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Diagnosis of conservation status of forest fragments using landscape ecology metrics

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Forest fragments present shapes and sizes that become them more or less susceptible to external factors, which can be measured by means of ecological indexes. The aim of this research was to diagnose conservation status and to quantify forest fragments in part of the Brazilian Atlantic Forest. Forest fragments were mapped and landscape ecology metrics were calculated, including area size, fractal dimension index, and edge index. These three metrics were modeled using the Weibull-3P probabilistic function in order to quantify fragments in a specified range. A bivariate function also was applied relating the indexes with fragment area size. The diagnosis revealed that the study area is highly fragmented, since the forested area covers only 13.7% of the total area. About 89% of the forest fragments have area from 10 to 100 ha, whereas fragments larger than 100 ha totalize about 11%. The metrics allowed discriminating the forest fragments by their conservation status. This study suggests that smaller fragments should be managed as stepping stones to the larger ones. As conclusion, larger forest fragments present more complex shapes and high edge effect. Thus, smaller forest fragments present variability of shapes from simple up to the more complex ones, besides edge effect much more variable than the larger fragments. The frequency of fragments in relation to the studied variables follows a normal. This means that well-conserved forest fragments, that is, with biggest areas, lower edge effects, and more rounded shape, are the scantiest ones.

Key words: Forest area size, edge index, fractal dimension index, probability density function.

INTRODUCTION

The human pressure on forests in Brazil has occurred since the beginning of its colonization. The Atlantic Forest biome was the first to suffer strong effects on the vegetation, which has increasingly been fragmented.

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Forest fragmentation can be defined as any area of natural vegetation interrupted by human barriers such as roads and crops, or natural barriers such as rivers and lakes, which can reduce the flow of animals, pollens and seeds (Forman and Godron, 1981).

The consequences caused by fragmentation are not yet fully understood, but one of them certainly is the decreasing of areas of the original habitats, which affects genic flow and abundance of biodiversity (Lawrence and Vandecar, 2015; Cumming et al., 2012). Besides the area size, the dynamics of forest fragments correlate with their shape, degree of insulation, type of neighborhood and historic of disturbance, interfering in the composition, as well as in vegetation and wildlife survival (Souza et al., 2008; Hill and Curran, 2003; Viana and Pinheiro, 1998).

In landscape ecology concept, the forest fragmentation consists of a mosaic of patches contained in a matrix, in which its structure suffers external influences such as wind, fire, and human intervention. In this sense, ecological metrics are used to relate perimeter and area, reflecting the level of complexity and edge of patches. Analogously, considering the assumption that the circle is the geometric shape with a smaller perimeter for a certain area, the most rounded forest fragment has the lower edge effect, besides its shape is less complex (Broadbent et al., 2008; Couto, 2004; Forman and Godron, 1981).

Some ecological metrics as area size and perimeter-area indexes were adopted by Santos et al. (2016) aiming to select forest fragments to collect forest seeds. The fragments were staggered based on their potential genetic richness, since indexes of edge and shape provide estimates of the degree of susceptibility to external disturbances.

The seed selection and collection without adopting appropriate technical criteria result in reduction of physiological and genetic quality, including germination and development of biological immunity of forest seeds and seedlings (Piña-Rodrigues et al., 2007).

Few studies are developed aiming to contribute to the management of natural forests, mainly with respect to forest fragments with sufficient condition to ensure genetic quality of forest seeds. From the mapping of forest fragments in part of the Brazilian Atlantic Forest, this study was conducted with the hypothesis that the pressure from human activities reduced substantially the well-conserved forests in the region.

The aim of this study was: (1) to present a diagnosis of conservation status of forest fragments using as criteria landscape ecology metrics and (2) to generate probabilistic models to quantify forest fragments.

MATERIALS AND METHODS

Study area and forest mapping

The study area encompasses part of two states of southeastern Brazil. The region is located in the Itapemirim river basin and surrounding Caparaó National Park, which corresponded to a buffer covering an area of 10 km from the Park's boundaries. The basin and the park are included in the southeastern part of the state of Minas Gerais, and in the southern part of the state of Espirito Santo.

The geographical localization is between parallels 20° 48' and 21° 05' south and meridians 40° 48' and 41° 58' west. The region encompasses 30 counties and occupies a total area of around 6,640 km².

According to Köppen classification, the study area has three climates: Aw or savanna climate, Cwa, and Cwb. The vegetation belongs to Atlantic Forest biome with predominant formation of dense rainforest, semi-deciduous forest, sandbanks, and mangrove.

The mapping of forest fragments was performed as a stage of a project called "Forest Seeds Network of Surrounding the Caparaó and of Itapemirim River Basin", in which fragments with area larger than 10 hectares (ha) were delimited, since smaller fragments are more susceptible to biodiversity changes and inbreeding (Santos et al., 2016).

Coffee production and cattle grazing are the most important agricultural activities in the region; therefore, coffee plantations and grasslands are the main causes of pressure on the vegetation (Mannigel, 2008; Sales et al., 2013). Pirovani (2010) describes that coffee cultivations intensified in the second half of the 19th century, but after that some factors (as loss of fertility) contributed to coffee areas be changed to grasslands.

