MULTI-SPATIOTEMPORAL SIMULATION OF EDGE EFFECT ON FOREST PATCHES IN THE BARRA SECA RIVER BASIN, ES

Letícia Guanier[1*], Fabricia Benda Oliveira[2], Carlos Henrique Rodrigues de Oliveira[3], Vicente Sombra da Fonseca[4]

[1*]Federal University of the Espírito Santo, Department of Geology, Alegre, Espírito Santo, Brazil - leticiaguarnier.geo@gmail.com
[2]Federal University of the Espírito Santo, Department of Geology, Alegre, Espírito Santo, Brazil - fabriciabenda@gmail.com
[3]Federal Institute of Education, Science and Technology of Espírito Santo, Alegre, Espírito Santo, Brazil - carlos.oliveira@ifes.edu.br
[4]Federal University of the Espírito Santo, Department of Geology, Alegre, Espírito Santo, Brazil - vfsombra@gmail.com

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Resumo

Simulação espacial multitemporal de fragmentos florestais sob o efeito de borda em fragmentos da bacia hidrográfica do rio Barra Seca (ES). A Mata Atlântica encontra-se intensamente fragmentada, processo que desencadeou expressivo aumento das áreas de borda dos seus remanescentes florestais, apresentando diferentes intensidades de alterações físico-biológicas atuantes nessas áreas de transição entre o fragmento e a matriz. Neste estudo, objetivou-se compreender e analisar a simulação de diferentes distâncias de efeitos de borda na estrutura da paisagem florestal na bacia hidrográfica do rio Barra Seca (ES), nos anos de 1985, 1996, 2006 e 2016, através de índices de ecologia da paisagem. Através de técnicas de sensoriamento remoto pela classificação supervisionada, utilizando o algoritmo *Bhattacharya*, isolaram-se as classes dos fragmentos florestais da área de estudo. As métricas de ecologia de paisagens foram calculadas com as extensões *Patch analyst* e *V-Late 2 Beta*. Os fragmentos foram divididos em classes de tamanho: menores de 5 ha; 5-10 ha; 10-100 ha; e acima de 100 ha. A simulação do efeito de borda foi efetuada utilizando as distâncias de borda de 20, 40, 60, 80, 100, 140 e 200 m. A fragmentação florestal aumentou entre 1985 a 2016, com redução do número dos fragmentos maiores do que 100 ha. A paisagem da bacia é composta majoritariamente por fragmentos pequenos, que possuem maiores áreas relativas de influência de efeito de borda, e quando aplicado distância de borda maior do que 60 m, muitos fragmentos menores do que 10 ha são completamente dominados pelo efeito de borda. A simulação permitiu a verificação da intensificação do efeito de borda nos fragmentos florestais da bacia do rio Barra Seca.
Palavras-chave: Sensoriamento remoto, Ecologia florestal, Floresta tropical úmida, Fragmentação.

Abstract

The Atlantic Forest is intensely fragmented and this fragmentation process has caused an expressive increase of forest remnants and, consequently, increased edge effect with different physical-biological intensities in the transition areas between the patch and the matrix. This study used landscape metrics to understand and analyze how different edge effect distances affect the structure of the forest landscape in the Barra Seca River basin (ES), in 1985, 1996, 2006 and 2016. Remote sensing images were processed and using the Bhattacharya algorithm with supervised classification, the forest patches of the study area were classified and isolated. Landscape ecology metrics were computed with Patch Analyst and V-Late 2 Beta extensions. The forest patches were divided into four size classes as follows smaller than 5 ha (C1); between 5 and 10 ha (C2); between 10 and 100 ha (C3); and over 100 ha (C4). The edge effect simulation using landscape metrics was performed using the edge effect distances of 20, 40, 60, 80, 100, 140, and 200 m. Forest fragmentation increased between 1985 and 2016 while the number of patches greater than 100 ha decreased. Currently, the basin landscape consists mainly of small patches, which have larger relative areas affected by edge effect while many patches smaller than 10 ha are completely dominated by edge effect for distances greater than 60 meters. The edge effect simulation for different distances allowed verifying the intensification of the edge effect on the forest patches of the Barra Seca River basin.
Keywords: Remote sensing, Forest ecology, Tropical rain forest, fragmentation.

