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## Multitemporal Analysis of Land Use and Cover Changes of a River Basin in the Atlantic Coast of Brazil

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### ABSTRACT

Based on the historical context of exploitation of the natural resources of the Caeté River Basin, the objective of this work was to identify and assess land use and cover changes in this region. This basin is in the Atlantic Coast of Brazil, in the northeastern state of Pará. It is one of the oldest colonized regions in the Amazon and is strongly affected by the intensive investments of the agricultural sector. This work was based on cartographic materials of the TerraClass project of the Brazilian National Institute of Space Research (INPE) in partnership with the Brazilian Agricultural Research Corporation (EMBRAPA). These cartographic materials consisted of 222/61 and 223/61 orbital images from 2004, 2010, and 2014. The land use and cover of the Caeté River Basin is diverse, mainly represented by the classes: Pasture, Forest, and Occupational Mosaic. The area of the Pasture class had an increase in the basin from approximate 39% in 2004 to 41% in 2014. The Forest class covered 33% of the area in 2004 and 38% in 2014; this increment may be associated with public forest conservation policies. The Occupational Mosaic class remained at 1% from 2004 to 2014. The major challenge for this work was the acquisition of relevant images since the study region presents great cloud interference. Multitemporal analyses of land use and cover changes at river basin level are important to identify and mitigate possible problems related to the management of water resources.

Keywords: remote sensing, hydrography, state of Pará.

## Análise Multitemporal das Mudanças na Cobertura da Terra de uma Bacia Hidrográfica na Costa Atlântica

### RESUMO

Baseado na contextualização histórica de exploração dos recursos naturais da região, este trabalho visa identificar e analisar as mudanças na cobertura da terra na bacia hidrográfica do Caeté. A área de estudo localiza-se na Costa Atlântica do Nordeste Paraense, e compõe uma das regiões mais antigas de colonização da Amazônia, com forte influência aos investimentos intensivos no setor da agropecuária. Utilizou-se as bases cartográficas do projeto TerraClass desenvolvido pelo Instituto Nacional de Pesquisas Espaciais (INPE) em parceria com a Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Os resultados cartográficos obtidos utilizaram as imagens orbitais 222/61 e 223/61 referentes aos anos de 2004, 2010 e 2014. A Bacia hidrográfica do Caeté apresentou intensa dinâmica de uso do solo, vinculado principalmente as principais classes: pastagem, com o percentual aproximado de 39% no ano de 2004 a 41% em 2014 elucidando um aumento nesta forma de uso ao longo da bacia. A classe de floresta logrou 33% em 2004 a 38% em 2014, este incremento pode estar associado a conservação das florestas, por meio de políticas públicas. Por fim, o mosaico de ocupações mostrou uma constância entorno de 1% nos anos de 2004 a 2014. O maior desafio da pesquisa concentrou-se na aquisição de imagens relevantes, visto que o local de estudo apresenta grande interferência de nuvens. A análise multitemporal das alterações a nível de bacia hidrográfica são necessárias para quantificar e mitigar eventuais problemas referentes à gestão dos recursos hídricos.

Palavras-chave: sensoriamento remoto, hidrografia, estado do Pará.

## Introduction

Environmental analyzes with land use and cover mapping, and monitoring and characterization of river basins, are increasingly necessary, since changes in land use can directly impact water resources (Steinke and Saito, 2010). However, the use of high capacity systems for treatment and analysis of multi-thematic information, such as Remote Sensing techniques and Geographic Information System (GIS), is essential for spatial monitoring.

River basin areas are chosen as spatial unit for case studies because their components act in constant interaction and respond to the interference of natural and anthropogenic actions. According to Souza et al. (2012), these dynamics can affect the entire ecosystem.

River basins are fundamental units for the planning of environmental use and conservation, since they are highly vulnerable to human activities, and may be misused, generating socio-environmental problems regarding their natural resources, the region's economy, and the quality of life of the population involved (Silva et al., 2013).

The Caeté River Basin is in the northeastern state of Pará, Brazil, which is the most populated region of the state (IBGE, 2017). This region is one of the oldest colonized regions in the Amazon, dating from the 17<sup>th</sup> century and, nowadays, it has been strongly affected by the intensive investments of the agricultural sector (Rosário, 2000).

The local historical events contributed to an intense exploitation of natural resources, with deforestation of the native vegetation for timber, logs, firewood, and charcoal, and agriculture—

bovine and buffalo cattle breeding, and planting of subsistence crops of cassava, beans, rice, citrus and Amazonian fruits, mallow (to use its fiber for household utensils), black pepper and, more intensively in the last decade, African oil palm (Gorayeb et al., 2011).

In this context, the objective of this work was to identify and assess significant land use and cover changes in the Caeté River Basin from 2004 to 2014 and show the importance of further works connecting land uses with environmental effects related to water resources, given the dynamics of this ecosystems.

