Multitemporal spatial analysis of forest fragments in the Barra Seca River basin, ES: a case study

Análise espacial multitemporal de fragmentos florestais: estudo de caso na bacia hidrográfica do rio Barra Seca, ES

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Multitemporal spatial analysis for monitoring land cover and use is an important tool for understanding the evolutionary dynamics of a certain region. This study aims at determining and using landscape ecology indices to map and analyze the forest landscape structure in the Barra Seca River basin, an area of 2,216.56 km², in northern Espírito Santo, in 1985, 1996, 2006 and 2016. The forest patches composing the landscape were isolated and classified by area size using remote sensing techniques by supervised classification and the Bhattacharya algorithm. The landscape metrics and indices in the Patch Analyst extension and V-Late 2 Beta allowed identifying 2366, 2540, 3156 and 3052 forest patches in 1985, 1996, 2006 and 2016, respectively. These patches were classified by size into four classes as follows, smaller than 5 ha (C1), between 5 and 10 ha (C2), between 10 and 100 ha (C3), and larger than 100 ha (C4). The landscape metrics was used to determine quantitatively the area index; density and size; shape; edge; proximity and core area using the edge effect of 35, 60 and 120 m for the patch classes and applied to the total forest patches per year. The number of forest patches smaller than 100 ha increased between 1985 and 2016, while larger patches decreased. The patches greater than 100 ha had the most irregular shapes and higher core area index, even for the edge effect of greater distance. The metrics indices show that landscape fragmentation and irregular shaped patches are increasing in the basin while edge effect is being maximized.

Keywords: Atlantic Forest; landscape metrics; remote sensing.

Resumo

A análise espacial multitemporal para o monitoramento da estrutura da paisagem de fragmentos florestais é uma importante ferramenta para entender a dinâmica evolutiva de uma região. Neste estudo, objetivou-se mapear e analisar a estrutura da paisagem florestal na bacia hidrográfica do rio Barra Seca, com área de 2,216.56 km², localizada no Norte do Espírito Santo, nos anos de 1985, 1996, 2006 e 2016, por meio de índices de ecologia da paisagem. Utilizando técnicas de sensoriamento remoto pela classificação supervisionada, usando o algoritmo *Bhattacharya*, foram isoladas as classes dos fragmentos florestais que compunham a paisagem. A análise da paisagem, por meio de métricas de ecologia de paisagem, foi obtida por meio da extensão *Patch analyst* e *V-Late 2 Beta*. Foram obtidos nos anos de 1985, 1996, 2006 e 2016, respectivamente, 2366, 2540, 3156 e 3052 fragmentos florestais. Os fragmentos foram divididos em classes de tamanho, consistindo em fragmentos menores de 5 ha; entre 5 a 10 ha; entre 10 a 100 ha; e acima de 100 ha. A quantificação por meio de métricas de paisagem foi realizada com os grupos de índices de área; densidade e tamanho; forma; borda; proximidade e área central, sendo este aplicado no conjunto dos fragmentos florestais por ano analisado, utilizando o efeito de borda de 35, 60 e 120 m. O índice de número de fragmentos florestais elevou-se entre 1985 a 2016, nos fragmentos menores que 100 ha, e reduziu para os fragmentos de áreas maiores. Os fragmentos maiores que 100 ha apresentam os formatos mais irregulares e maior índice de área central, mesmo sob efeito da maior distância de efeito de borda. Os resultados dos índices métricos apontam para um aumento da fragmentação da paisagem da bacia, aumento de formas mais irregulares das manchas de vegetação e maximização do efeito de borda.

Palavras chave: Mata Atlântica; métricas de paisagem; sensoriamento remoto.

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INTRODUCTION

The increasing socioeconomic development and population growth observed in coastal regions affect and deplete the natural resources in these areas (MAANAN, et al., 2014). The natural vegetation is replaced by anthropic activities that reduce and cause forest to fragment into patches of different sizes and shapes (MORETTI, 2011).