INTRODUCTION

The Atlantic Forest is considered a priority area for conservation due to its high biodiversity and threat level (MYERS *et al*., 2000). The main threat against this biome is caused by disturbances of natural ecosystems that result mainly from anthropic processes types and the resulting forest fragmentation, one of the most significant threats to biodiversity (HAGEN *et al*., 2012).

Only 11.26% of the original Atlantic Forest cover remains while the degradation of this biome keeps growing at an accelerated rate (RIBEIRO *et al*., 2009). In Espírito Santo, the Atlantic Forest remnants account for only 9% of the original area, with a history of fragmentation and degradation that became more accentuated in the 1960s because this biome was the largest source of wood for the construction of Brasília (THOMAZ, 2010). Furthermore, even small size forest patches may have a significant number of species of fauna and flora, constituting priority areas for conservation (HAGEN *et al*., 2012).

The decreasing size of forest remnants caused by the fragmentation process changes the biotic community and the patch physical parameters. These changes act more intensely on the patch edges, affecting differently the biodiversity and the area under edge effect influence while depending on several factors, such as biome permeability, environment (matrix) characteristics, species sensitivity to changes, distance between forest patches and their dimensions (PRIMACK; RODRIGUES, 2001).

The edge effect, therefore, changes the structure and dynamics of ecosystems and is one of the main consequences of forest fragmentation. Thus, a quantitative analysis of the landscape structure using landscape metrics helps to understand such changes (ZARAGOZÍ *et al*., 2012).

The intensity of the processes related to the physical and biogeographic changes that act on the patch varies according to its dimensions (PRIMACK; RODRIGUES, 2001). To this end, it becomes important to study forest patches by size classes to understand better the evolutionary dynamics that shaped the current landscape.

The Barra Seca River basin has one of the few continuous remnants of the Atlantic Forest in Espírito Santo, and it is one of the 14 centers with high plant diversity in Brazil (PEIXOTO; SILVA, 1997). Thus, the objective of this study is to investigate how the edge effect distance affects the forest patches of the Barra Seca River basin (ES), using remote sensing techniques and landscape metrics.

MATERIAL AND METHODS

Study site

The Southeast Atlantic Region houses the hydrographic basin of the Barra Seca River, which flows into the sea between Linhares and São Mateus, in Espírito Santo. Although this basin is considered a subunit of the Doce River hydrographic system, the waters have no direct contact (Figure 1).

The Barra Seca River basin covers an area of 2216.56 km² and all the coastal sub-basins that occur in the area of quaternary accumulation, immediately north of the Doce River mouth.

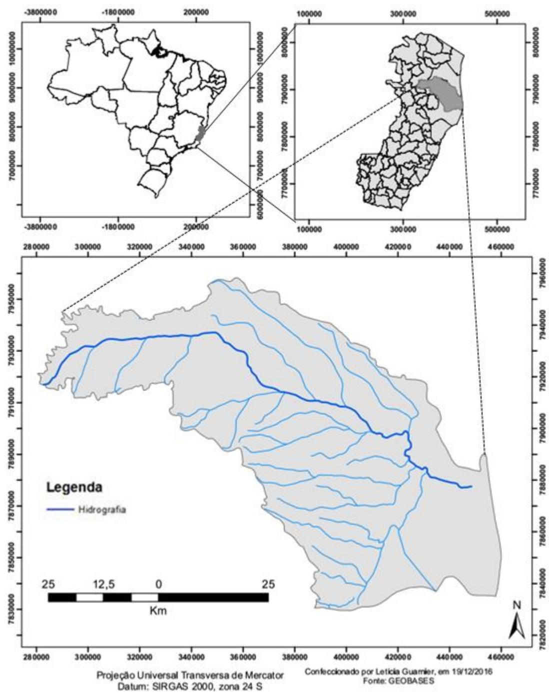

Figure 1 – Map of the Barra Seca River basin (ES) (Barra Seca River shown in dark gray).
Figura 1 – Localização da bacia hidrográfica do rio Barra Seca (ES) (rio Barra Seca em destaque (cinza escuro) na hidrografia).

Table 1 – Landscape metrics and indices used to analyze forest patches.
Tabela 1 – Índices de ecologia da paisagem utilizados para análise de métricas nos fragmentos florestais.

Group	Acronym	Metrics	Description
Area	CA	Class area	Sum of areas of all forest patches
Density	NUMP	N° of patches	Total number of patches in the landscape/class
Core area	NCA	N° of core areas	Total number of core area patches
	TCA	Total core area	Size of core patches
	TCAI	Total core area index	Relative measurement of the core landscape area
	MCA	Mean core area	Sum of core patch area divided by the number of core patches

Source: McGarigal; Marks (1994).