1:15,000 scale and 1-m spatial resolution digital aerial photographs obtained in 2007 from the State Institute for the Environment were used. The ArcGIS software (version 9.3) was used to assist the digitization of fragments adopting 1:2,500 scale and after to estimate areas and perimeters.

Landscape ecology metrics

After complete the mapping, landscape ecology metrics were calculated to each forest fragment, whose values were used as criterion to identify those well-conserved forest fragments (Figure 1).

The metrics corresponded to fractal dimension index (Equation 1): it refers to the shape complexity of forest fragments and assumes lower values for simple and regular shapes, whereas the higher values correspond to more complex and convoluted shapes (Santos et al., 2016; Couto, 2004).

$$FDI = \frac{2\ln\left(\frac{P}{4}\right)}{\ln(A)} \quad (1)$$

The second metric was the circularity or edge index (Equation 2): it reflects the edge effect and susceptibility of forest fragments to external factors (Santos et al., 2016; Viana and Pinheiro, 1998). Circular form assumes one as maximum value. This index is expressed by:

$$EI = \sqrt{\frac{A}{Ac}} \quad (2)$$

where FDI is the fractal dimension index; EI is the edge index; P is the perimeter of the fragment, in m; A is the area size, in m²; Ac is the area (m²) of a circle with same perimeter; ln is the natural logarithm.

Finally, the third landscape ecology metric was area size (ha) of the fragment. The metrics were modeled with the Weibull-3P

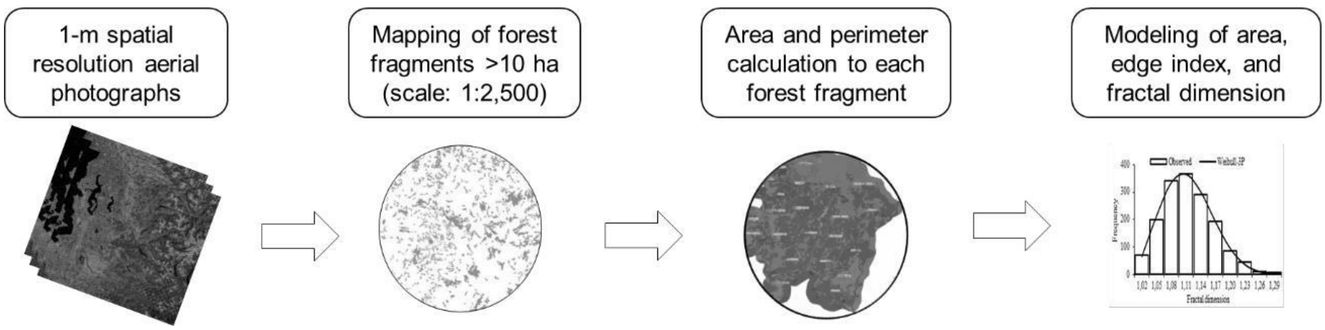

Figure 1. Methodological procedure to model landscape ecology metrics of forest fragments.

Table 1. Descriptive statistics of the variable area size (ha) of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

Group	Minimum	Maximum	Average	Median	CV (%)	No. of fragments
10-100 ha	10.0	99.8	29.0	21.4	67.1	1,438
100-500 ha	100.2	498.2	195.7	155.1	50.8	155
> 500 ha	537.7	4,293.1	1,098.3	800.6	72.1	27
Total	10.0	4,293.1	62.8	24.2	286.2	1,620

CV: Coefficient of variation.

probability density function (pdf) to quantify the occurrence of forest fragments in a given interval. The procedure was repeated to the three metrics. The Weibull-3P pdf (Equation 3) is expressed by:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} e^{-\left(\frac{x-a}{b}\right)^{c}} \quad (3)$$

where x is the variable of interest; a, b and c are the location, shape and scale parameters of the model respectively; *e* is the exponential.

In relation to the variable area size, the pdf was adjusted by groups; being from 10 to 100 ha, 100 to 500 ha and larger than 500 ha. This separation was required due to the high variation of area sizes when encompasses all of them together. Table 1 presents the main descriptive statistics in relation to the groups of area size.

To the other variables (DFI and EI), these three groups were disregarded due to their low variations. The modeling counted on ten frequency classes, except the group larger than 500 ha, whose number of classes was reduced to six, due to its low number of observations.

Thus, these functions could be used to estimate only one variable. Then, bivariate normal function also was applied to the bivariate case (Pennacchi et al., 2006). The generalization of the univariate normal function (Equation 4) leads to the multivariate normal function (Equation 5):

$$f(x) = \frac{1}{(2\pi)^{1/2}\sigma} e^{-\frac{1}{2}\left[\left(\frac{x-\mu}{\sigma}\right)^2\right]} \quad (4)$$

with $x \varepsilon R$, $\mu \varepsilon R$ and $\sigma \varepsilon R^+$.

