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# Landscape analysis and land use evolution in the hydrographic basin of Barra Seca river, ES

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**ABSTRACT**

*Multitemporal analysis for monitoring land cover and use is an important tool for understanding the evolutionary dynamics of a region, assisting the knowledge on the environmental reality. This study aimed at mapping the land cover classes of the Barra Seca River basin, in northern Espírito Santo, obtained using the Bhattacharya algorithm supervised classification in 1985, 1996, 2006 and 2016. The land use and occupation map allowed characterizing quantitatively the areas identified in the basin map in 10 classes as follows water bodies, agriculture and grasses, dense tree cover, sparse tree cover, exposed soil, wetlands, urban areas, rocky outcrops, shade, and clouds. The landscape maps were obtained using the Patch Analyst extension. In the studied time interval, the land use and occupation in the basin changed little, with areas dominated mostly by agriculture and grasslands, followed by forests while the basin vegetation area also remained mostly unchanged. However, the quantitative analysis using landscape metrics indicates an increasing fragmentation and edge effect in the Barra Seca River basin.*

*Keywords: Atlantic Forest, landscape metrics, remote sensing*

# 1 Introduction

Coastal regions are subject to continuous population growth and socioeconomic development that requires expanding land use and, consequently, causing depletion of the natural resources present in such areas (MAANAN et al., 2014). However, the degradation of natural landscapes caused by developing anthropic activities can be avoided or minimized when the nature of the interaction between natural and anthropic landscape is known (CREPANI et al., 2001).

Thus, the spatial and temporal analysis of land use and coverage of a basin is an important tool for evaluating the environmental situation and allowing to propose environmental policies that are more efficient to maintain quality of life and the interaction and balance of environmental, economic and social issues (MONTEBELO et al., 2005).

The mapping of natural phenomena and environmental changes using remote sensing satellite images is the most common use of this tool (SILVA and AMARO, 2008). In addition, the different spatial structures resulting from the process of land use and occupation are obtained quickly, safely, accurately, and at a low cost (RODRÍGUEZ, 2000; ARAGÃO and ALMEIDA, 2009).

The Barra Seca River basin area has significant ecological significance, as it includes important remnants of the Atlantic Forest, a biome that has been significantly reduced in Espírito Santo, with only 9% of its original coverage remaining (MATA ATLÂNTICA FOUNDATION, 2015).

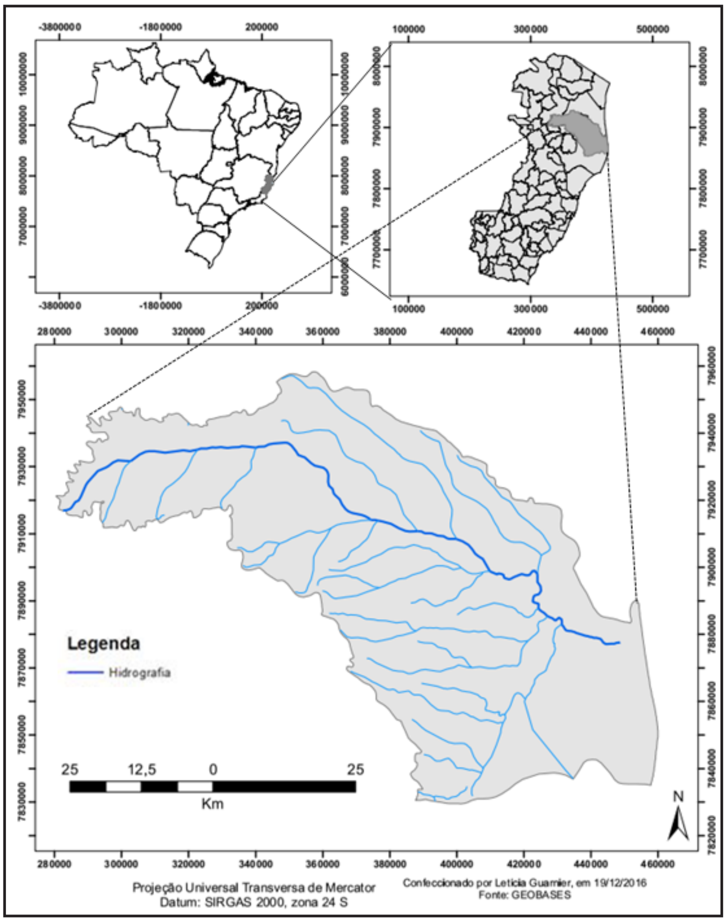
The studies applying landscape metrics and indices become highly relevant since they allow understanding the factors that control the maintenance of biodiversity. This method has been suggested by several authors (METZGER, 1997; SOARES FILHO, 1998; METZGER, 2000; SANTOS, 2009; LIMA, 2010; PANG et al., 2010; LIU and YANG, 2015; MÕISJA et al., 2016; SUN and ZHOU, 2016).