The forest fragmentation process caused by anthropogenic disturbances is a relevant threat to biodiversity since it introduces several new factors into the evolutionary history of organisms (VIANA; PINHEIRO, 1998). The Atlantic Forest biome is composed of an intensely fragmented landscape, with a high degree of disturbance and low connectivity among forest remnants (AYRES et al., 2005). Therefore, the Atlantic Forest is considered a priority conservational area due to its high biodiversity and threat level (MYERS et al., 2000).

Although the Barra Seca River basin (BSRB) still has important remnants of the Atlantic Forest, this biome has been significantly reduced in Espírito Santo state with only 9% of its original coverage remaining (FUNDAÇÃO MATA ATLÂNTICA, 2015). The main component of the BSRB is the Barra Seca River, which runs through the most significant remnants of Atlantic Forest in the state of Espírito Santo, in the Sooretama Biological Reserve and Natural da Vale Reserve. In addition, the basin contains numerous forest remnants, which despite being among the most fragmented tropical forests in the world (MYERS et al., 2000), has a high level of richness and diversity, with many endemic species (MARINHO-FILHO, 1996).

The fragmentation of forest remnants into smaller patches changes the patch biotic community and physical parameters (FAHRIG, 2003). These changes act more intensely on the fragment edges, affecting the biodiversity and effects of influence area differently, depending on several factors, such as biome permeability, surrounding environment characteristics (matrix), species sensitivity to changes, distance between fragments and their dimensions, among others (PRIMACK; RODRIGUES, 2001). The edge effect changes the structure and dynamics of ecosystems, constituting one of the main consequences of forest fragmentation. Therefore, quantifying the landscape structure using landscape metrics to analyze distribution, shape and spatial arrangement of forest patches helps to understand these changes (PANG et al., 2010; ZARAGOZÍ et al., 2012).

The general objective of this work was to analyze the changing structure of the forest landscape of the BSRB in Espírito Santo in 1985, 1996, 2006 and 2016, based on the theoretical and methodological fundamentals of Landscape Ecology, following geographical and biological/ecological approaches to understand the forest fragmentation process and spatial distribution using landscape metrics and Remote Sensing techniques, from Landsat satellite Images.

MATERIAL AND METHODS

Study site

The BSRB is a sub-unit of the Rio Doce hydrographic system located in the Southeast Atlantic Hydrographic Region. The Barra Seca River flows into the sea in Barra Seca, between cities of Linhares and São Mateus, in Espírito Santo state (Figure 1). The total basin area is 2216.56 km², covering all the coastal sub-basins in the quaternary accumulation area, immediately north of the Doce River mouth (SCHINEIDER, 2010).

Mapping of forest patches

The landscape metric calculations used the forest fragments extracted from the land use map obtained from satellite images captured by the Landsat 5 and 8, TM and OLI sensors, respectively, provided free of charge by the National Institute for Space Research (INPE). Subsequently, the Spring software was used for geoprocessing these images and, using the Bathacharya algorithm, perform the supervised classification of land use classes by recognizing homogeneous areas from the image according to the spectral and spatial features, following the procedure of Guarnier et al. (2018). Finally, the land use generated maps were used to map the classes and isolate the class that corresponds to the forest fragments.

The landscape metrics parameters were obtained by the ArcGIS 10.1 software, in the Patch analyst and V-Late 2 Beta extensions. The procedure requires that the forest fragments are initially converted from raster to vector format, applying the smoothing the edges in this step, so that the metric measures,

Figure 1. Map of the Barra Seca River basin (ES); A: Brazil; B: Espírito Santo state; C: Barra Seca river basin.
Figura 1. Localização da bacia hidrográfica do rio Barra Seca (ES); A: Brasil; B: Espírito Santo; C: Bacia Hidrográfica do rio Barra Seca.

especially those involving area and edge, are closer to reality. The basin forest patches were classified according to area into four size classes as follows very small (C1), small (C2), medium (C3) and large (C4), measuring up to 5 ha, between 5 and 10 ha, between 10 and 100 ha, and above 100 ha, respectively. The landscape metrics was also determined for all patches together. The landscape indices used are shown in Table 1.