The generalization allows the combination of p normal variables in the function:

$$f(x_1, x_2, \ldots, x_p) = \frac{1}{(2\pi)^{p/2}\sigma_1\sigma_2\ldots\sigma_p} e^{-\frac{1}{2}\left[\left(\frac{x_1-\mu_1}{\sigma_1}\right)^2 + \left(\frac{x_2-\mu_2}{\sigma_2}\right)^2 + \ldots + \left(\frac{x_p-\mu_p}{\sigma_p}\right)^2\right]} \quad (5)$$

where x_i is the variables of the model; σ_i and μ_i is the parameters of the model; p is the number of variables; *e* is the base of natural logarithm; π is the "pi" constant.

Integrating $f(x_1, x_2)$, it was possible to obtain the probability of occurrence or percentage of forest fragments in a desired interval of area size and of fractal dimension or of edge index. Through the bivariate models, we drew 3D graphs relating area size and one of the indexes, by using the software Matlab version R2012a.

The normal bivariate function presupposes that linear combinations of the components $\underline{X}$ follow a normal distribution N p-variate with mean vector $\underline{\mu}$ and covariance matrix Σ $\left[\underline{X} \sim N_p(\underline{\mu}, \Sigma)\right]$ and then, the Chi-square (χ^2) test (Equation 6) for normality was performed at 50% of probability.

$$P\left[\underline{X}: (\underline{X} - \overline{\underline{X}})' S^{-1} (\underline{X} - \overline{\underline{X}}) \leq \chi^2_p(0.5)\right] \quad (6)$$

where $\overline{\underline{X}}$ estimates $\underline{\mu}$ and S estimates Σ.

The initial hypothesis (H_0) corresponds to existence of data normality while the alternative hypothesis (H_1) corresponds to non-normality.

Accuracy and goodness of fit

The accuracy of the Weibull-3P probability density function (pdf)

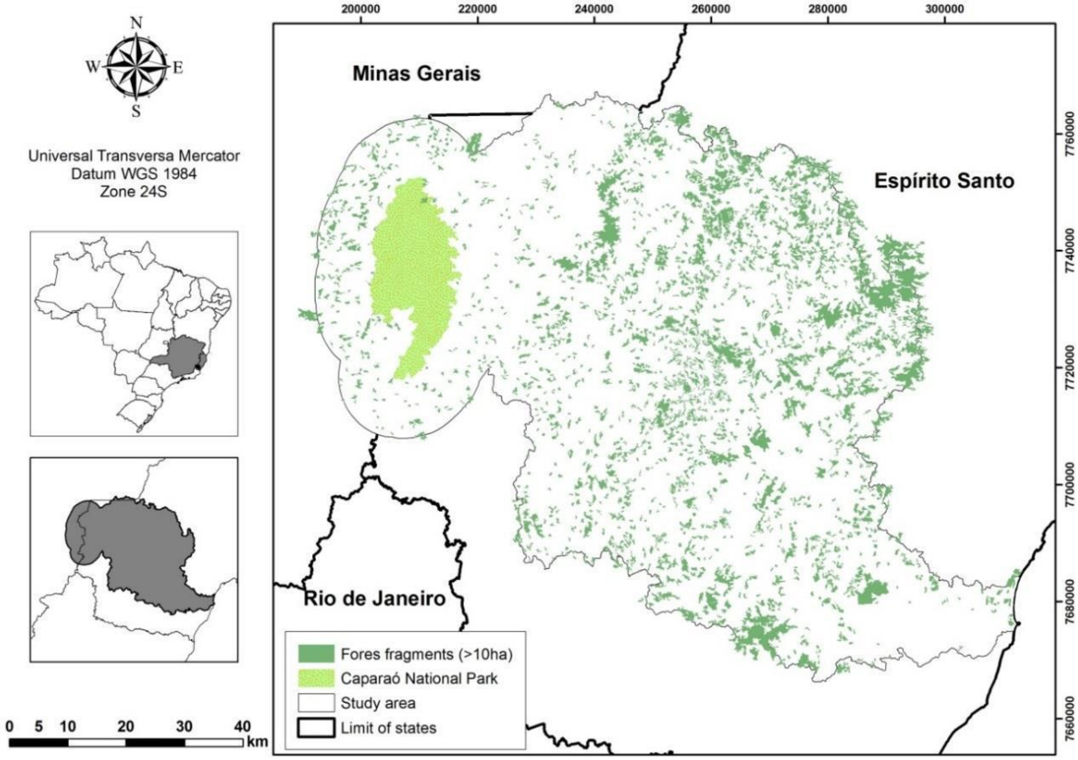

Figure 2. Forest fragments with area larger than 10 ha in the Itapemirim river basin and surrounding the Caparaó National Park.

was evaluated by adopting the standard error of estimate (SEE) in percentage (Equation 7). The goodness of fit was verified by the Kolmogorov-Smirnov (KS) test (Equation 8) at 95% probability level (Razali and Wah, 2011).

$$SEE (\%) = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{y}_i)^2}{n - p}} \cdot \frac{100}{\bar{y}} \quad (7)$$

$$KS = sup_x |Fo(x) - Fe(x)| \quad (8)$$

where Fo is the observed cumulative frequency; Fe is the estimated cumulative frequency; sup_x is the supremum difference; Y_i e $\hat{y}_i$ is the observed and estimated variables, respectively; $\bar{y}$ is the average of observed variable; n is the number of observations; p is the number of parameters.