The objective of this study was to analyze the changing landscape of the Barra Seca River basin, in Espírito Santo, using Remote Sensing images obtained by the Landsat satellite in 1985, 1996, 2006 and 2016.

# 2 Material and Methods

## 2.1 Study site

**Figura 1 Map of the Barra Seca River basin (ES) (Barra Seca River shown in dark gray)**



The Barra Seca River basin, located in the Southeast Atlantic Hydrographic Region, is considered a sub-unit of the Rio Doce hydrographic system although there is no direct contact between the waters of these two basins. The Barra Seca River flows into the sea between Linhares and São Mateus, in Espírito Santo (Figure 1).

The coastal sub-basins located in the quaternary accumulation area north of the Doce River mouth are part of the Barra Seca basin, which covers a total area of 2216.56 km² (SCHINEIDER, 2010).

Several aspects of the Barra Seca River basin have been intensively studied, especially its biodiversity (PAULA, 2006; SARMENTO-SOARES and MARTINS-PINHEIRO, 2012; DADALTO, 2014; SARMENTO-SOARES and MARTINS-PINHEIRO, 2014), geological features (CORRÊA, et al., 2008; FRANÇA et al., 2013; BOSO JR., 2015; FRANÇA et al., 2015 ), and morphological (VICENS and MARQUES, 2006; RIBEIRO et al., 2007; SCHINEIDER, 2010) and hydrological (ZON and MENDONÇA, 2008; LANI et al., 2009) characteristics.

## 2.2 Temporal evolution of land use and occupation in the Barra Seca River basin

This study used remote sensing images of the basin area captured by the TM and OLI sensors of the Landsat 5 and 8 satellites, respectively, which were provided free of charge by the National Institute for Space Research (INPE).

All pre-processing and sorting steps were performed in the Spring software. The data pre-processing consisted of geometric correction, highlighting, elaboration of color composition and mosaic preparation of the images.

There are several studies in the literature that compare the efficiency of the classifiers for digital image processing (GOES et al., 2006; LEON et al., 2007; MANTELLI et al., 2007; OLIVEIRA et al., 2011). After reviewing the literature, the supervised classification using the Bhattacharya algorithm was chosen since it has been used in several mapping works for land use and cover, and uses segmented satellite image (COUTINHO, 1997; NOGUEIRA et al., 2001; VASCONCELOS and NOVO, 2004; BACANI et al., 2006; TORRES, 2011; MIGUEL et al., 2012; NUNES and LEITE, 2014).

The 10 classes were chosen according to the most representative elements in the landscape as follows dense tree cover, sparse tree cover, agriculture and grasslands, exposed soil, wetlands, urban areas, rocky outcrop, water bodies, shade, and clouds.

Prior to image classification, the segmentation stage consisted of applying the segmentation algorithm according to the growth of the regions in the images, adopting the values of 8 for similarity and 12 for area, which represented a good level of clustering.

The Bhattacharya distance algorithm, which recognizes homogeneous areas of the image according to the spectral and spatial characteristics, was used for performing the supervised classification by regions.

Finally, the post-classification was performed, using the matrix editing, applying the 3x3 median majority filter.