RESULTS

The mapping of the area indicated a total of 2365, 2540, 3155 and 3052 forest patches in 1985, 1996, 2006 and 2016, respectively (Table 2). The landscape metrics showed that the total class area (CA) of forest patches increased 51.6% in C1 (<5 ha), 19.8% in C2 (5 and 10 ha) and 24.4% in C3 (10 and 100 ha) classes while decreasing 10.6% in class C4 (> 100 ha) over the studied period (Table 2).

In the 1985 and 2016 period, the increase of areas smaller than 100 ha was associated with an increasing number of forest patches in these classes and decreasing number of patches larger than 100 ha in C4. Class C1 increased 39.3%, from 1294 patches in 1985 to 1803 in 2016 while the C4 class (> 100 ha) decreased 14.8%, from 88 fragments in 1985 to only 75 in 2016 (Table 2).

Table 2 – Landscape metrics for patches according to size class in the Barra Seca River Basin, ES, in 1985, 1996, 2006 and 2016.
Tabela 2 – Valores dos índices de ecologia de paisagem relacionados as métricas de área e densidade, para as classes de tamanho dos fragmentos florestais na Bacia do Rio Barra Seca, ES, nos anos de 1985, 1996, 2006 e 2016.

Index	Classes	Years			
		1985	1996	2006	2016
CA	C1 (<5 ha)	2812.05	3320.76	4179.12	4262.99
	C2 (5 to 10 ha)	2882.20	2834.01	3394.12	3453.32
	C3 (10 to 100 ha)	16176.26	17969.72	19360.98	20128.45
	C4 (>100 ha)	83037.88	71782.39	78805.33	74233.57
NumP	C1 (<5 ha)	1294	1475	1957	1803
	C2 (5 to 10 ha)	414	403	477	485
	C3 (10 to 100 ha)	569	599	642	689
	C4 (>100 ha)	88	63	79	75

The high number of patches in the very small and small size classes, C1 and C2, highlights the predominance of very small areas for the maintenance of the biota of the basin. Despite the small number of patches in class C4 compared to other size classes over the period, the total core area of class C4 is significant compared to the total core areas of the other classes, emphasizing the importance of class C4 to the maintenance of biodiversity in the Barra Seca River basin.

The total core area of forest patches for the years 1985, 1996, 2006 and 2016, are shown in Table 3.

Table 3 – Landscape metrics calculated for different edge effect distances and size classes of the forest patches in the Barra Seca River Basin, ES, in 1985, 1996, 2006 and 2016.

Tabela 3 – Valores dos índices de ecologia da paisagem relacionados as métricas de área central com diferentes distâncias de efeito de borda, para as classes de tamanho dos fragmentos florestais na Bacia hidrográfica do Rio Barra Seca, ES, no ano de 1985, 1996, 2006 e 2016.