In summary, the proposed methodology consisted of quantifying forest fragments given a desired interval of ecological indexes by using a pdf. The same procedure was done in the bivariate case, assuming as variables the area size and one of the indexes.

Thus, it is expected that this study may contribute to management plans of networks of forest seeds located in Brazilian Atlantic Forest, especially the "Forest Seeds Network of Surrounding the Caparaó and of Itapemirim River Basin". Among the contributions, the quantification and selection of well-conserved forest fragments were mentioned with the aim to collect seeds in forest fragments.

RESULTS AND DISCUSSION

Forest fragments (1,620) were identified and delimited corresponding to 924.11 km² or 13.7% of forest cover (Figure 2). The largest fragment found has area approximately equals to 43 km².

Functions for quantifying forest fragments

Area size

Table 2 presents the pdf parameters and statistically analyzes estimated frequencies to each area size group. The adjustments resulted in regression parameters and F values are significant at 95% probability level.

Weibull-3P pdf showed good results according to the statistics, in which the standard error of estimate in percentage (SEE%) ranges approximately from 12 to 29%. The adjusted coefficients of determination (R^2_{adj}) resulted in values larger than 0.91.

The Kolmogorov-Smirnov test revealed satisfactory estimates of the Weibull-3P pdf to the three groups. Figure 3 shows the observed and estimated frequencies of fragments, to the three area size groups.

From all observed fragments, an amount of 1,438

Table 2. Parameters and statistics of Weibull-3P pdf fitted by area size groups of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

Group	Parameters			Statistical analyzes			
	a	b	c	SEE (%)	$R^2_{adj.}$	F	KS
10-100 ha	10.9094*	18.4998*	0.8437*	12.258	0.9969	1,672*	0.010^{ns}
100-500 ha	110.1597*	122.2787*	0.7139*	18.085	0.9882	442*	0.013^{ns}
>500 ha	654.3558*	1,329.5343*	0.7892*	29.361	0.9157	43*	0.036^{ns}

***Significant at 95% probability level; ns = not significant.

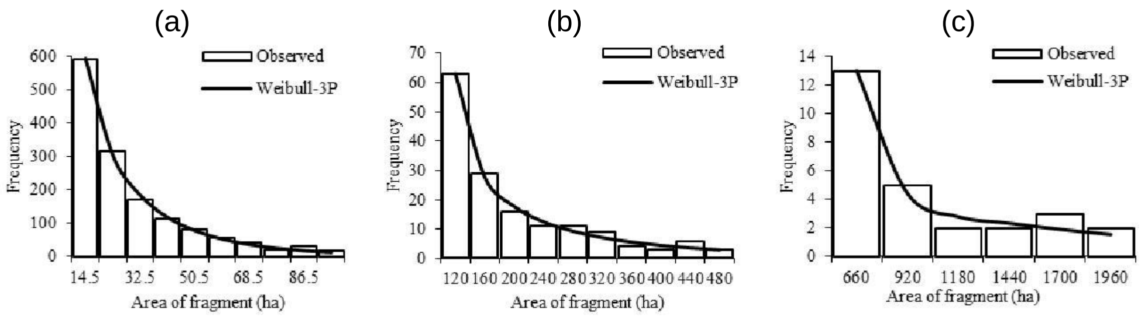

Figure 3. Frequency of forest fragments by area size groups from 10 to 100 ha (a), 100 to 500 ha (b), and larger than 500 ha (c), in the Itapemirim river basin and surrounding the Caparaó National Park.

Table 3. Parameters and statistics of the Weibull-3P pdf fitted to ecological indexes of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

Index	Parameters			Statistical analyzes			
	a	b	C	SEE (%)	$R^2_{adj.}$	F	KS
Fractal dimension	0.9936*	0.1306*	2.4321*	5.49	0.9954	1,132*	0.010^{ns}
Edge	0.0737*	0.4398*	2.7153*	4.47	0.9958	1,238*	0.015^{ns}

***Significant at probability level of 95%; ns: not significant.

(88.77%) has area between 10 and 100 ha, representing 417.34 km² of forest cover, whereas the fragments larger than 100 ha totalize 182 (11.24%), corresponding to about 600 km² of forest cover.

Although, fragments larger than 10 ha were mapped, Pirovani et al. (2014) also mapped forest fragments in part of our study area (Itapemirim sub-basin), finding around 68% of fragments smaller than 5 ha, and 22% between 5 and 50 ha. This means that if we would consider fragments smaller than 10 ha, we possibly would find most of the forest fragments in this class.

Ecological indexes

Table 3 shows the parameters and fit statistics of the estimated frequencies by the Weibull-3P pdf found to fractal dimension and edge index.