## 2.3 Landscape metrics of the Barra Seca River basin

The landscape metrics was performed using the landscape ecology indices for each date (1985, 1996, 2006, and 2016) in the Patch Analyst 5.2 extension of the ArcGIS 10.1 software.

Table 1 – Landscape metrics and ecology indices used for the analysis of classes

| Group | Acronym | Metrics | Identification |
|---|---|---|---|
| Density and size | MPS | Mean patch size | Sum of patch size divided by the number of patches |
| | NUMP | N° of patches | Total number of patches in the landscape/class |
| | PSCoV | Patch size coefficient of variation | Standard deviation of patch size divided by mean patch size, multiplied by 100 |
| Shape | MSI | Mean 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 |
| | MPFD | Mean patch fractal dimension | The values are closer to 1 and 2 for simple and complex shapes, respectively. |
| Edge | TE | Total edge | Sum of the perimeter of all patches |
| | ED | Edge density | Number of edges relative to the area |
| Proximity | MNN | Mean distance from nearest neighbor | Mean distances for individual classes at the class level and mean distance of the neighboring class at the landscape level |

Source: McGarigal and Marks (1994)

For each mapped class (except the shadow and cloud classes), the following groups of metrics were evaluated: patch density, size, shape, and edge indices (TABLE 1).

## 3 Results and Discussion

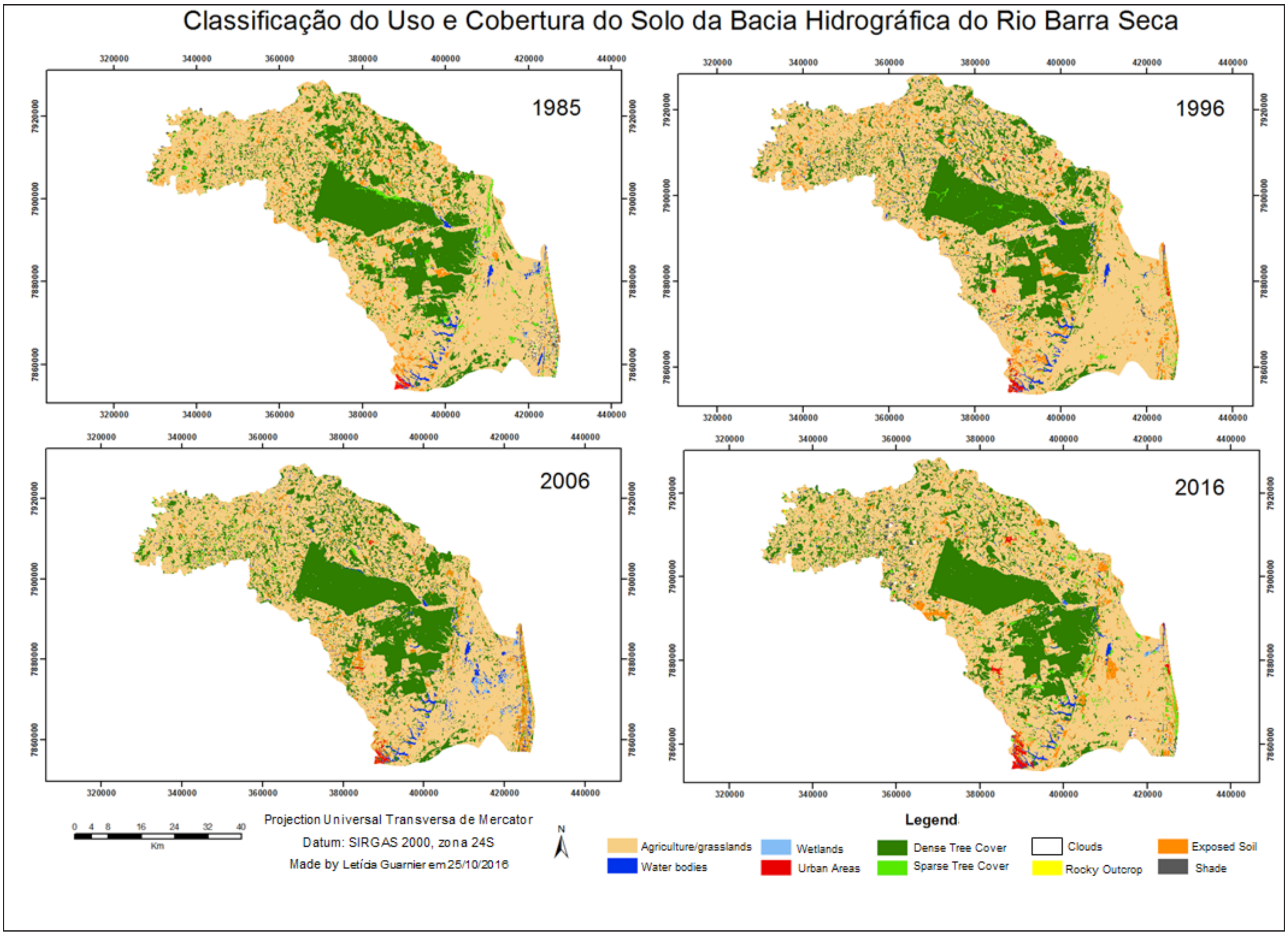
### 3.1 Temporal evolution of land use and cover in the Barra Seca River basin

