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ZONA DE AMORTECIMENTO DO PARQUE ESTADUAL DO RIO DOCE, MINAS GERAIS, BRASIL: PASSADO, PRESENTE E FUTURO

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Tese apresentada ao Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre da Universidade Federal de Minas Gerais como requisito parcial para obtenção do Título de Doutor em Ecologia, Conservação e Manejo da Vida Silvestre.

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Dedicatória

À meus pais e ao meu amor.

UFMG UNIVERSIDADE FEDERAL DE MINAS GERAIS

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"Se mais pessoas valorizassem o lar acima do ouro, o mundo seria muito mais feliz."

(Thorin, Escudo de Carvalho – Trilogia O Hobbit)

"*Todos querem o perfume das flores, mas poucos sujam suas mãos para cultivá-las*."

(Augusto Cury)

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Sumário

Resumo Geral

O ambiente é dinâmico e muda com o tempo. Assim, é necessário entender a importância das paisagens que compõem o ambiente para uma visão mais ampla do tempo e do espaço, de modo que se entenda que cada parte do território tem respostas diferentes para as mudanças ambientais e dos usos da terra. Este estudo utilizou uma abordagem multiescala em um dos *hotspots* de biodiversidade do Brasil, o Parque Estadual do Rio Doce (PERD), localizado em Minas Gerais. Uma região que sofre grande pressão antrópica, com destaque ao Desastre de Mariana, no Rio Doce, que é limítrofe à Unidade de Conservação. Foi analisada a evolução dos usos da terra dos últimos 30 anos (1985-2015) em escala regional para os municípios e em escala local, com maior refinamento, para a zona de amortecimento do PERD, seguida de elaboração de cenário futuro para os próximos 15 anos (2030), além de propostas de técnicas de manejo e corredores ecológicos para o momento presente. A fim de abranger uma maior gama de informações e envolvimento da comunidade que vive no entorno do Parque, foram realizados *workshops* envolvendo a população, gestores ambientais e empresas atuantes na região, bem como o próprio PERD. Com isso em mente, buscou-se gerar um maior envolvimento entre todas as categorias, mostrando como poderia ser no futuro em contraposição às interações e diálogos, com a elaboração de um planejamento de propostas, para que todos os envolvidos possam ajudar a delinear direções ambientais para um futuro positivo.

Palavras-chave: ecologia da paisagem; usos da terra; cenários futuros; corredores ecológicos; Parque Estadual do Rio Doce.

Introdução Geral

A sociedade contemporânea almeja sempre buscar o melhor conforto e bem estar, buscando a qualquer preço, porém, esquece que os recursos naturais mesmo em abundância, se acabam, podendo faltar futuramente. O avanço econômico e tecnológico precisa ser compatível com a conservação dos recursos naturais, pois os processos que regem esta interação estabelecem o padrão e as mudanças das paisagens, com base nos valores estéticos, econômicos ou ecológicos. Como resultado desta interação, podemos ter a degradação da qualidade ambiental, o que exigirá a adoção de políticas públicas capazes de minimizar os impactos e assegurar o desenvolvimento sustentável frente às ações antrópicas. (Grubba & Hamel, 2016; Feil & Schreiber, 2017; WWF, 2018).

As florestas tropicais possuem a maior diversidade e complexidade conhecida, porém, têm sido rapidamente convertidas para outros usos em taxas alarmantes na maior parte dos casos com danos ambientais irreversíveis e perda de uma biodiversidade única, fruto principalmente da pressão antrópica cada vez maior sobre os recursos naturais (Mittermeier *et al.*, 1998). De fato esta questão preocupa a comunidade científica e ambientalista e merece atenção especial, pois é notória a importância deste ecossistema, que além da sua megadiversidade, abriga um grande número de espécie endêmicas. São registrados cerca de 208 espécies de mamíferos, 992 de aves, 200 de répteis, 370 de anfíbios e 350 de peixes e mais de 20.000 espécies de plantas, sendo 8.000 endêmicas (Pinto et al., 2012; SOSMA, 2018).

A Mata Atlântica, um dos *"hot spots"* brasileiros (Myers, 1988), é uma das mais ricas em diversidade de espécies e ameaçadas do planeta. O bioma abrange uma área de cerca de 15,2% do total do território brasileiro, que inclui 17 Estados, dos quais 14 são costeiros. Atualmente restam apenas 12,4% da floresta que existia originalmente e, desses remanescentes, 80% estão em áreas privadas (SOSMA, 2018).

O bioma Mata Atlântica vem sofrendo fortes pressões antrópicas desde a colonização, o que resultou em um extenso desmatamento, cujo início se deu com a coleta desordenada e em grande escala do pau-brasil, em faixas litorâneas do Nordeste (Dean, 1997). Após o ciclo do pau-brasil, outros ciclos econômicos também contribuíram para a perda da cobertura florestal na Mata Atlântica. A expansão do café, por exemplo, foi responsável pelo desmatamento de grande parte da mata tropical, durante o século XIX, particularmente nas regiões interiores do Sudeste, conhecidas como "mar de morros" e que englobam a Serra da

Mantiqueira e a Serra do Mar, tendo a pecuária, a atividade de produção de carvão e mais tarde a cana-de-açúcar (essas marcantes na década de 80, notificadas neste estudo), as atividades que continuaram à invasão das áreas de mata e áreas planas do Sudeste (Dean, 1997). A redução da cobertura vegetal neste ecossistema continua até hoje, principalmente pela expansão urbana, atividades de mineração e a industrialização (Aguiar *et al.*, 2003; SOSMA, 2018).