## Material and Methods

### *Study area*

The Caeté River Basin is in the Atlantic Coast of Brazil in the northeastern state of Pará (Figure 1). This basin has an area of 2,235 km<sup>2</sup> and its main river has an extension of 150.4 km, with mouth in the Atlantic Ocean, in the Caeté-Urumajó Bay (Costa, 2017). It drains the waters of two municipalities: Santa Luzia do Pará (19,424 inhabitants), by the Curizinho river, a tributary in the right bank of the mid Caeté River, and Bragança (113,227 inhabitants), in the lower course of the Caeté River; and partially drains the waters of other seven municipalities—Bonito, Ourém, Santa Luzia do Pará, Capanema, Tracuateua, Bragança and Augusto Corrêa (IBGE, 2017).

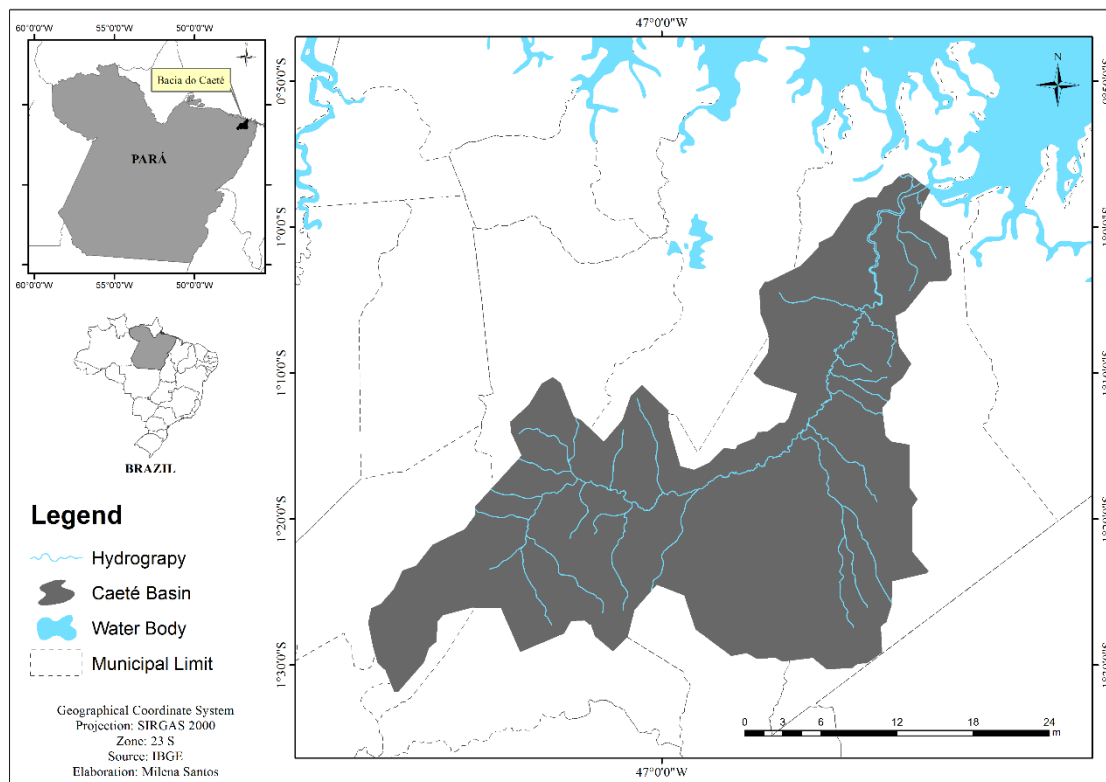


Figure 1. Location of the Caeté River Basin in the Atlantic Coast of Brazil, northeastern state of Pará.

The soil of the Caeté River Basin was predominantly formed by sediments of the Barreiras Group in the Cenozoic Era, and Clayey Sand deposits in the Quaternary Period. Its geomorphology is represented by the Brazilian Coastal Plateau and Coastal Plain, with maximum altitudes of 80 m and flat to slight undulating relief (BRASIL, 2006).

This basin is characterized by the presence of evergreen forest vegetation, aquatic plants, and Amazonian terra firme forest. However, this formation is, nowadays, intensely modified and marked by the prevalence of secondary vegetation, pastures, and permanent and temporary crops (PARÁ, 2006).

#### Methodology

The use of Remote Sensing techniques and Geographic Information System (GIS) to analyze land use and cover in river basins involves some technological and methodological procedures. Initially, a study was carried out to characterize the land use and cover in the Caeté River Basin in the

years 2004, 2010 and 2014 to analyze the main land uses around the main river.

Data were acquired from the Brazilian Institute of Geography and Statistics (IBGE), Brazilian Agricultural Research Corporation (EMBRAPA), Brazilian National Institute of Space Research (INPE), and reference studies conducted in the basin area. Geoprocessing techniques were applied for data processing and cartographic production, using an appropriate GIS software.

The orbit points 222/61 and 223/61, which cover the basin extension, were used together with cartographic bases from 2004, 2010, and 2014 of the TerraClass—a project of the INPE in partnership with the EMBRAPA, whose objective is quantify the deforestation of the Legal Amazon.