RESULTS

Landscape metrics of forest patches in 1985, 1996, 2006 and 2016

The mapping of forest fragments in the BSRB indicated a increase from 1985 to 2006, and decrease in 2016 (Table 2). The 0.92% annual fragmentation average was based on the data obtained for each transition period studied (1985-1996, 1996-2006 and 2006-2016).

The total area of forest patches remained moderately steady over the years (Table 2), however, the mean patch size (MPS) decreased significantly, from 1985 to 2016. The coefficient of variation of patch size (PSCoV) increased gradually, with increasing dispersions around the mean area. Because of forest fragmentation, mean shape index (MSI) and the total edge (TE) increased. On the other hand, the mean distance from the nearest neighbor (MNN) decreased, providing greater connectivity between the patches.

Table 1. Landscape metrics and indices used to analyze forest patches.

Tabela 1. Índices de ecologia da paisagem utilizados na análise de métricas nos fragmentos florestais.

Group	Acronym	Metrics	Description
Area	CA	Class area	Sum of areas of all forest patches
Density and size	MPS	Mean patch size	sum of areas divided by the number of patches
	NUMP	N° of patches	Total number of patches in the landscape/class
	PSSD	Patch size standard deviation	Ratio of variance of patch size
	PSCoV	Patch size coefficient variation	Standard deviation of patch size divided by mean patch size, multiplied by 100
Edge	TE	Total edges	Sum of the perimeter of all patches
	ED	Edge density	Number of edges relative to the area
Shape	MSI	Shape index	Values are close to 1 for simple patch shapes and up to 2 for complex patch shapes
	AWMSI	Area-weighted mean shape index	It differs from the MSI because larger patches have more weight than smaller ones
Proximity	MNN	Mean distance from nearest neighbor	Mean of the distances for individual classes at the class level and the average distance of the neighboring class at the landscape level
Central Area	NCA	N° of core areas	Total number of patches in the core area
	TCA	Total core area	The size of core patches
	TCAI	Total core area index	Relative measurement of core landscape area
	MCA	Mean core area	Total size of core patches divided by the number of core patches

Source: McGarigal and Marks (1994).

Table 2. Landscape metrics and indices calculated for the forest patches of the Barra Seca River basin, in 1985, 1996, 2006 and 2016.

Tabela 2. Índices de métricas de paisagem calculados para os fragmentos florestais da Bacia hidrográfica do Rio Barra Seca, para os anos de 1985, 1996, 2006 e 2016.

Group	Index	Unit	1985	1996	2006	2016
Area	CA	Hectares (ha)	105142.30	95906.87	105758.49	102078.33
Density and Size	MPS	Hectares (ha)	44.44	37.79	33.51	33.44
	NumP	dimensionless	2366	2540	3156	3052
	PSSD	Hectares (ha)	804.34	727.86	991.76	1013.05
	PSCoV	%	1809.99	1927.66	2959.57	3028.87
Edge	TE	Meter (m)	5568087.38	5433538.59	6468453.91	675927.53
	ED	m/ha	52.95	56.65	61.16	66.15
Shape	MSI	dimensionless	1.45	1.49	1.47	1.59
	AWMSI	dimensionless	5.03	4.31	6.22	6.67
	MPFD	dimensionless	95906.87	37.76	2540.00	727.86
Proximity	MNN	Meter (m)	197.5	202.05	162.23	165.13

Legend: CA: Area of all patches; MPS: Medium Patch Size; NUMP: Number of Patches; PSSD: Standart Total Edges; PSCov: Coefficient of variation of size; TE: total edges; ED: edge density; MSI: Mean Shape Index; AWMSI: Area Weighted Mean Shape Index; MPFD: Mean Patch Fractal Dimension; MNN: Mean distance from nearest neighbor.

A patch area deficit of 7.1% was found for the edge effect distance of 35 m over the sampled time interval, which according to Primack and Rodrigues (2001) corresponds to the minimum edge distance for the Ombrophilous Dense Forest. Furthermore, deficits of 8.05% and 6.5% were observed for edge effect distances of 60 and 120 m, respectively, in the same period (Table 3).