The analysis of the land use maps (Figure 2) shows a changing landscape in the Barra Seca River basin.

Table 2 shows the areas occupied by each class in 1985, 1996, 2006 and 2016 and the changing classes between 1985 and 2016.

The results indicated that the dense tree cover and agriculture and grasslands classes, which make up the largest portion of the Barra Seca River basin, remained relatively stable while the other classes changed more significantly over the studied period. Unlikely, Pirovani et al. (2015) reported that the landscape surrounding the Reserva de Patrimônio Particular e Natural (RPPN, Natural and Private Heritage Reserve) in Cafundó (ES) remained unchanged from 1970 to 2007.

**Figura 2- Maps of use and land cover of the Barra Seca River basin (ES) in 1985, 1996, 2006 and 2016**




The agriculture and grasslands class accounted for more than 60% of the basin area over the studied years and this predominance of pasture and cultivated areas has been verified in several basins (DÉSTRO and CAMPOS, 2006; ALBANE et al., 2007; ARAGÃO and ALMEIDA, 2009).

Between 1985 and 2016, the urban areas increased significantly by expanding the already existing urban areas, and the urban area in the coastal region of the basin (IBGE, 2016). Also, it is observed that the area of some water bodies decreased significantly in the coastal region of the basin. Sarmento-Soares and Martins-Pinheiro (2014) have highlighted that one of the

Table 2 – Temporal evolution of the areas in the studied classes of the Barra Seca River basin (ES).

| Classes*/Year | 1985 | | 1996 | | 2006 | | 2016 | | Variation (1985 – 2016) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Area (Km²) | (%) | Are-a(Km²) | (%) | Area (Km²) | (%) | Area (Km²) | (%) | Area (Km²) | (%) |
| Dense tree cover | 947.04 | 27.14 | 911.43 | 26.12 | 1009.11 | 28.92 | 928.57 | 26.60 | -18.47 | -1.95 |
| Sparse tree cover | 106.56 | 3.05 | 48.29 | 1.38 | 49.45 | 1.42 | 92.82 | 2.66 | -13.74 | -12.89 |
| Agriculture and grasslands | 2176.24 | 62.38 | 2245.20 | 64.35 | 2126.51 | 60.95 | 2179.91 | 62.44 | 3.67 | 0.17 |
| Exposed soil | 167.85 | 4.81 | 192.67 | 5.52 | 187.92 | 5.39 | 181.52 | 5.20 | 13.66 | 8.14 |
| Rocky outcrop | 0.45 | 0.01 | 0.76 | 0.02 | 0.84 | 0.02 | 0.64 | 0.02 | 0.19 | 41.94 |
| Water bodies | 37.48 | 1.07 | 51.67 | 1.48 | 73.68 | 2.11 | 45.35 | 1.30 | 7.87 | 21.01 |
| Wetlands | 4.65 | 0.13 | 1.93 | 0.06 | 19.03 | 0.55 | 5.06 | 0.15 | 0.41 | 8.84 |
| Urban areas | 8.80 | 0.25 | 13.25 | 0.38 | 12.22 | 0.35 | 26.97 | 0.77 | 18.18 | 206.61 |
| Shade | 34.76 | 1.00 | 22.48 | 0.64 | 10.30 | 0.30 | 20.75 | 0.59 | - | - |
| Clouds | 5.15 | 0.15 | 1.54 | 0.04 | 0.16 | 0.01 | 9.64 | 0.28 | - | - |
| Total | 3488.98 | 100 | 3489.23 | 100 | 3489.24 | 100 | 3491.23 | 100 | - | - |