The digital data available of the TerraClass project present orbit points of the Landsat 5 satellite (TM sensor) in the Lat/Long Projection System, and Geodetic Reference System - SAD69, with mapping scale of 1:100,000 (INPE, 2016). However, the data presented in the maps in this research were reclassified to the Geocentric Reference System for

the Americas (SIRGAS 2000), an updated geodetic system officially adopted in Brazil.

The areas of each class were summed and their percentages regarding the total area of the

basin were found, consequently, the main land uses described by the TerraClass was reclassified (Table 1).

Table 1. Land use and cover classes used.

TerraClass			
2004	2010	2014	Reclassification
Annual Crops	Annual Crops	Annual Crops	Agriculture
Not Surveyed	Not Surveyed	Not Surveyed	Not Surveyed
Deforested Area	Deforested Area	Deforested Area	Deforested Area
Forest	Forest	Forest	Forest
*****	*****	Reforestation Area	Forest
Secondary Vegetation	Secondary Vegetation	Secondary Vegetation	Forest
Water Body	Water Body	Water Body	Water Body
Mine Area	Mine Area	Mine Area	Mine Area
Urban Area	Urban Area	Urban Area	Occupational Mosaic
Occupational Mosaic	Occupational Mosaic	Occupational Mosaic	Occupational Mosaic
Others	Others	Others	Others
Pasture with Bare Soil	Pasture with Bare Soil	Pasture with Bare Soil	Pasture
Open Pasture	Open Pasture	Open Pasture	Pasture
Abandoned Pasture	Abandoned Pasture	Abandoned Pasture	Pasture
Regeneration with Pasture	Regeneration with Pasture	Regeneration with Pasture	Pasture
No Forest	No Forest	No Forest	Pasture

The classification proposed by the TerraClass project presents 16 classes distributed and listed according to the land use and cover of the region. However, they were reclassified to 9 classes, grouping correlated or similar areas.

This reclassification was necessary to make the studied classes similar in all years. This made possible to evaluate the dynamics of land use and cover and compare the three periods.

Based on the mapping of the land use and cover of the basin and thematic maps, transitional matrices were developed to evaluate the area of each mapped class. This method was used to assess the changes occurred in the study area in the periods of 2004-2010, and 2010-2014. Romero-Ruiz et al. (2012) and Coelho et al. (2014) confirmed the applicability of this method, which allows pixel-to-pixel comparisons of the increases and decreases of the area of each class.

Cross-tabulation tables were developed from the cartographic bases of the TerraClass project and reclassified using an appropriate software. The execution of the cross tabulation processed by the GIS software is described in Figure 2. The rectangles are the actions in the program; the circles are the generated documents; and the rectangle with the semicircular arrow represents the repetition of the actions until the collection of the tables of each class composing the study area; and the arrows indicate the chronological sequence of the steps.

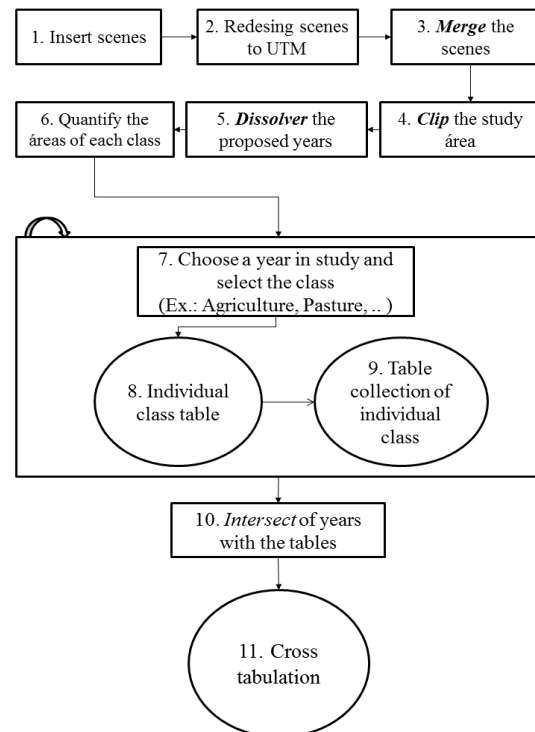


Figure 2 - Methodology flowchart for the cross-tabulation tables.

The cross-tabulation tables had columns in relation to the rows representing the land uses inside the class, and vice versa. Both the column and row correspond to the class in relation to the year. The total value of the class for that year is shown at the end of each row and column. Diagonal

values represented the areas of the class that did not change from one year to the other. The values entered in the table were expressed in hectares (ha).

### Results and discussion

The years 2004, 2010 and 2014 were compared due to the need of a better understand of

the land use and cover dynamics in the Caeté River Basin.

This basin underwent intense processes of occupation and transformation due to human interferences during the last decade that resulted in spatial modifications of the natural environments (Figures 3, 4, and 5).