Figure 2 shows the edge effect for increasing distances versus the central area metrics (mean core area, MCA; total core area index, TCAI; number of core areas, NCA; and total core area, TCA). The highest TCA, MCA and TCAI but lower NCA for the forest patches were obtained for the studied edge effect distances in 1985. Whereas the lowest MCA and TCA were observed in 2016. These data show the intensification of edge effects due to the increasing forest fragmentation observed during the studied years.

Figure 2 shows that for the 120 m edge distance, the MCA increased markedly over the period, which is related to the sharp decrease of NCA for the same distance. The TCAI measures the relative amount of patch area per year considered and decreased markedly with increasing edge effect distance

Table 3. Landscape metrics and indices calculated for different edge effect distances for the forest patches of the Barra Seca River basin (ES) in 1985, 1996, 2006 and 2016.

Tabela 3. Valores dos índices de ecologia de paisagem das métricas de área central utilizando diferentes distâncias de faixas sob o efeito de borda, para os anos de 1985, 1996, 2006 e 2016 nos fragmentos florestais da bacia do rio Barra Seca, ES.

Years	Index	Edge Effect (m)		
		35	60	120
1985	NCA	2866	2241	963
	TCA	869213717.20	767021444.70	602243820.05
	TCAI	82.67	72.95	57.27
	MCA	303284.62	342267.5	625384
1996	NCA	3216	2364	948
	TCA	783573784.20	686571358	534649147.50
	TCAI	81.7	71.59	55.75
	MCA	243648.56	290427.81	563975.90
2006	NCA	4042	2813	1122
	TCA	849198567.30	738817436.70	589883704.20
	TCAI	80.30	69.90	55.78
	MCA	210093.67	170391.40	525743.05
2016	NCA	4398	2955	1108
	TCA	807649508.80	705246768.60	563340256.20
	TCAI	79.12	69.09	55.19
	MCA	183640.18	238662.20	508429.80

Legend: NCA: Number of core áreas; TCA: Total Core Area e; TCAI: Total Core Area Index; MCA: Mean core areas.

Figure 2. Behavior of the (A) mean core area, (B) total core area index, (C) number of core areas and (D) total core area versus increasing edge distance in the Barra Seca (ES) River basin in 1985, 1996, 2006 and 2016.

Figura 2. Comportamento nos anos de 1985, 1996, 2006 e 2016 da (A) área central média, (B) índice de área central total, (C) número de áreas centrais e (D) área central total, em relação ao aumento da distância de borda na bacia do rio Barra Seca (ES).

(Figure 2D). For the 120 m edge effect distance, the forest area free of edge effect was reduced by almost half over the studied time interval.

Landscape Metrics for Forest Patch Size Classes

Tables 4 and 5 show the indices of landscape metrics calculated for the forest patches of the BSRB according to size classes while Figure 3 shows the distribution of the fragments according to their class in the years studied.

Table 4. Landscape metrics and indices calculated for C1 and C2 forest patches of the Barra Seca River basin, in 1985, 1996, 2006 and 2016.

Tabela 4. Índices de métricas de paisagem calculados para os fragmentos florestais da Bacia hidrográfica do Rio Barra Seca, para os anos de 1985, 1996, 2006 e 2016, para as classes C1 e C2.

Group	Index	Size Classes							
		C1 (<5 ha)				C2 (5 – 10 ha)			
		1985	1996	2006	2016	1985	1996	2006	2016
Area	CA	2812.05	3320.76	4179.12	4262.99	2882.20	2834.01	3394.12	3453.32
Density and size	MPS	2.17	2.25	2.14	2.36	6.96	7.03	7.12	7.12
	NumP	1294	1475	1957	1803	414	403	477	485
	PSSD	1.22	1.21	1.17	1.07	1.39	1.40	1.41	1.39
	PSCoV	56.25	53.67	54.98	45.07	19.93	19.91	19.80	19.45
Edge	TE	827839.50	988506.60	1255144.60	1337202	541729.30	563347.90	664906.80	732981.10
	ED	294.39	297.68	298.98	313.68	187.96	198.78	195.90	212.25
Shape	MSI	1.27	1.29	1.28	1.38	1.40	1.49	1.48	1.60
	AWMSI	1.30	1.33	1.31	1.41	1.41	1.50	1.49	1.61
	MPFD	1.31	1.31	1.31	1.31	1.29	1.30	1.29	1.31
Proximity	MNN	531	412.60	389.20	412.60	992.80	965.98	879.50	862.50