Years	**Class**	**Index**	**Edge distance (m)**						
			20	**40**	**60**	**80**	**100**	**140**	**200**
1985	C1 (<5 ha)	NCA	1445	1137	434	107	6	0	0
		TCCA	1340.02	435.40	89.12	7.62	0.01	0	0
		TCAI	47.65	15.48	3.17	0.27	0	0	0
		MCA	0.93	0.38	0.21	0.07	0.00	0	0
	C2 (5-10 ha)	NCA	481	550	471	337	178	3	0
		TCCA	1857.18	1022.98	466.56	160.04	34.87	0.14	0
		TCAI	64.44	35.49	16.19	5.55	1.21	0	0
		MCA	3.86	1.86	0.99	0.47	0.20	0.05	0
	C3 (10-100 ha)	NCA	674	902	885	893	539874	428	141
		TCCA	12690.35	9505.88	6811.31	4744.11	3191.88	1339.84	303.21
		TCAI	78.45	58.76	42.11	29.33	19.73	8.28	1.87
		MCA	18.83	10.54	7.64	5.31	3.98	3.13	2.15
	C4 (>100 ha)	NCA	210	385	421	457	479	401	326
		TCCA	78219.31	73523.85	69051.09	65170.35	61541.63	55259.93	47882.04
		TCAI	94.2	88.54	78.09	78.48	74.11	66.55	57.66
		MCA	372.47	190.97	164.02	142.60	128.48	137.81	147.78
1996	C1 (<5 ha)	NCA	1639	1369	487	101	9	0	0
		TCCA	1553.67	467.81	88.60	9.56	0.18	0	0
		TCAI	46.79	14.09	2.67	0.29	0.01	0	0
		MCA	0.95	0.34	0.18	0.09	0.02	0	0
	C2 (5-10 ha)	NCA	487	572	468	293	127	3	0
		TCCA	1765.25	912.28	379.57	117.10	23.81	0.04	0
		TCAI	62.29	32.19	13.39	4.13	0.84	0	0
		MCA	3.62	1.59	0.81	0.40	0.19	0.01	0
	C3 (10-100 ha)	NCA	814	1118	1082	991	856	462	149
		TCCA	13893.18	10221.42	7197.24	4989.58	3339.50	1395.49	327.10
		TCAI	77.31	56.88	40.05	27.77	18.58	7.77	1.82
		MCA	17.07	9.14	6.65	5.03	3.90	3.02	2.20
	C4 (>100 ha)	NCA	162	306	327	300	336	292	233
		TCCA	68177.44	64681.13	60991.72	56558.35	55855.55	51231.91	45788.94
		TCAI	94.98	90.11	84.97	78.79	77.81	71.37	63.79
		MCA	420.85	211.38	186.52	188.83	166.24	176.05	198.22
2006	C1 (<5 ha)	NCA	2165	1783	604	124	5	0	0
		TCCA	1941.66	573.21	106.90	8.74	0.11	0	0
		TCAI	46.46	13.72	2.56	0.21	0	0	0
		MCA	0.90	0.32	0.18	0.07	0.02	0	0
	C2 (5-10 ha)	NCA	564	687	570	347	155	0	0
		TCCA	2133.3	1117.9	471.2	150.0	32.6	0.2	0
		TCAI	62.85	32.94	13.88	4.42	0.96	0	0
		MCA	3.78	1.63	0.83	0.43	0.21	0.04	0

	C3 (10-100 ha)	NCA	841	1253	1221	1103	938	480	166
		TCCA	14885.56	10849.89	7410.42	5219.61	3472.00	1440.74	312.79
		TCAI	76.88	56.04	38.28	26.96	17.93	7.44	1.62
		MCA	17.70	8.66	6.06	4.73	3.70	3.00	1.88
	C4 (>100 ha)	NCA	236	516	530	497	458	379	246
		TCCA	74274.96	69932.80	65955.04	62568.67	59497.73	54274.72	48194.02
		TCAI	94.25	88.74	83.7	79.4	75.5	68.87	61.16
		MCA	314.72	135.53	124.68	125.89	129.91	143.21	195.91
2016	C1 (<5 ha)	NCA	2240	1751	587	98	6	0	0
		TCCA	1876.94	521.64	87.78	7.77	0.10	0	0
		TCAI	44.03	12.24	2.06	0.18	0	0	0
		MCA	0.84	0.30	0.15	0.08	0.02	0	0
	C2 (5-10 ha)	NCA	650	773	564	300	126	3	0
		TCCA	2067.46	1012.03	392.89	119.64	25.24	0.04	0
		TCAI	59.87	29.31	11.38	3.46	0.73	0	0
		MCA	3.18	1.31	0.70	0.40	0.20	0.01	0
	C3 (10-100 ha)	NCA	1102	1558	1335	1096	949	486	716
		TCCA	15168.62	10892.74	7623.77	5218.92	3482.56	1444.74	322.95
		TCAI	75.36	54.12	37.88	25.93	17.3	7.18	1.6
		MCA	13.76	7.00	5.71	4.76	3.67	2.97	2.06
	C4 (>100 ha)	NCA	308	505	472	458	434	329	224
		TCCA	69962.91	65967.84	62419.46	59288.21	56516.00	51879.64	46559.82
		TCAI	94.25	88.87	84.09	79.87	76.13	69.89	62.72
		MCA	227.15	130.33	132.24	129.45	130.22	157.69	207.86

Figure 2 shows the behavior of the total core area index (TCAI) and mean core area (MCA) obtained for the different edge effect distances. The total core area index (TCAI) decreased markedly in all smaller classes (<100 ha; C1, C2, and C3) for edge effect distances of 40 m and higher, during all evaluated years. Furthermore, over the 80 m edge effect distance, the relative core area of the classes smaller than 10 ha (C1 and C2) is close to zero, demonstrating that for small forest fragments at this given distance, the area without influence of edge effect is practically nonexistent.