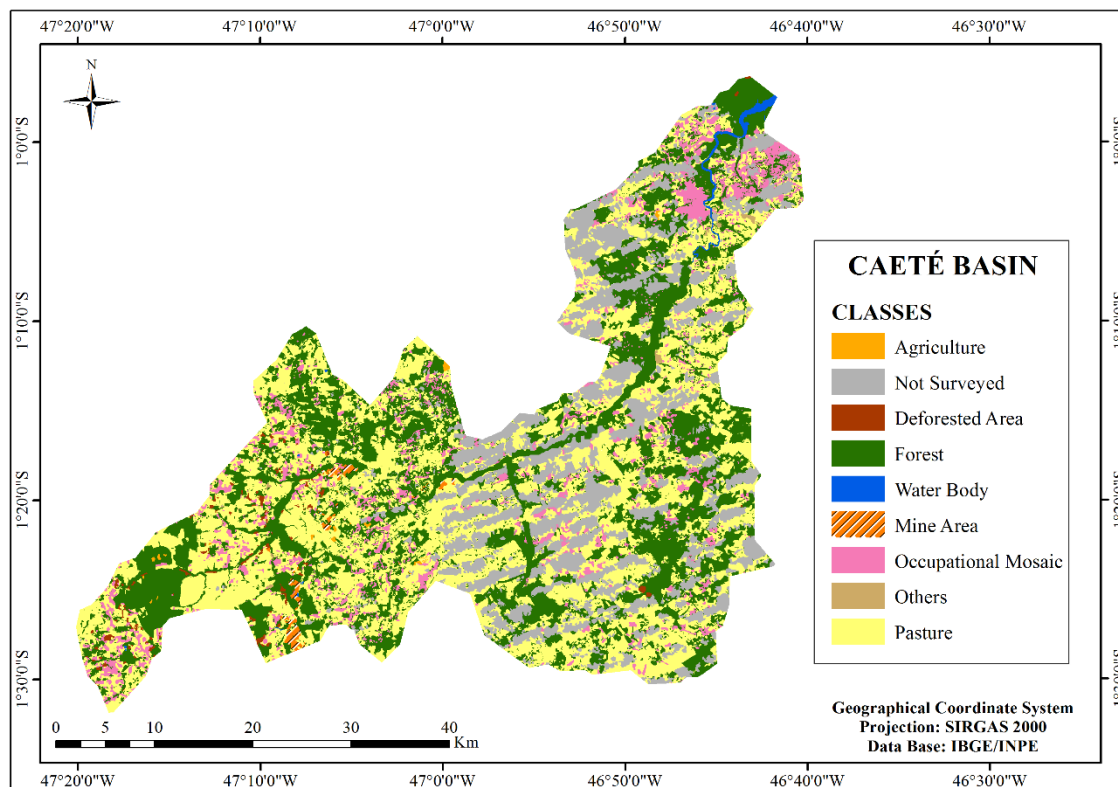


Figure 3. Spatial distribution of land use and cover of the Caeté River Basin in 2004.

