adapted to classify and describe the reality of that place.

Conclusions

The whole area under study can be covered during sampling. Moreover, with the experience acquired, the presented results can more adequately describe the studied area. We presented herein a new methodological proposal for PA zoning. The PA classification presents a systematization to the process of territorial planning with input variables having quantitative and qualitative parameters, which allows an approximation of the reasoning of specialists obtaining a numerical result easy to classify in the zones as established in the National System of Nature Conservation Units. The model provides methods of automating decisions based on fuzzy logic. This methodology is promising because it can be used automatically and independently. It also allows adaptation to any PA because it meets the law requirements. The intersections between the fuzzy set output will be areas of special attention because being in an intermediate stage, the management of this area can be improved for insertion into a category of greater preservation.

This model introduces a tool that can be used to review and monitor the zoning of protected areas that the legislation has defined to be periodically reviewed. In practice, the model offers zoning in which the spatial division presents no rigid limits, but rather flexible boundaries to the real objective of the area, thereby providing the manager with detailed spatial classification maps that can be used to plan impediments and permissions for the proper management of the area.

Future studies can work on the insertion of new variables. For example, in open areas to visitation, the variable “human intervention” can be inserted to verify the degree of impact of human action, qualifying factors as the presence of garbage, fires, tree cuttings, and signs of hunting, among others. For example, we can compare the model performance of areas with different characteristics including characteristics other than reforestation.

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APPENDIX

Coordinates:

Coordinates in the Universal Transverse Mercator (UTM) projection zone 21S and WGS 84 (World Geodetic System 84) ellipsoid.

Point	longitude	latitude
1	767209	7251377
2	766778	7251376
3	766162	7251118
4	766501	7250791
5	765779	7250325
6	765280	7249668
7	765747	7249377
8	766461	7249379
9	766466	7249388
10	767971	7250740
11	768107	7250908
12	768241	7251278
13	767098	7250960
14	767104	7250496
15	767327	7250269
16	767028	7250243
17	766827	7250542
18	767312	7251509
19	767369	7251962
20	767385	7252360
21	766053	7250987
22	766649	7251414
23	767101	7251257
24	767447	7252459
25	767634	7252816
26	767799	7252901
27	768540	7253207
28	768633	7253195
29	768741	7252997
30	768803	7252822
31	768494	7252703
32	768162	7252579
33	768270	7253055
34	767436	7249342
35	766973	7249448
36	766627	7249622
37	767113	7249927
38	767630	7249576
39	767917	7249943
40	767916	7250327
41	767626	7250008
42	766624	7250176
43	766810	7253571
44	766837	7254195
45	766814	7254640
46	766679	7254946
47	766290	7254799
48	766031	7254491
49	766287	7254256
50	766436	7253945
51	766251	7253683
52	766214	7253284

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Coordinates in the Universal Transverse Mercator (UTM) projection zone 21S and WGS 84 (World Geodetic System 84) ellipsoid.		
Point	**longitude**	**latitude**
53	766639	7255076
54	766707	7255565
55	766435	7255773
56	766298	7256113
57	766440	7256570
58	766708	7256859
59	767215	7256764
60	767391	7256276
61	767554	7255888
62	767721	7255495
63	767517	7255290
64	767628	7255060
65	767764	7254750
66	768007	7254634
67	767736	7254358
68	767561	7253874
69	767596	7253409
70	766467	7249868
71	765194	7249443
72	767238	7253017
73	766884	7253348
74	766828	7253100
75	766827	7252735
76	766834	7252429
77	766834	7251943
78	767009	7251743
79	766349	7251242
80	765967	7250650
81	765462	7250222
82	768641	7253572
83	768307	7253487
84	768012	7252424
85	767999	7251938
86	767931	7251239
87	767573	7251373

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