Legend: CA: Area of all patches; MPS: Medium Patch Size; NUPP: Number of Patches; PSSD: Standart Total Edges; PSCov: Coefficient of variation of size; TE: total edges; ED: edge density; MSI: Mean Shape Index; AWMSI: Area Weighted Mean Shape Index; MPFD: Mean Patch Fractal Dimension; MNN: Mean distance from neares neighbor.

Table 5. Landscape metrics and indices calculated for C3 and C4 forest patches of the Barra Seca River basin, in 1985, 1996, 2006 and 2016.

Tabela 5. Índices de métricas de paisagem calculados para os fragmentos florestais da Bacia do Rio Barra Seca, para os anos de 1985, 1996, 2006 e 2016 para as classes C3 e C4.

Group	Index	Size Classes							
		C3 (10 a 100 ha)				C4 (> 100 ha)			
		1985	1996	2006	2016	1985	1996	2006	2016
Area	CA	16176.26	17969.72	19360.98	20128.45	83037.88	71782.39	78805.33	74233.57
Density and size	MPS	28.43	30.00	30.16	29.21	943.61	1139.40	997.54	989.78
	NumP	569	599	642	689	88	63	79	75
	PSSD	19.59	20.96	20.70	20.92	4067.98	4483.90	6191.30	6388.72
	PSCoV	68.89	69.88	68.64	71.61	431.11	393.53	620.66	645.47
Edge	TE	1782877.9	2083358.0	2283708.4	2543030.1	2404074.5	1798326.1	2261716.5	2139714.3
	ED	110.22	115.94	117.95	126.34	28.95	25.05	28.70	28.82
Shape	MSI	1.68	1.81	1.84	1.95	2.99	3.07	3.28	3.27
	AWMSI	1.81	1.97	2.01	2.12	5.93	5.15	7.72	8.45
	MPFD	1.28	1.29	1.30	1.31	1.31	1.32	1.33	1.33
Proximity	MNN	479.50	479.20	424.90	390.80	931.60	1372.97	864.01	1018.60

Legend: CA: Area of all patches; MPS: Medium Patch Size; NUPP: Number of Patches; PSSD: Standart Total Edges; PSCov: Coefficient of variation of size; TE: total edges; ED: edge density; MSI: Mean Shape Index; AWMSI: Area Weighted Mean Shape Index; MPFD: Mean Patch Fractal Dimension; MNN: Mean distance from neares neighbor.

The landscape metrics using the patch class size approach indicated that the total area (CA), number of patches (NUPP) and total edge (TE) increased in classes C1 (<5 ha), C2 (5 to 10 ha) and C3 (10 to 100 ha), whereas class C4 (> 100 ha) decreased in the studied period. Despite the area variation in the classes, the mean patch size, MPS, increased for all classes. Annual fragmentation values of 1.24%, 0.51%, 0.64% and -0.2% were observed for C1, C2, C3, and C4, respectively, considering the annual average of the classes in the studied transition intervals (1985-1996, 1996-2006 and

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Figure 3. Forest fragments classified according to the size of the Barra Seca River Basin for the years 1985, 1996, 2006 and 2016.

Figura 3. Fragmentos florestais classificados segundo o tamanho da Bacia do Rio Barra Seca para os anos de 1985, 1996, 2006 e 2016.

2006-2016). The mean shape indices (MSI) and area weighted mean shape index (AWMSI) indices were directly correlated with class size, increasing with increasing class size.