For patches larger than 100 ha (C4), the core areas show a slight gradual decrease with increasing edge distance. Only in this size class, the farthest edge effect distance of 200 m had nearly no effect on forest patches, demonstrating that only the C4 class has an area capable of supporting species sensitive to the edge effect for the 200 m distance.

The mean core area (MCA) shows an upward curvature and much higher values in class C4 (> 100 ha) compared to the other classes. The curve shape shows that as the edge effect distance increased, the MCA also increased for the distances of 100 m and over in 1985 and 1996, 60 m and over in 2006, and 80 m and over in 2016 (Figure 2). The MCA increase that is observed from a certain edge distance onward is related to a decrease in the number of core patches, which follows the same trend as the MCA index, therefore, the total core area (TCA) is divided by a lower number of core patches, thus increasing the mean value.

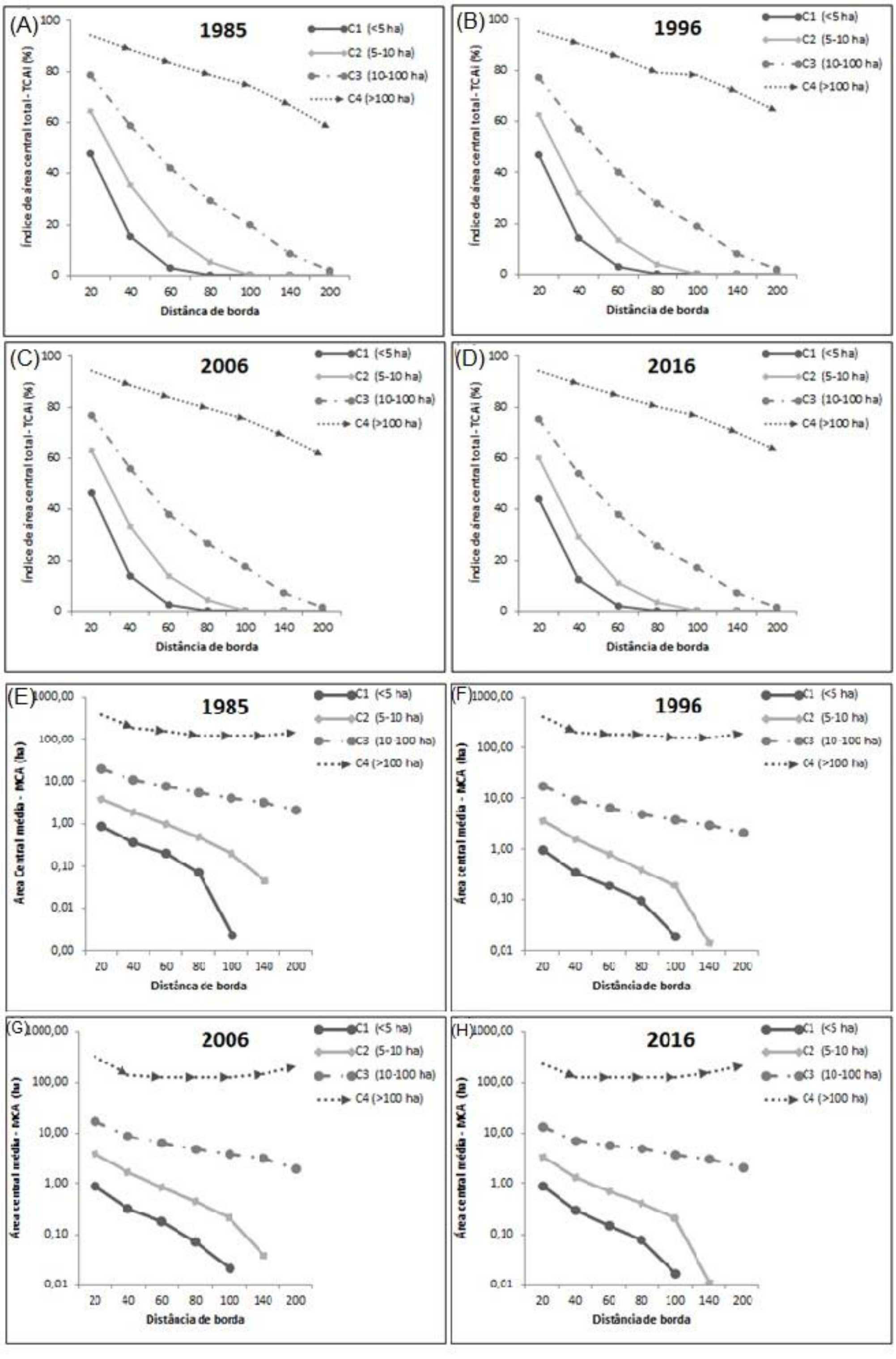

Figure 2 – Total core area index (TCAI) in (A) 1985, (B) 1996, (C) 2006 and (D) 2016 and mean core area (MCA) in (E) 1985, (F) 1996, (G) 2006 and (H) 2016 versus increasing edge distance according to patch size classes in the Barra Seca River basin (ES).

Figura 2 – Comportamento do índice de área central total (TCAI) para os anos de (A) 1985, (B) 1996, (C) 2006 e (D) 2016 e comportamento da área central média (MCA) para os anos de (E) 1985, (F) 1996, (G) 2006 e (H) 2016, em relação ao aumento da distância de borda nas classes na bacia hidrográfica do rio Barra Seca (ES).

DISCUSSION

The forest patches of the Barra Seca River basin are highly fragmented, constituted mainly by small size patches, and undergoing a continuous process of fragmentation in the studied time interval. Forest fragmentation causes the forest area to decrease while simultaneously increasing edge effect and dividing large remnants into small and non-continuous fragments and the influence of distance of isolation and time since isolation are associated, resulting in variation in response of the different species and populations (ROGAN; LACHER JR. 2018).

The intense fragmentation of the Atlantic Forest remnants is verified along the whole extension while most of the forest patches (83.4%) are smaller than 50 ha and distributed in a landscape of low connectivity between forest patches, with average isolation distance of 1400 m that increases to 3500 m for patches larger than 50 ha (RIBEIRO *et al*., 2009).