The coefficients and F test values were significant at 95% probability level and the KS values were not significant, indicating proper goodness of fit. The standard errors of estimate in percentage (SEE%) reached the maximum value of 5.5% and the adjusted coefficients of determination ($R^2_{adj.}$) were close to one.

Figure 4 shows the curve estimated by the Weibull-3P pdf and the observed frequency (Figure 4a), as well as the amplitude of the fractal dimension index to each area size group (Figure 4b).

The frequency distribution of the fractal dimension presented mode equal to 1.11 (Figure 4a), value interpreted as fragments with simple up to slightly irregular shapes (Hott et al., 2007). The index revealed a decrease of the amplitude with increase of group sizes, as well as the mean values tended to place in the middle of the amplitude. It is observed that the increase in area

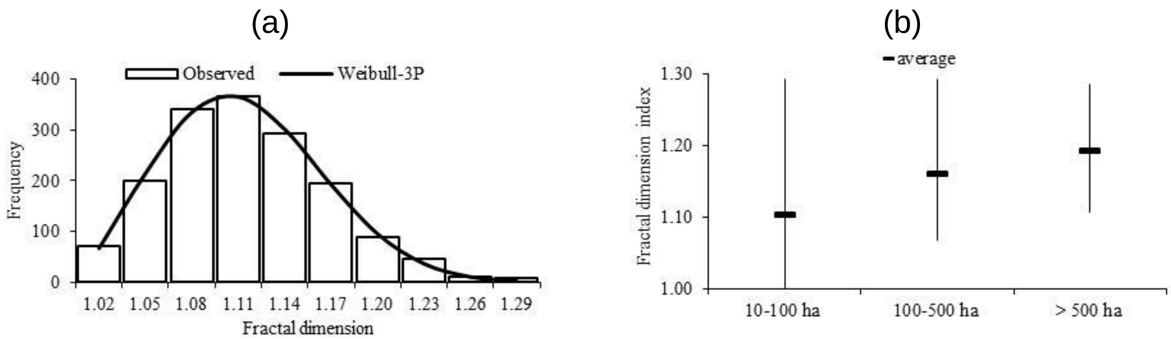

Figure 4. Frequency distribution (a) and amplitude (b) of fractal dimension index of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

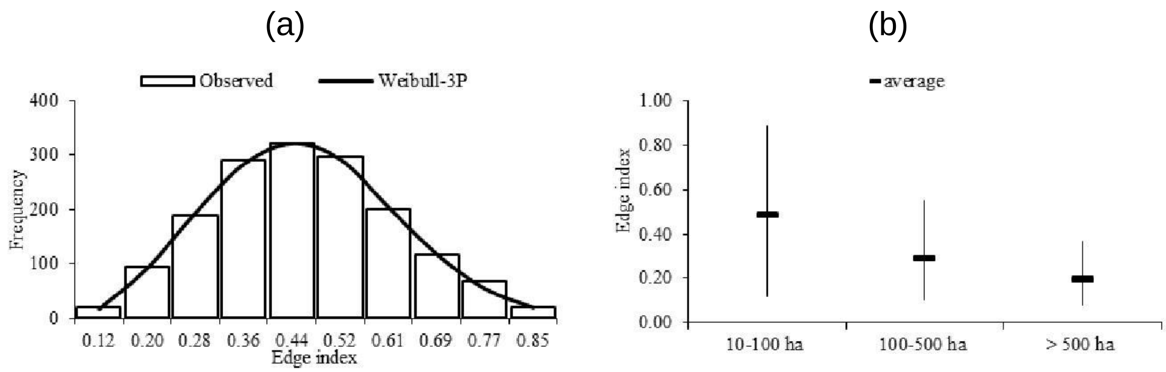

Figure 5. Frequency distribution (a) and amplitude (b) of edge index of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

size tended to increase the shape complexity of the forest fragments (Figure 4b).

Figure 5 shows the estimated curve by the Weibull-3P pdf and the observed frequency (Figure 5a) and the amplitude of edge index to each area size group (Figure 5b).

As observed in the fractal dimension index, the amplitude of edge index decreased with the increase in area size. The minimum, medium and maximum values to the group from 10 to 100 ha were equal to 0.12, 0.49 and 0.89, respectively. To the group from 100 to 500 ha, they were equal to 0.10, 0.29 and 0.55 respectively and, to the group of fragments larger than 500 ha, equal to 0.08, 0.20 and 0.37, respectively.

The fragments with rounded and simpler shapes occurred only in the group from 10 to 100 ha, while the fragments with area from 100 to 500 ha tend to have either elongated or very elongated shapes. Regarding to the fragments larger than 500 ha, the edge index (Figure 5b) and the fractal dimension index (Figure 4b) showed that they have very complex and elongated shapes. As consequence, these fragments have elevated perimeter-area ratio and are more susceptible to external factors (Laurance et al., 2000).