Source: Authors (2017)

main causes for this was the readjustment process of agricultural and oil drainage.

The dense tree cover class decreased slightly by 1.95%, which represents 18.47 km² between 1985 and 2016. Although the decrease of the dense tree cover class is not very expressive, the actual deforestation data of the Atlantic Forest in the basin can be masked by the increasing silviculture activities in the region (IBGE, 2004, IBGE, 2015), since the training samples for classifying the images represent native and planted forests.

The changing native vegetation has been verified by several authors in studies of temporal analysis of images. Aragao and Almeida (2009) estimated an increase from 6% to 8% in the area of the Japaratuba river basin, between 1997 and 2006. Jesus (2010) reported that the coverage area of the forest class decreased from 46.5% in 1988 to 36.7% in 2009, in São Gonçalo do Rio Abaixo (MG). Leite and Rosa (2012) observed that the native vegetation diminished 31% in the Formiga river basin (TO) between 1973 and 2011.

### 3.2 Landscape metrics of land use and coverage in the Barra Seca River basin

With a wealth index consisting of total 10 classes for each year analyzed, the Shannon diversity index (SDI) was calculated as 1.03, 0.98, 1.02, and 1.04 in 1985, 1996, 2006 and 2016, respectively. The SDI represents the diverse uses of the basin area; the small decrease observed in this index reveals little expressive alteration in the class arrangement and distribution in the landscape over the studied interval.

However, the other landscape metrics indices used in the quantitative analysis of the landscape structure of the Barra Seca River basin showed a constant changing class dynamics in 1985 (Table 3), 1996 (Table 4), 2006 (Table 5) and 2016 (Table 6).

In the studied time interval (1985-2016), the metrics showed that the dense tree cover, sparse tree cover, water bodies and urban areas classes changed the most (Table 7).

Table 3 – Landscape metrics and ecology indices calculated for each class of the Barra Seca River basin in 1985

| Classes | Size and density* | | | Shape* | | | Edge* | |
|---|---|---|---|---|---|---|---|---|
| | MPS | NUMP | PSCoV | MSI | AWMSI | MPFD | TE | ED |
| Dense tree cover | 46.15 | 2052 | 1622.73 | 1.47 | 4.61 | 1.30 | 5015502.66 | 14.38 |
| Sparse tree cover | 5.18 | 2057 | 391.42 | 1.51 | 2.40 | 1.33 | 2277205.03 | 6.53 |
| Agriculture and grass-lands | 372.64 | 584 | 2343.46 | 1.55 | 65.44 | 1.32 | 11771458.75 | 33.74 |
| Exposed soil | 6.404 | 2621 | 240.157 | 1.393 | 1.821 | 1.31 | 2870342.93 | 8.23 |
| Rocky outcrop | 3.47 | 13 | 90.76 | 1.45 | 1.60 | 1.32 | 12055.90 | 0.03 |
| Water bodies | 9.56 | 392 | 341.28 | 1.56 | 2.65 | 1.32 | 582972.25 | 1.67 |
| Wetlands | 4.26 | 109 | 246.00 | 1.51 | 2.23 | 1.33 | 113633.76 | 0.33 |
| Urban areas | 4.83 | 182 | 581.58 | 1.44 | 3 | 1.35 | 162925.05 | 0.47 |

*MPS (Mean patch size); NUMP (Number of patches); PSCoV (Patch size coefficient of variation); MSI (Mean shape index); AWMSI (Area-weighted mean shape index); MPFD (mean patch fractal dimension); TE (Total edges); ED (Edge density).