The forest patch connectivity was evaluated by the degree of isolation of such patches given by the mean nearest neighbor (MNN) index, which decreased in classes C1, C2, and C3, while increasing in C4, in the 1985 to 2016 period. The decreasing MNN values observed in classes below 100 ha is related to the increasing number of patches while the increasing mean distance between patches above 100 ha is related to the decreasing patch number and area.

DISCUSSION

The number of fragments in the BSRB increased about 29% in the range sampled, indicating a significant fragmentation process, moreover, most patches are very small (<5 ha) and more than 70% are smaller than 10 ha over the studied period. These results corroborate the high levels of fragmentation previously reported for the Atlantic Forest in Brazil, where 83.4% of the patches are smaller than 50 ha (RIBEIRO et al., 2009).

Several studies in the literature highlight the intense forest fragmentation of the Atlantic Forest, with a high number of small patches. Cemin et al. (2009) reported that 87.82% of the forest patches were smaller than 1 ha in the Arroio Jacaré (RS) sub-basin. Miranda (2012), Pirovani et al. (2014) and Santos and Rocha (2015) reported that 75, 89.2 and 66.4% of the forest patches were smaller than 5 ha in the Itapemirim River basin (ES), Oeste Paulista River mouth (SP), and Itapetinga State Park (SP), respectively. While Hentz et al. (2015) revealed that 45.8% of the patches in the catchment area of the Iguaçu River (PR) were less than 10 ha.

The intense fragmentation of the study area heightens the ecological deterioration of the forest patches over the period, verified by the increased shape and edge indices and decreased patch mean size that together maximize the edge effect in the basin landscape (DE PAULA et al., 2016). The increased

edge distance may result in forest patches consisting of habitats with edge effect characteristics. Therefore, the smaller patches are no longer computed in the MCA, and this, in turn, is accentuated by the increased edge distance.

The predominance of very small areas with a high number of patches in the very small and small size classes, C1 and C2, hampers the maintenance of the biota of the basin (TURNER, 1996). Furthermore, these tiny patches are considered fragile to sustain biodiversity over time due to the low number of individuals inhabiting them (SAUNDERS et al., 1991). Also, these areas are smaller than the minimum required for the survival of populations, have low conservation level, and therefore, little biological richness (METZGER, 1999).

Patches larger than 100 ha have better ecological qualities and ability to maintain biodiversity, however, they also have higher shape indices, which intensifies the edge effect. Several studies in the literature highlight the more irregular features of the larger patches in the Atlantic Forest, such as those obtained by Hentz et al. (2015), Jesus et al. (2015) and Pirovani et al. (2014) for the hydrographic basins of Iguaçu River (PR), Poxim River (SE) and Itapemirim River (ES), respectively.

The shape indices are good indicators of patch susceptibility to disturbances, especially edge effect since they establish a relationship between forest patch area and its perimeter (VIANA; PINHEIRO, 1998). Therefore, the increasing shape indices in all size classes reveal a maximizing edge effect since the forest patches tend to move away from 1, considered the best possible shape since it minimizes edge effect (LANG; BLASCHKE, 2009).

The connectivity between patches is relevant when studying the structure of the landscape since proximity influences the gene flow between forest patches and, therefore, the maintenance of the biotic community (VIANA; PINHEIRO, 1998). In this sense, the connectivity index has been applied to guide the decision-making process on conservation and restoration actions, through the dispersal ability of the species, for example, (CROUZEILLES et al., 2014; DALLOZ et al., 2017; TAMBOSI; METZGER, 2013) and creating ecological corridors in the Atlantic Forest (SANTOS et al. 2018). The forest fragmentation observed in this study directly affected the increasing patch connectivity index. However, when analyzed in conjunction with the other indices, this index does not indicate increased forest conservation and landscape quality since the decreasing habitats for biodiversity implies that the biotic community faces more competition for the ecological niches now (HIRZAY; LE LAY, 2008).