With respect to the normal bivariate functions, the initial hypothesis assumed to the Chi-square test was accepted, indicating data normality at 50% probability level. Therefore, its application was performed to each ecological index in relation to area size (ha) in logarithm scale. Table 4 shows the parameters μ_i and σ_i of the normal bivariate functions fitted to the three groups of area size (ha).

The integration of the bivariate functions (Equation 9) applied with the parameters (Table 4) allowed us to make3D graphs, which is as shown in Figure 6.

$$F(x_{1_a} \le x_1 \le x_{1_b}, x_{2_a} \le x_2 \le x_{2_b}) = \int_{x_{1_a}}^{x_{1_b}} \int_{x_{2_a}}^{x_{2_b}} \frac{1}{(2\pi)^{p/2}\sigma_1\sigma_2} e^{-\frac{1}{2}\left[\left(\frac{x_1-\mu_1}{\sigma_1}\right)^2 + \left(\frac{x_2-\mu_2}{\sigma_2}\right)^2\right]} dx_1, dx_2 \quad (9)$$

where x_1 is the ecological indexes; x_2 is the logarithm of area size (ha); x_{i_a} is the lower limit of the variable; x_{i_b} is the upper limit of the variable; σ_i and μ_i are the parameters of the model; p is the number of variables; *e* is the base of natural logarithm; π is the “pi” constant.

Table 4. Parameters of the normal bivariate functions applied to ecological indexes of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

Ecological indexes	Group	Parameters of x_1		Parameters of x_2	
		μ_1	σ_1	μ_2	σ_2
Fractal dimension index	10-100 ha	1.1033	0.0483	1.3821	0.2556
	100-500 ha	1.1604	0.0420	2.2451	0.1930
	>500 ha	1.1924	0.0375	2.9697	0.2262
Edge index	10-100 ha	0.4867	0.1426	1.3821	0.2556
	100-500 ha	0.2923	0.0859	2.2451	0.1930
	>500 ha	0.1983	0.0619	2.9697	0.2262

x_1: Ecological indexes; x_2: logarithm of area size (ha).