Source: Authors (2017).

Table 4 – Landscape metrics and ecology indices calculated for each class of the Barra Seca River basin in 1996

| Classes | Size and density | | | Shape | | | Edge | |
|---|---|---|---|---|---|---|---|---|
| | MPS | NUMP | PSCoV | MSI | AWMSI | MPFD | TE | ED |
| Dense tree cover | 40.29 | 2262 | 1847.41 | 1.5 | 4.69 | 1.3 | 5126325.40 | 14.69 |
| Sparse tree cover | 5.03 | 960 | 196.07 | 1.54 | 2.02 | 1.33 | 1111840.83 | 3.19 |
| Agriculture and grasslands | 392.52 | 572 | 2338.70 | 1.56 | 63.28 | 1.56 | 11447397.48 | 32.81 |
| Exposed soil | 6.67 | 2889 | 308.69 | 1.38 | 2.02 | 1.31 | 3234290.76 | 9.27 |
| Rocky outcrop | 4.25 | 18 | 121.63 | 1.41 | 1.53 | 1.32 | 16853.52 | 0.05 |
| Water bodies | 5.54 | 932 | 367.05 | 1.57 | 2.32 | 1.33 | 1094388.39 | 3.14 |
| Wetlands | 2.36 | 83 | 82.56 | 1.49 | 1.61 | 1.34 | 65574.51 | 0.19 |
| Urban areas | 6.69 | 198 | 395.59 | 1.56 | 2.61 | 1.35 | 236896.67 | 0.68 |

Source: Authors (2017)

Table 5 – Landscape metrics and ecology indices calculated for each class of the Barra Seca River basin in 2006

| Classes | Size and density | | | Shape | | | Edge | |
|---|---|---|---|---|---|---|---|---|
| | MPS | NUMP | PSCoV | MSI | AWMSI | MPFD | TE | ED |
| Dense tree cover | 36.17 | 2790.00 | 2901.21 | 1.48 | 6.69 | 1.30 | 5948851.41 | 17.05 |
| Sparse tree cover | 3.29 | 1503.00 | 170.73 | 1.45 | 1.69 | 1.33 | 1324503.85 | 3.80 |
| Agriculture and grasslands | 257.76 | 825.00 | 2728.06 | 1.58 | 70.25 | 1.33 | 13110539.44 | 37.57 |
| Exposed soil | 6.40 | 2937.00 | 380.95 | 1.38 | 2.34 | 1.31 | 3352396.49 | 9.61 |
| Rocky outcrop | 4.44 | 19 | 106.01 | 1.42 | 1.53 | 1.32 | 18588.48 | 0.05 |
| Water bodies | 5.82 | 1265.00 | 334.13 | 1.57 | 2.31 | 1.33 | 1544597.13 | 4.43 |
| Wetlands | 6.18 | 308.00 | 249.95 | 1.45 | 2.14 | 1.32 | 362217.09 | 1.04 |
| Urban areas | 6.24 | 196.00 | 385.43 | 1.45 | 2.82 | 1.33 | 223910.12 | 0.64 |

Source: Authors (2017)

Table 6 – Landscape metrics and ecology indices calculated for each class of the Barra Seca River basin in 2016

| Classes | Size and density | | | Shape | | | Edge | |
|---|---|---|---|---|---|---|---|---|
| | MPS | NUMP | PSCoV | MSI | AWMSI | MPFD | TE | ED |
| Dense tree cover | 36.56 | 2540 | 2920.55 | 1.57 | 6.76 | 1.31 | 5631489.43 | 16.14 |
| Sparse tree cover | 6.25 | 1486 | 312.35 | 1.68 | 2.46 | 1.34 | 2041834.12 | 5.85 |
| Agriculture and grasslands | 370.10 | 589 | 2317.52 | 1.75 | 69.19 | 1.32 | 12794434.65 | 36.66 |
| Exposed soil | 7.77 | 2313 | 415.46 | 1.53 | 2.31 | 1.32 | 3042616.74 | 8.72 |
| Rocky outcrop | 6.41 | 10 | 105.37 | 1.62 | 1.74 | 1.33 | 13285.36 | 0.04 |
| Water bodies | 5.17 | 878 | 380.79 | 1.61 | 2.55 | 1.34 | 1028314.39 | 2.95 |
| Wetlands | 4.48 | 113 | 301.53 | 1.64 | 2.27 | 1.35 | 122584.31 | 0.35 |
| Urban areas | 12.32 | 219 | 452.63 | 1.76 | 3.35 | 1.35 | 383235.36 | 1.10 |