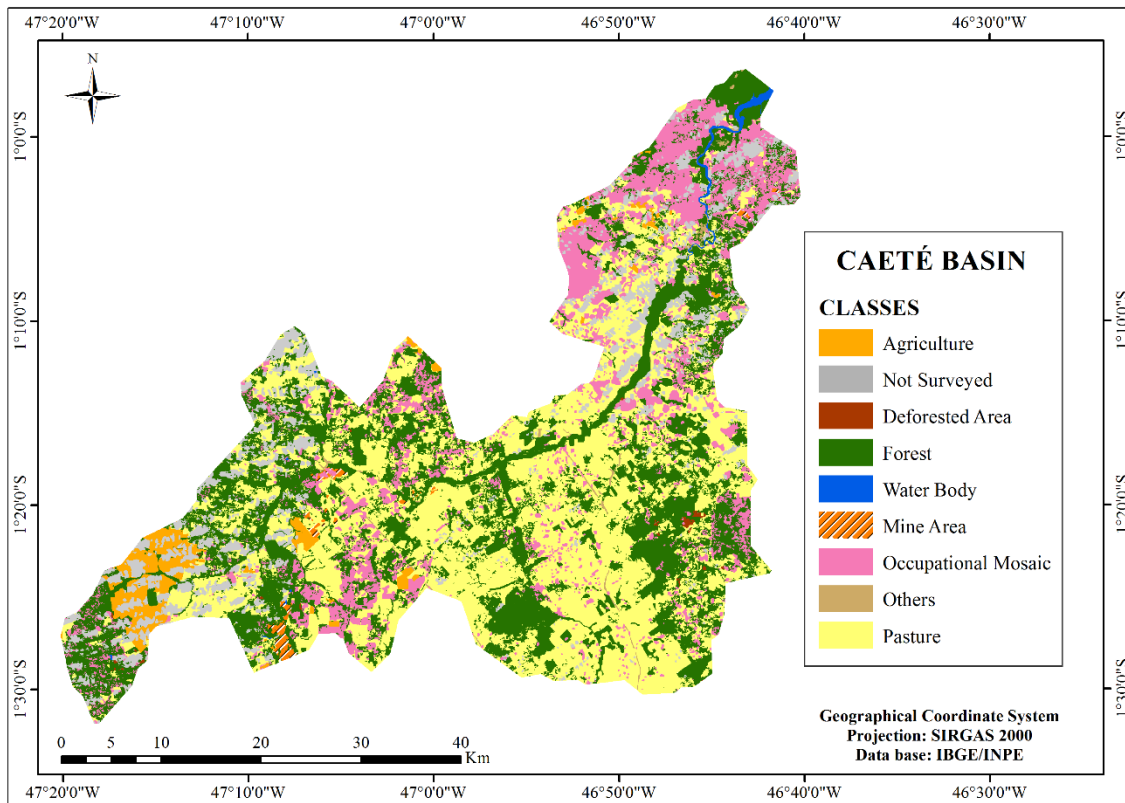


Figure 4. Spatial distribution of land use and cover of the Caeté River Basin in 2010.

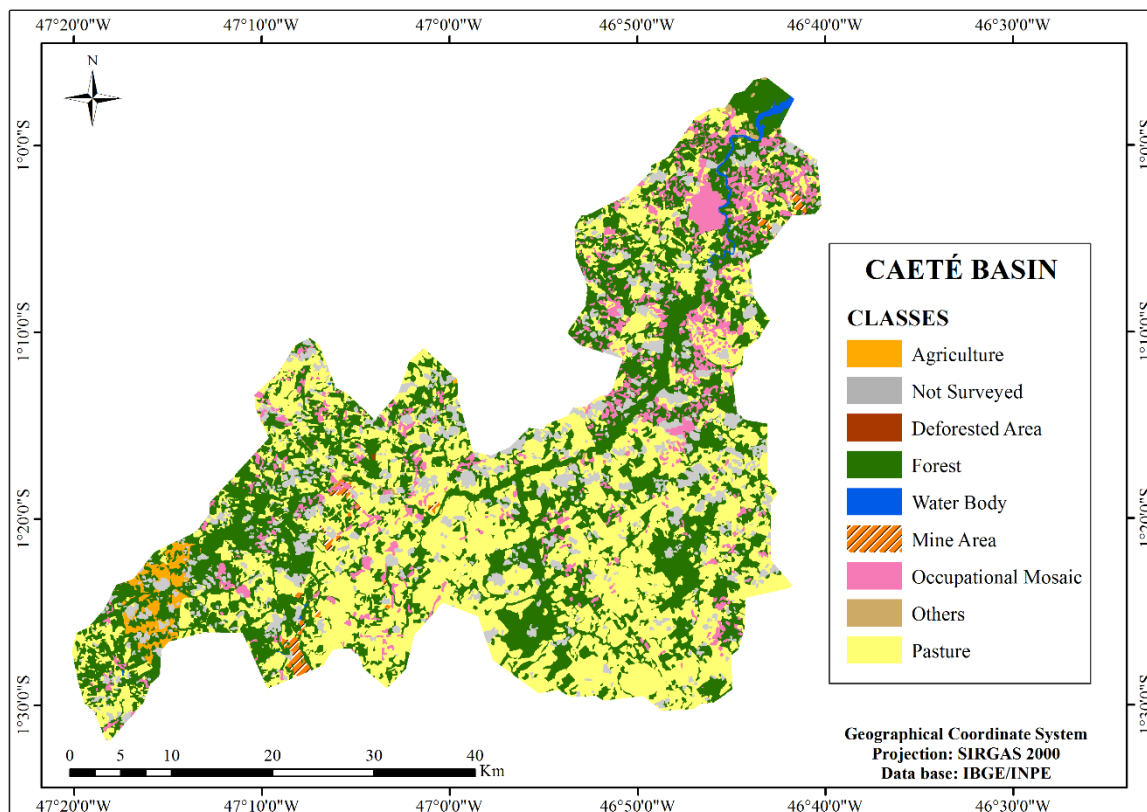


Figure 5. Spatial distribution of land use and cover of the Caeté River Basin in 2014.

Figures 3, 4, and 5 show significant changes in the land use and cover of the Caeté

River Basin from 2004 to 2010, and 2010 to 2014, with intense expansion of pasture areas, resulting



in deforestation of approximately 18,047.74 ha of native forests.

According to other studies carried out in this region (Gorayeb et al., 2010, Costa et al., 2016; Vale et al., 2016), pasture areas, temporary crops, and monocultures are the main causes of deforestation, contributing to the reduction or even elimination of native fauna and flora, lowering of the soil fertility, changing of soil physical characteristics, and potentiating the soil and water contamination due to the inadequate use of agrochemicals.

The region has a high conversion rate of forest to pastures; however, the forest class has

increased. The native vegetation had been maintained, and protected reserve areas had been conserved, in areas near the Caeté River.