Large forest patches are very important for the maintenance of both the biotic community and ecological processes. On the other hand, small patches are less rich and may have insufficient areas to house viable populations of many species present in the study area that are at risk of extinction such as *Panthera onca*, *Puma concolor*, *Tapirus terrestris*, *Priodontes giganteus*, and several others (SRBEK-ARAUJO *et al*., 2014). However, small patches are crucial because they act as a complement to habitat and refuge areas for the broad-lived biota while reducing the degree of isolation of the larger patches and consisting of important ecological stepping stones (ROGAN; LACHER JR. 2018).

The ecological quality of the patches can be determined more efficiently by the core area compared to only the total area (MCGARIGAL; MARKS, 1994). Therefore, a fragment with large total area, but with influence of the matrix over the entire area does not harbor species that are sensitive to the edge effect (TURNER; GARDNER, 1990). Thus, the extension of the edge zone (the region under the matrix influence) is crucial for the existence of interior habitats in forest fragments (MATLACK, 1994). Several studies demonstrate an intense fragmentation of the Atlantic Forest and predominance of small patches (CEMIN *et al.* 2009; ZANELLA *et al*., 2012; PIROVANI *et al*. 2014).

The similarity analysis of the behavior of the metrics indices allowed clustering forest fragments into two groups, one smaller (C1, C2, and C3) and another larger (C4) than 100 ha. The analyzed core area indices decreased markedly for fragments smaller than 100 ha from the edge effect distance of 40 m onward. In addition, the total core area (TCA), total core area index (TCAI) and mean core area (MCA) decreased with increasing edge distance yearly and over the studied time interval, except for TCA. TCA decreased with increasing edge distance yearly between 1985 and 2016, but increased over the studied time interval.

For forest fragments larger than 100 ha, the TCA and the TCAI decreased with increasing distance of edge effect and sharply from the edge distance of 100 m in the studied period. The MCA index behaved similarly to other classes, reducing sharply from the edge distance of 40 m; however, it increased between the edge effect distance of 100 and 200 m, in the 1985 and 2016 interval. This result can be explained by the decreasing number of core areas from the edge effect distance of 80 m when the number of core areas is higher in 1985 compared to 2016.

The tendency of core area to increase for small fragments (<100 ha) and decrease for large fragments, is related to the increasing forest fragmentation of the study area, which creates a large number of small fragments thus increasing the total area of these fragments.