Source: Authors (2017)

Table 7 – Variations of landscape indices over the studied time interval (1985 – 2016).

| Classes | Variation (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | MPS | NUMP | PSCoV | MSI | AWMSI | MPFD | TE | ED |
| Dense tree cover | -26.24 | 19.21 | 44.44 | 6.43 | 31.91 | 0.85 | 10.94 | 10.92 |
| Sparse tree cover | 17.07 | -38.43 | -25.31 | 9.94 | 2.61 | 0.47 | -11.53 | -11.55 |
| Agriculture and grasslands | -0.69 | 0.85 | -1.12 | 11.72 | 5.41 | 0.37 | 8.00 | 7.98 |
| Exposed soil | 17.63 | -13.32 | 42.20 | 8.95 | 21.07 | 0.27 | 5.66 | 5.65 |
| Rocky outcrop | 45.80 | -30.00 | 13.87 | 10.33 | 8.40 | 0.86 | 9.25 | 9.24 |
| Water bodies | -85.10 | 55.35 | 10.38 | 3.01 | -3.97 | 1.25 | 43.31 | 43.30 |
| Wetlands | 4.75 | 3.54 | 18.42 | 7.81 | 1.90 | 1.12 | 7.30 | 7.29 |
| Urban areas | 60.76 | 16.89 | -28.49 | 17.98 | 10.54 | -0.17 | 57.49 | 57.20 |

Source: Authors (2017)

The metric index values showed that mean patch size decreased 26.24% while the number of patches increased 19.21%, indicating intensifying forest fragmentation, and that the ecological quality of the dense tree cover class diminished in the studied time interval. The negative effects on this class are compounded by the fact that forest patches had more complex and irregular shapes that increased edge effects, and consequently, the damages to the biotic community of the basin.

The most relevant changes in the sparse tree cover class include the decreasing number of patches by 38.43% and mean patch size increase by 17.07% over the 1985 and 2016 time interval.

The shape indices point toward an evolutionary landscape over the analyzed period.  The hydrographic basin of the Barra Seca River evolved toward a more irregular and complex patch shapes, moving away from 1, considered the best possible shape due to the lower edge effect, thus increasing the edge indices (LANG and BLASCHKE, 2009).

Likewise, several studies have indicated the intense fragmentation of the Atlantic Forest (CEMIN et al., 2009, PIROVANI et al., 2014, HENTZ et al., 2015, SANTOS and ROCHA, 2015). According to Goerl et al. (2011), the fragmentation process may be associated with the economic use of the soil due to the resulting replacement of natural vegetation by agricultural and pastoral areas.

Despite the relative stability of patch areas, the landscape metrics and indices show fragmentation of forest remnants and increasing edge effect on forest patches leading to quality loss of forest conservation.

The physical-biological alterations associated with edge effect act to reduce the biodiversity according to species sensitivity to such changes (METZGER, 2000; UEZU et al., 2005). The recommended mitigation measures propose to manage the fragmented landscapes by increasing patch area and protecting its edges, as to maximize the biological flow (ZANELLA et al., 2012).

## 4 Conclusion

The delimitation of the Barra Seca River Basin was successfully performed using remote sensing. The analyses of soil cover data allowed classifying area occupation into 10 classes, with the agriculture and grasslands and dense tree cover classes covering more than 85% of the study area in the 1985, 1996, 2006 and 2016 years.

The landscape metrics and ecology indices obtained for the forest patches shows a tendency toward intensifying forest fragmentation and edge effect processes.

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