Permanent preservation areas are important to the maintenance of the natural environment and contribute to modulate the water flow. Urban and mining areas had expanded throughout the basin, especially around the towns.

The heterogenous landscape of the Caeté River Basin is showed by its different land use and cover classes and their proportions found in 2004, 2010 and 2014 (Figure 6).

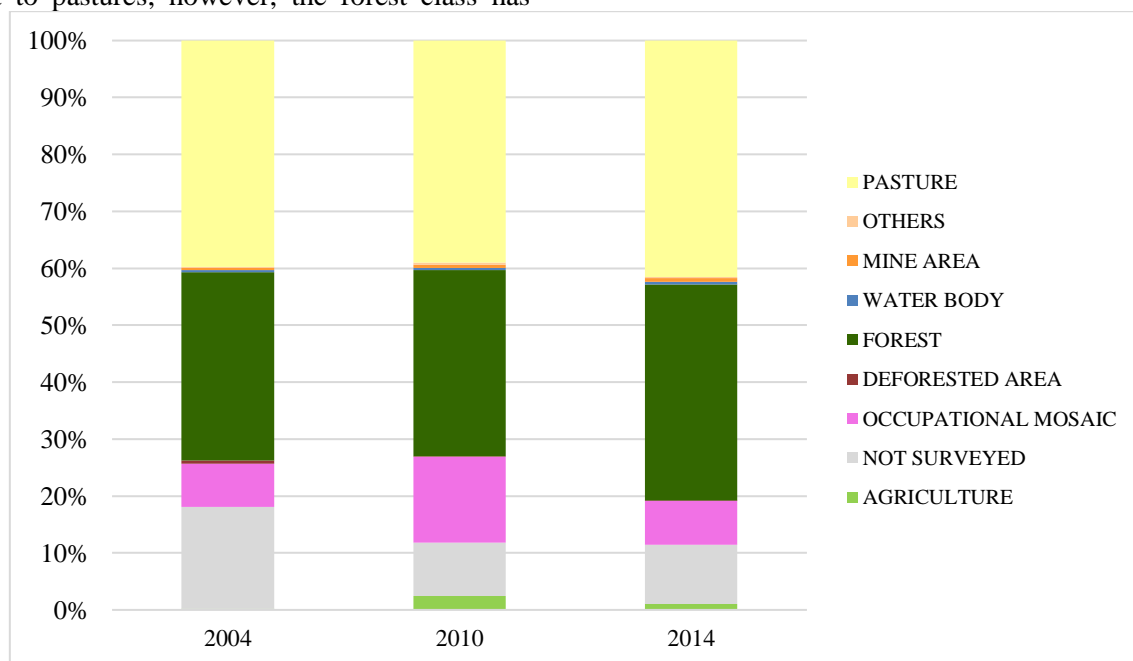


Figure 6 – Area proportions of land use and cover classes in the Caeté River basin in 2004, 2010 and 2014.

The most frequent land use and cover classes were Pasture, Forest, and Occupational Mosaic in all years. Pasture was the predominating class in all years, with percentages of 39.72% (2004), 39.03% (2010) and 41.51% (2014) of the total basin area. Similar results were found by Costa (2017).

Livestock farming in the basin is extensive and covers large areas and has no major investments. This results in serious environmental problems, such as reduction or even elimination of native fauna and flora, lowering of the soil fertility, and changing soil physical characteristics.

The Occupational Mosaic class—subsistence agriculture areas with cassava, orange, coconut, vegetables, and regional crops—was also significant in the area. The cultivation of cassava

generates one of the main commercial agricultural products of the region, the cassava flour.

The proportions of the Occupational Mosaic class were 7.57% (2004), 15.07% (2010), and 7.78% (2014). According to the methodological parameters, the Occupational Mosaic class includes the Urban Mosaic Class, defined by the TerraClass Project as urban areas or spots resulting from population concentrations. However, only two of the seven municipalities (Santa Luzia and Bragança) located in the basin, had their urban centers in the drainage area of the basin.

The classes that represent productive activities such as agriculture and mining had little significant values. Mining represented 0.33% (2004), 0.54% (2010), and 0.65% (2014) of the Caeté River Basin area.

Mining is a major economic activity in the region, with extraction of sand and pebbles (Gorayeb et al., 2009; Costa et al., 2006). Illegal mining is also among the main environmental problems of the basin, together with deforestation, and pollution of water with agrochemicals and fertilizers coming from the municipalities of Santa Luzia and Bragança.

The multitemporal classification showed an increased deforestation in the Caeté basin. The Forest class represents clear-cut areas of the natural forest, covering at least 50% of the soil, according to the criteria developed by TerraClass. The proportion of this class in this classification was 0.71% of the total area.

According to Vale and Bordalo (2016), at least 80% of deforested areas in the Amazon are occupied by planted pastures or secondary vegetation resulting from degraded pastures, belonging to large landowners. In this scenario, the deforestation process is more intense due the land appropriation.