Many studies have demonstrated that edge effect acts on reducing biodiversity, which is caused by physical-biological changes and the sensitivity of species to the changing characteristics of forest fragments (CHIARELLO, 1999; PARDINI *et al*., 2009; LIMA *et al*., 2015 FREITAS *et al*., 2018). Several actions can be taken to mitigate edge effects, such as the management of the fragmented landscape with forest restoration alternatives, which aim at increasing the fragment area and protecting the edges as to maximize the biological flow (ZANELLA *et al*., 2012).

The edge should be protected with fast-growing species (CALEGARI *et al*., 2010), preferably native, which already interact with the local biota. In addition, agroforestry systems consisting of a consortium of tree species and herbaceous species can be used as well, working as buffer between protected areas and intensively managed area (PARDINI *et al*., 2009; ASASE; TETTEH, 2010). Another suggestion is the encouragement of silviculture, especially with species that require low biocide management, which favor the permeability of the fauna, thus increasing the connectivity between fragments (BAKER *et al* 2013), such as *Eucalyptus* and *Hevea brasiliensis* (seringueira),

CONCLUSIONS

- The landscape metrics and indices used to study the forest fragments of the Barra Seca River basin reveals the continuous intensification of forest fragmentation processes between 1985 and 2016 and, consequently, edge effect on the biodiversity that inhabit the forest patches.
- The landscape of the studied basin consists mostly of small fragments, less than 100 ha, that act to decrease the connectivity distance between larger fragments.
- The spatial simulation of the edge effect demonstrates this process behavior in the landscape and over time.
- In fragments smaller than 5 ha, the edge effect predominates over the area for distances of 80 m and greater.
- The total core area increased in the fragments smaller than 100 ha and reduced in larger fragments in the 1985 to 2016, time interval.

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REFERENCES

ASASE, A; TETTEH, D. A. The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana. **Agroforest Syst**, v.79, p. 355 - 368. 2010

BAKER, S. C; SPIES, T. A; WARDLAW, T. J; BALMER, J; FRANKLIN, J. F; JORDAN, G. J. The harvested side of edges: Effect of retained forests on the re-establishment of biodiversity in adjacent harvested areas. **Forest Ecology and Management**, v.302, p. 107 - 121. 2013.

CALEGARI, L.; MARTINS, S. V.; GLERIANI, J. M.; SILVA, E.; BUSATO, L. C. Análise da dinâmica de fragmentos florestais no município de Carandaí, MG, para fins de restauração florestal. **Revista Árvore**, v. 34, n. 5, p. 871 - 880. 2010.

CEMIN, G.; PERICO, E.; REMPEL, C. Composição e configuração da paisagem da sub-bacia do arroio Jacaré, Vale do Taquari, RS, com ênfase nas áreas de florestas. **Revista Árvore**, Viçosa-MG, v. 33, n.4, p. 705 - 711. 2009.

CHIARELLO, A. G. Effects of fragmentation of the Atlantic Forest on mammals communities in South-eastern Brazil. **Biol. Conserv**, v.89, p. 71 - 72. 1999.

COELHO V. H. R.; MONTENEGRO, S. M. G. L.; ALMEIDA, C. N.; LIMA, E. R. V.; RIBEIRO NETO, A.; MOURA, G. S. S. Dinâmica do uso e ocupação do solo em uma bacia hidrográfica do semiárido brasileiro. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 18, n. 1, p. 64 - 72. 2014.

FREITAS, S.R; CONSTANTINO, E; ALEXANDRINO, M. M. Computational geometry applied to develop new metrics of road and edge effects and their performance to understand the distribution of small mammals in an Atlantic forest landscape**. Ecological Modelling**, v. 388, p. 24 - 30. 2018

GUARNIER, L; OLIVEIRA. F. B. de; FONSECA, V. S. da; OLIVEIRA, C. H. R. de. Landscape analysis and land use evolution in the hydrographic basin of Barra Seca river, ES. **Ciência e Natura**, Santa Maria, v.40, e50. 2018.

HAGEN, M; KISSLING, W. D; RASMUSSEN, C; AGUIAR, M. A. M. de; BROWN, L. E; CARSTENSEN, D. W; ALVES-DOS-SANTOS, I; DUPONT, Y. L; EDWARDS, F. K; GENINI, J; GUIMARÃES JR, P. R; JENKINS, G. B; JORDANO, P; KAISER-BUNBURY, C. N; LEDGER, M. E; MAIA, K. P; MARQUITTI, F. M. D; MCLAUGHLIN, O; MORELLATO, L. P. C; O´GORMAN, E. J; TRØJELSGAARD, K; TYLIANAKIS, J. M; VIDAL, M. M; WOODWARD, G; OLESEN, J. M. Biodiversity, Species Interactions and Ecological Networks in a Fragmented World. **Advances in Ecological Research**, v. 46, p. 89 - 2010. 2012.