The degree of isolation for the total patches was considerably lower than that obtained for each size class in all evaluated years. However, the MNN index showed that connectivity increased and decreased in classes smaller and greater than 100 ha, respectively. This result emphasizes that connectivity increased due to habitat fragmentation while demonstrating that the small patches play an important role connecting the larger patches (LAURANCE, 2004). Goerl et al. (2011) stated that the small patches result from the economic use of the soil when the natural vegetation is replaced with agricultural and pastoral areas.

Ribeiro et al. (2009) reported that the average isolation degree of the Atlantic Forest patches in the Bahia biogeographic sub-region, including the BSRB, is 1441 m, higher than that found in the present study for all size classes and years (Table 3). Ribeiro et al. (2009) also found average patch distance of 3532 m when excluding patches smaller than 50 ha from the calculation, emphasizing the importance of small patches acting as stepping stones for the larger patches. In this work, the connectivity index (MNN) increased when analyzing the fragments together, regarding only the connectivity of fragments larger than 100 ha (Tables 2 and 5). However, the difference between the connectivity, when fragments smaller than 100 ha are removed from the analysis, is less pronounced than that reported by Ribeiro et al. (2009), which may be related to different working scales.

The patch isolation degree analyzed by the mean nearest neighbor has been used by several authors. Pirovani, Silva and Santos (2015) also reported that the MNN index decreased from 923.3 to 813.5 m between 1970 and 2007, in the region surrounding the Private Reserve of Natural Patrimony (RPPN), in Cafundó (ES). Pirovani et al. (2014) reported 793.5 m as the mean patch distance in the Itapemirim River Basin (ES). Jesus et al. (2015) obtained a MNN index of 657.3 m in the Poxim River basin (SE). Bezerra (2010) reported MNN index equal to 277.5 m, for forest patches in the sub-basin of Horizonte Stream (ES).

The lower MNN values observed in C1 and C3 compared to the other classes highlight the importance of small patches in the conservation ecology of forest remnants, given their greater

connectivity and the possibility of biodiversity permeability, contributing to forest maintenance and preservation (PRIMACK and RODRIGUES, 2001). The joint analysis of landscape metrics and indices revealed advancing fragmentation of forest remnants and edge effect and possible deterioration of forest patch quality over time, despite the relative stability of patch area.

Several studies reported that edge effect influences the decreasing biodiversity caused by physical-biological changes and species sensitivity to these changes (CHIARELLO, 1999; METZGER, 2000; UEZU et al., 2005). Numerous actions have been proposed to mitigate edge effect, for example, the management of fragmented landscapes with forest restoration alternatives, aiming to increase patch area and protect its edges, to maximize the biological flow (ZANELLA et al., 2012). Moreover, edge protection procedures should be performed with fast-growing species (CALEGARI et al., 2010), preferably native, which already interact with the local biota (MIRANDA, 2012), and agroforestry systems consisting of tree and herbaceous species consortium (MACHADO, 2012). Another suggestion is the encouragement of silviculture, especially with species that require low biocidal management, such as *Eucalyptus* and *Hevea brasiliensis* (seringueira), which favor fauna permeability, thus increasing patch connectivity (DÁRIO and ALMEIDA, 2000).

CONCLUSIONS

The forest patch analysis in the BSRB indicates a continuous intensification of forest fragmentation processes between 1985 and 2016 and, consequently, advancing edge effect on the biodiversity that makes up the forest patches. The landscape of the studied basin is mostly composed of small patches, less than 100 ha, which act to decrease the connectivity distance between the larger patches.

Remote sensing technology has great potential since it provides detailed and accurate land-use information at low cost. However, there are limitations associated with the methodology since determining land-use data with high geometric and thematic accuracy is generally limited by the availability of adequate remote sensing data, in terms of spatial and temporal resolution, in addition to the appropriate digital analysis techniques. Also, the use of remote sensing techniques to delimit and analyze forest fragments may contain photointerpretation and image quality related errors.

ACKNOWLEDGEMENTS

Thanks are due to Instituto Federal do Espírito Santo (IFES) for providing the financial support to the manuscript translation.

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Received: 11/15/2017
Accepted: 03/19/2019