The great challenge for this study was the cloud interference in the region, which limited the accuracy of the classification in the three years studied. Thus, some areas were characterized as Not Surveyed, which reached percentages of 17.88% (2004), 9.37% (2010), and 10.40% (2014). The Others class had percentage of 0.82% (sum of the three periods), representing mainly rocky outcrops, sandbanks, and river beaches.

The land use and cover changes were described by the transition rates between each evaluation (2004/2010, 2010/2014). The increases and decreases in the areas of the classes and their variations were expressed in hectares (ha) in columns and rows (Table 2 and 3). The values in the diagonal indicate the areas that were maintained with the same type of land use throughout the years studied, and the data that are outside the diagonal represent the classes that have undergone land conversion.

Based on the methodology used (Figure 2), the area of the Not Surveyed class decreased 17,420.15 ha from 36,587.65 ha (2004) to 19,167.50 ha (2010). Thus, the Not Surveyed class increased the areas of the Forest, Occupational Mosaic, and Pasture classes.

The area of the Forest class reduced 3,354.50 ha, from 8,583.24 ha (2004) to 5,228.74 ha (2010). The area of the Occupational Mosaic class decreased 5,087.51 ha, from 7,097.62 ha (2004) to 2,010.11 ha (2010). The area of the Pasture class decreased 8,939.26 ha, from 17,856.80 ha (2004) to 8,917.54 ha (2010).

These results indicate the importance of considering the Not Surveyed class, since despite the presence of clouds in the Atlantic Coast region, these results can be correlated over time (Tables 2 and 3).

Table 2. Proportional ratio between areas of land use and cover classes in 2004 and 2010.

		2004									
Classes		AC	NS	OM	DA	FOR	WB	MA	OT	PAS	Total 2010
2010	AC	181.87	230.63	100.17	47.77	2.672.29				1.797.75	5.030.49
	NS	26.10	2.664.20	2.010.11	238.43	5.228.74		54.98	27.42	8.917.54	19.167.50
	OM	12.53	7.097.62	6.493.44	79.47	6.314.95	2.03	84.44	37.87	10.721.32	30.843.67
	DA					285.94					285.94
	FOR	26.58	8.583.24	3.046.91	509.02	37.345.21	9.14	84.02	50.00	17.161.30	66.815.41
	WB					0.05	839.89				839.94
	MA	0.53	36.45	34.93	1.87	95.95		645.61	56.04	235.96	1.107.34
	OT	0.75	118.72	33.68	18.28	194.28		3.44	20.49	338.81	728.43
	PAS	154.03	17.856.80	3.764.75	260.67	15.576.42		144.29	97.40	42.098.79	79.953.14
Total 2004		402.39	36.587.65	15.483.98	1.155.51	67.713.81	851.07	1.016.78	289.21	81.271.47	204.771.86

AC = Annual Crops; NS = Not Surveyed; OM = Occupational Mosaic; DA = Deforested Areas; FOR = Forest; WB = Water Body; MA = Mine Area; OT = Others; PAS = Pasture

Table 3. Proportional ratio between areas of land use and cover classes in 2010 and 2014.

		2010									
CLASSES		AC	NS	OM	DA	FOR	WB	MA	OT	PAS	Total 2014
2014	AC	2.117.48									2.117.48
	NS	837.38	3.638.55	2.967.65	51.66	5.623.70		67.11	5.05	8.733.37	21.170.45
	OM	23.62	2.298.85	7.441.99		2.942.25		29.59	0.57	3.116.03	15.852.89
	DA					17.75				0.00	17.75
	FOR	809.42	7.558.22	8.488.89	94.82	40.996.51		57.90	1.45	19.540.22	77.547.42
	WB						839.89				839.89



MA	0.79	68.98	130.24		202.60		794.93	0.11	120.88	1.318.53
OT		199.06	112.24		111.94		0.22	9.94	99.93	533.34
PAS	1.205.46	6.290.56	11.692.99	139.46	16.901.63		155.93	3.16	48.230.90	84.620.08
Total 2010	4.994.14	20.054.21	30.834.01	285.94	66.796.37	839.89	1.105.68	20.28	79.841.33	204.771.86

AC = Annual Crops; NS = Not Surveyed; OM = Occupational Mosaic; DA = Deforested Areas; FOR = Forest; WB = Water Body; MA = Mine Area; OT = Others; PAS = Pasture

The total area of the Forest class reduced from 67,713.81 ha in 2004 to 66,815.41 in 2010 (Table 2). The Forest class lost 3,268.04 ha for the Occupational Mosaic class; it had 6,314.95 ha in 2004 and 3,046.91 ha in 2010. An area of 1,584.88 ha of Forest was converted into Pasture; it had 15,576.42 ha in 2004 and 17,161.30 ha in 2010. Conversions of forest areas into pastures has contributed to the increase degraded areas and loss of biodiversity in the Amazon (Souza et al., 2016).