LIMA, P. B; Lima, L. F; SANTOS, B. A; TABARELLI, M; ZICKEL, C. S. Altered herb assemblages in fragments of the Brazilian Atlantic forest. **Biological Conservation**, v. 191, p. 588 - 595. 2015.

MACNEELY, J. A., MILLER, K. R., REID, W. V., MITERMEIER, R. A.; WERNER, T. B. Conserving the world’s biological diversity. The World Bank, World Resources Institute, IUCN, **Conservation International e WWF**, 1990, 185p.

MATLACK, G. R. Vegetation dynamics of the forest edge – trends in space and successional time. **Journal of Ecology**, v. 82, p. 113 - 123. 1994.

MCGARIGAL, K.; MARKS, B. J. Fragstats: Spatial pattern analysis program for quantifying landscape structure. **Reference manual. For. Sci. Dep. Oregon State University**. Corvallis Oregon, 1995, 141p.

PARDINI, R; FARIA, D; ACCACIO, G. M; LAPS, R. R; MARIANO-NETO, E; PACIENCIA, M. L. B; DIXO, M; BAUMGARTEN, J. The challenge of maintaining Atlantic forest biodiversity: A multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. **Biological Conservation**, v. 142, p. 1178 - 1190. 2009.

PEIXOTO, A. L.; SILVA, I. M. Tabuleiro forests on the northern Espírito Santo, south-eastern Brazil. Pp 369-372. In: DAVIS, S. D.; HEYWOOD, V. H.; HERRERA-MACBRYDE, O.; VILLA-LOBOS, J.; HAMILTON, A. C. (Eds.). **Centers of Plant Diversity: A Guide and Strategy for their conservation**. Cambridge: WWF/IUCN Publisher. 1997.

PIROVANI, D. B.; SILVA, A. G.; SANTOS, A. R.; CECíLIO, R. A.; GLERIANI, J. M.; MARTINS, S. V. Análise espacial de fragmentos florestais na bacia do rio Itapemirim, ES. **Revista Árvore**, Viçosa-MG, v. 38, n. 2, p. 271 - 281. 2014.

PRIMACK, R. B.; RODRIGUES, E. **Biologia da Conservação**. Londrina, Gráfica Editora Midiograf, 2001.

RIBEIRO, M. C.; METZGER, J. P.; MARTENSEN, A. C.; PONZONI, FF. J. HIROTA, M. M. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. **Biological Conservation**, v. 142: 1141–1153. 2009.

ROGAN, J. E; LACHER JR, T. E. Impacts of habtat loss and fragmentation on terrestrial biodiversity. **Reference Module in Earth Systems and Environmental Sciences**, 2018

SRBEK-ARAUJO, A. C.; ROCHA, M. F.; PERACCHI, A. L. A mastofauna da Reserva Natural Vale, Linhares, Espírito Santo, Brasil. **Ciência & Ambiente**, v. 49, p. 153 - 167. 2014.

THOMAZ, L. D. A Mata Atlântica no estado do Espírito Santo, Brasil: de Vasco Fernandes Coutinho ao século 21. **Bol. Mus. Biol. Mello leitão**, v. 27, p. 5 - 20. 2010.

TURNER, M. G.; GARDNER, R. H. **Quantitative methods in landscape ecology: the analysis and interpretation of landscape heterogeneity**. New York: Springer-Verlag, 1990. 536 p.

ZANELLA, L.; BORÉM, R. A. T.; SOUZA, C. G.; ALVES, H. M. R.; BORÉM, F. M. Atlantic Forest Fragmentation Analysis and Landscape Restoration Management Scenarios. **Natureza & Conservação**, v. 10, n. 1, p. 57 - 63. 2012.

ZARAGOZÍ, B.; BELDA, A.; LINARES, J.; MARTÍNEZ-PÉREZ, J. E.; NAVARRO, J. T.; ESPARZA, J. A free and open source programming library for landscape metrics calculations. **Environmental Modelling e Software**, v. 31, p. 131 - 140. 2012.