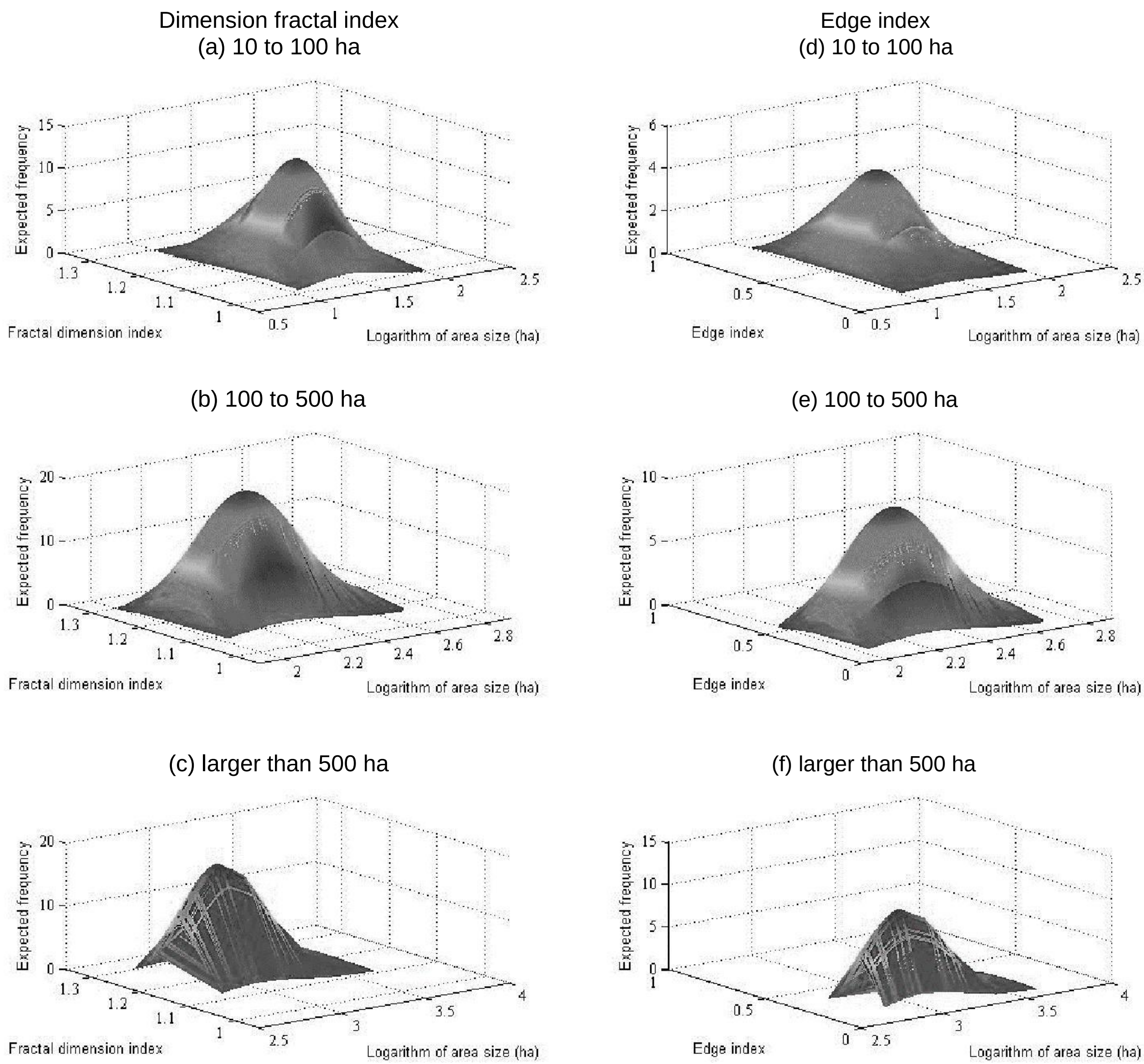

Figure 6. Normal bivariate distribution of the fractal dimension (a, b, and c) and edge indexes (d, e, and f) to groups of area size of forest fragments, in the Itapemirim river basin and surrounding the Caparaó National Park.

Table 5. Estimated frequency by normal bivariate functions for forest fragments larger than 500 ha, in the Itapemirim river basin and surrounding the Caparaó National Park.

Classes of area size (ha)		660-920	920-1,180	1,180-1,440	1,440-1,700	1,700-1,960	≥1,960	Total
Classes of fractal dimension index	1.01-1.03	-	-	-	-	-	-	-
	1.03-1.06	-	-	-	-	-	-	-
	1.06-1.09	-	-	-	-	-	-	-
	1.09-1.12	-	-	-	1	-	-	1
	1.12-1.15	3	-	-	-	-	-	3
	1.15-1.18	2	1	2	-	-	-	5
	1.18-1.21	7	-	-	-	2	2	11
	1.21-1.24	1	3	-	-	-	-	4
	1.24-1.27	-	1	-	1	-	-	2
	1.27-1.30	-	-	-	-	1	-	1
	Total	13	5	2	2	3	2	27
Classes of edge index	0.08-0.16	1	4	-	1	1	2	9
	0.16-0.24	9	1	2	-	2	-	14
	0.24-0.32	3	-	-	-	-	-	3
	0.32-0.40	-	-	-	1	-	-	1
	0.40-0.48	-	-	-	-	-	-	-
	0.48-0.56	-	-	-	-	-	-	-
	0.56-0.64	-	-	-	-	-	-	-
	0.64-0.73	-	-	-	-	-	-	-
	0.73-0.81	-	-	-	-	-	-	-
	0.81-0.89	-	-	-	-	-	-	-
	Total	13	5	2	2	3	2	27

Figure 6 shows graphs that represent the frequency distribution of forest fragments in bivariate case, where area size is represented by the x axis, ecological index by the y axis, and expected frequency by the z axis. The values of mode seen at the top of the distribution indicate a trend in increasing the fractal dimension index as the area size increases. The opposite trend occurred in the edge index, where the frequency decreases from larger fragments to smaller ones.

It can also be observed that the increase of the area size of the fragments makes the distribution to be more restricted, indicating that smaller fragments present largest values of fractal dimension and edge index, in which such variation reduces with the increasing of their area size.

Diagnosis of forest conservation status

The results allow us to consider that the studied area is too fragmented, reducing the number of fragments in the extent to which the forest area increases. Area size of the forest fragment is highly related to its capacity for inhabiting the biodiversity, which makes this variable very important for selecting well-conserved forest fragments (Santos et al., 2016; Viana and Pinheiro, 1998). This fact, also described in the island biogeography, was confirmed by studies that evaluated the relation between forest area and the number of species, such as Rush and Stutchbury (2008), Echeverría et al. (2007) and Nour et al. (1997).

Table 5 shows the frequency of forest fragments estimated by the normal bivariate function (Equation 9) for fragments larger than 500 ha, since they are more important in regards to forest conservation.

Despite the fact that the studied region has a mountainous relief, coffee monoculture is the dominant agricultural activity in the region (Mannigel, 2008; Sales et al., 2013; Pirovani, 2010). The influence of relief (slope, slope orientation, and altitude) on the spatial distribution of forest cover was studied by Santos et al. (2016a) and Silva et al. (2007).

In the surrounding Caparaó National Park, Santos et al. (2016a) found that the forest coverage in permanent preservation areas is strongly related to altitude, in which the greater human intervention occurs in altitudes below 1,110 m. In addition, Santos et al. (2016a) detected that the slope orientation directed to south and slopes larger than 45 degrees are the most forested areas.

Silva et al. (2007) also obtained relation with the presence of forest cover and slopes larger than 10 degrees and altitudes above 923 m, however, the authors found no influence of slope orientation.