The Pasture class lost 6,956.57 ha to the Occupational Mosaic class, reducing from 10,721.32 ha in 2004 to 3,764.75 ha in 2010 (Table 2). The Occupational Mosaic class represents areas of various land uses (TerraClass, 2012), with family farms that use traditional livestock breeding, with removal of vegetation and burning practices. This class covered 15% of the total area of the Caeté River Basin in 2010.

The Occupation Mosaic class reduced significantly from 2010 to 2014, losing 5,546.64 ha to the Forest class; it had 8,488.89 ha in 2010 and 2,942.25 in the year 2014 (Table 3). This result was mainly due to the increase of urban areas and appearance of various land uses along the Caeté River Basin during these years.

The Pasture class lost 2,638.59 ha to the Forest class; it had 19,540.22 ha in 2010 and 16,901.63 ha in 2014 (Table 3). Despite the transition dynamics in land use and cover, the total area of the Forest class increased 10,751.05 ha, from 66,796.37 ha in 2004 to 77,547.42 ha in 2014.

Pasture was the most converted class but had the greatest area not converted among all classes studied, remaining with 48.230,90 ha (Table 3). Moreover, no Annual Crops were found in 2010, but it had 1,205.46 ha in 2014; and the Occupational Mosaic increased 14,981.12 ha, from 30,834,01 ha in 2010 to 15,852.89 ha in 2014.

The main agricultural crop in the basin was African oil palm, mainly produced in the upper Caeté river. This crop is expanding in the northeast of Pará; however, it causes alterations in the soil and in the water cycle. According to Costa (2016), the use of this species in monoculture is concerning due to the need of pesticides, especially considering the location of the Basin, which may affect indirectly the Atlantic Coast.

The total area of the Pasture class increased 4,778.75 ha, from 79,841.33 ha in 2010 to 84,620.08 ha in 2014 (Table 3). This land use is the result of intense human occupations in this part of the Amazon biome, which removed approximately 20% of the native vegetation cover (INPE / PRODES, 2014).

According to the analysis of the presented data, the area of six classes—Annual Crops, Occupational Mosaic, Forest, Mine Area, Others and Pasture—increased, and the Not Surveyed, Deforested Area and Water Body classes reduced from 2004 to 2014, when comparing Table 2 with Table 3.

Three classes—Not Surveyed, Forest, and Deforested Area—stood out with significant differences in areas from 2004 to 2014, when analyzing Tables 2 and 3. The total area of the Not Surveyed class had the largest reduction (14,663.18 ha), from 36,587.65 ha (2004) to 21,924.47 ha (2014). The Forest class increased 9,833.61 ha, from 67,713.81 ha (2004) to 77,547.42 ha (2014). The Deforested Area class reduced 1,137.80 ha, from 1,155.51 ha (2004) to 17.75 ha (2014).

Regarding the Forest class, preservation of riparian forests along the Caeté River and green areas at the river mouth was reinforced with the creation of the Caeté-Taperaçu Marine Extractive Reserve in 2005, which is ran by the Chico Mendes Institute for Biodiversity Conservation (ICMBio). The data show an increase of green areas from 2004 to 2014, confirming the importance of environmental legislation for the management and preservation of green areas and natural resources.

The Pasture areas increased 3,348.61 ha, from 81,271.47 ha in 2004 to 84,620.08 ha in 2014. According to Costa et al. (2016), the predominance of pastures in the Caeté River Basin is the results of the intense deforestation of the primary vegetation for cattle breeding. This caused environmental problems, such as soil compaction, which reduces soil water infiltration capacity, causing surface runoff, and erosion, and at more advanced stages, originates gullies. The deforestation rate in the Amazon is around 5 thousand km<sup>2</sup> per year, mostly for conversion of forest areas into pastures. (INPE/PRODES, 2014)

## Conclusions

The multitemporal analysis was effective in indicating the main land use and cover classes in the Caeté River Basin and determining the conversions of the classes during the periods evaluated. The main uses of the basin cause negative environmental impacts, such as loss of biodiversity, and degradation of forests and water beds.

Three classes of land use and cover stood out in the region. The first was the Pasture, characterized by large areas, presence of large animals, and removal of native vegetation, which favors erosion and environmental pressure on the basin. The second was the Forest class, characterized by its important vegetation for the maintenance of the natural resources and the dynamic equilibrium in the basin, which modulates interactions in natural environments. The third was the Occupational Mosaic, characterized mainly by urban areas and small crops, marked by family farms.

The Pasture areas was very high in 2014 when compared to 2004 and 2010.

The land use and cover changes altered the spatial pattern, affecting the natural characteristics of the basin. Thus, mitigating the environmental pressures on the river basin is needed. This can be achieved through studies that integrated social and environmental approaches to problems, identifying potential and real degradation sources.

The assessments of soil use and cover changes proved to be efficient to develop representative analyzes that can be used in integrate projects for implementation of policies and in further researches on the management of water bodies.

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