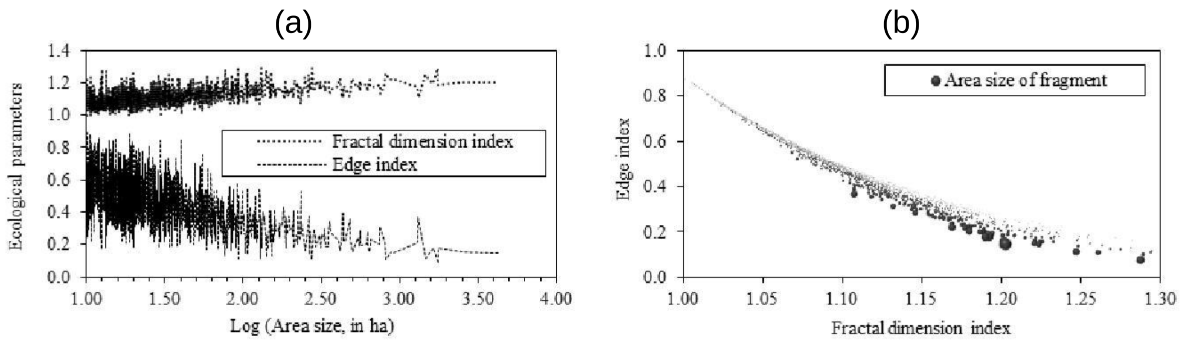

Figure 7. Relation between landscape ecology metrics of forest fragments in the Itapemirim river basin and surrounding the Caparaó National Park.

Thus, in relation to fractal dimension index, the lowest values induce us to associate with intense anthropic action basically by agricultural activities; on the other hand, the highest values indicate well-conserved fragments and low anthropic impact (Couto, 2004). Fragments with large area size generally are conservation areas protected by buffer zones that favor their surrounding preservation, allowing natural formations that promote increasing of shape complexity.

The small fragments in turn, generally are legal reserves of small and medium farms, oftentimes surrounded by grasslands, crops, and planted forests, which mischaracterizes the natural neighboring areas and reduces its fractal dimension index. As discussed earlier, steeper and higher altitude areas tend to present less agricultural activities than flatter and lower ones, thus, the more unfavorable is the relief, the more conserved the forest fragments tend to be (Silva et al., 2007).

In relation to edge index, according to limits established by Viana and Pinheiro (1998), approximately 80% of the fragments is very elongated (value less than 0.6), 18% is elongated (value between 0.6 and 0.8) and 2% is rounded (value greater than 0.8). Similar proportions were found by Nascimento et al. (2006) in forest fragments in the Itapemirim river sub-basin.

These results show the importance of maintaining buffer zones to the larger forest fragments, which favors the decrease of pressures on the biodiversity, while the smaller fragments act as stepping stones between the largest ones, contributing to the flow of animals and genetic interactions (Forman and Godron, 1981).

Figure 7a shows the variation of both indexes in function of the area size (in logarithm to the base 10). Figure 7b shows the scattering between the three landscape ecologic metrics, where the area size of the forest fragment is equivalent to the bubble size. The smaller and bigger bubbles are compatible to 10 and 4,300 ha, respectively. Figure 7a shows that the variation of the indexes reduces with the increase of the area size of the fragment. Especially in fragments smaller than 100 ha, such variation indicates the existence of different surrounding areas.

Such finding corroborates the existence of many forest fragments in different environmental conditions and edge effect, as described in Santos et al. (2016b), Harper et al. (2004) and Steininger et al. (2001). This suggest us that area size must not be the only criteria for selection well-conserved forests, since fractal dimension and edge index range even in fragments of equal areas.

We noted a clear trend in decreasing the edge index as the fractal dimension index increases (Figure 7a). Figure 7b indicates that the smallest fragments are well distributed along the both axis, on the other hand, the largest fragments are within a little more restrict interval of fractal dimension and edge index.

According to Figure 7, the forest fragments with area size larger than 500 ha are characterized by having complex shapes (large fractal dimension index), what provokes increases in the edge effect. However, such behavior also may occur in smaller fragments.

Santos et al. (2016) selected forest fragments to collect seeds employing other ecologic variables besides the ones used in this research, as internal area of forest fragment, distance among neighboring fragments, besides area size of neighboring fragments. The author observed that the size of the fragment is highly relevant for its selection if the objective is to collect seeds.

Echeverría et al. (2007) also employed similar indexes to evaluate impacts of forest fragmentation on species composition and forest structure. The authors observed that area size of fragment exerted strong effect in both components.

Conclusions

The largest forest fragments (>500 ha) differ from the smallest ones (<100 ha) in relation to ecological indexes. Larger forest fragments have more complex shapes and high edge effect. Smaller forest fragments have since simple shapes up to more complex ones, besides having quite variable edge effect.

The frequency of fragments by area size presents an exponential model, consequently, the frequency of forest fragments decreases as much as its area increases. However, the fractal dimension and edge indexes follow a Gaussian model, thus, fragments with medium values for such indexes are majority in the region. Area size of the fragment, when modeled together with fractal dimension or edge index (that is, a bivariate case), have frequency following a Gaussian model, meaning that forest fragments with bigger areas, lower edge effects, and more rounded are the scantiest ones in the region.

Conflict of Interests

The authors have not declared any conflict of interests.

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