A dinâmica da paisagem da Mata Atlântica resultou em alterações severas nos ecossistemas que compõem este bioma, especialmente pela perda de habitats e isolamento de espécies (Hirota, 2003; Lima et al., 2017; Fioravanti, 2018). O processo de fragmentação e isolamento de habitats está aumentando e hoje, as maiores áreas de remanescentes estão protegidas em unidades de conservação de proteção integral localizadas principalmente na região serrana do estado do Espírito Santo e ao longo da região costeira dos estados da Bahia, Rio de Janeiro, São Paulo, Paraná e Santa Catarina (Pinto et al., 2006; MMAa, 2015).

O número total de unidades de conservação (UC) é expressivo na Mata Atlântica (1257), sendo a soma de todos os tipos, incluindo as Reservas Particulares do Patrimônio Natural (RPPN), uma área total de 11.553.664,80 ha, representando 9,40% de toda a área terrestre protegida do Brasil. (Pinto et al., 2006; MMA, 2015b; SOSMA & INPE, 2018; CNUC, 2018). As unidades de conservação de proteção integral, consideradas de maior relevância para conservação da biodiversidade em virtude das suas restrições de uso, somam 420 e ocupam 2.883.641,92 ha (1,93%) desse bioma.

No âmbito da produção de conhecimentos científicos e tecnológicos destinados à conservação e utilização sustentável dos recursos naturais, merece ser referenciado o Programa de Pesquisas Ecológicas de Longa Duração (PELD). No Estado de Minas Gerais, este programa tem como uma de suas áreas de estudo o Parque Estadual do Rio Doce, localizado no município de Marliéria, tendo como enfoque estudos em ambientes terrestres e aquáticos relacionados à Mata Atlântica e ao Sistema Lacustre do Médio Rio Doce (PELD/UFMG, 2015).

O Parque Estadual do Rio Doce (PERD) é uma unidade de conservação de proteção integral, que se localiza na região leste do estado de Minas Gerais e é considerada uma das principais áreas contínuas de Mata Atlântica preservada. Nessa região, o cenário natural tem sido substancialmente modificado pelo processo de urbanização, que foi incrementado com a exploração de metais e a forte presença de multinacionais do ramo. O crescimento populacional e industrial resultante destas atividades econômicas vem pressionando os ecossistemas aquáticos regionais com o aterro das margens dos rios, canais, lagos e lagoas; ocasionando a queimada da vegetação que precede a introdução de espécies para cultivos madeiráveis como o eucalipto; o desmatamento, a supressão da mata ciliar e a fragmentação florestal; o lançamento de efluentes domésticos sem tratamento e o assoreamento dos leitos d'água da bacia, que é potencializado pelas práticas de cultivo agrícola, etc. Toda essa gama de atividades têm causado alterações consideráveis em suas características naturais, alterando a paisagem de toda a região, comprometendo a possibilidade de seus usos múltiplos, além de causar riscos diretos à biodiversidade presente (IEF, 1994, 2002; Kazmierczak & Seabra, 2007; Peixoto, 2012).

Para compatibilizar o uso das terras e a sustentabilidade ecológica, social e econômica, é necessário planejar a ocupação e a conservação da paisagem como um todo. Para tanto, devem ser consideradas as interações espaciais entre unidades culturais e naturais, incluindo assim o homem no sistema de análise (Metzger, 2001). Nesse sentido, são necessários estudos destinados à caracterização da paisagem e à quantificação dos impactos ambientais causados pelo uso antrópico ao meio natural. Tais estudos poderão orientar ações estratégicas para a minimização da degradação ambiental, implementações dos processos de recuperação de áreas degradadas e melhorias em prol da conservação regional (Metzger, 1999; Almeida, 2008).

Uma das principais bases de estudo da degradação ambiental é a Ecologia da Paisagem, que se propõe a lidar com as mudanças de mosaicos naturais para antropizados, adotando uma perspectiva para propor soluções aos problemas ambientais que acontecem ao longo do tempo (Metzger, 2001; Almeida, 2008; WWF, 2015).

Segundo Metzger (2001), a Ecologia da Paisagem possui duas abordagens: a) geográfica, que procura entender as modificações estruturais e funcionais, adicionadas pelo homem no mosaico como um todo, incorporando de forma explícita toda a complexidade das inter-relações espaciais de seus componentes, tanto naturais quanto culturais; b) ecológica, que busca entender quais são os principais problemas ambientais, tanto relacionados à fragmentação de habitats, quanto ao uso inadequado dos solos e da água. Reconhecidamente, o estudo da Ecologia da Paisagem pode subsidiar as ações de planejamento de ocupação territorial, gestão dos recursos naturais e conservação da biodiversidade .

Visando abranger esta interdisciplinaridade da ecologia com a geografia, este estudo teve como objetivos principais: 1) avaliar a dinâmica da paisagem do Parque Estadual do Rio Doce/MG e sua zona de amortecimento (ZA) para compreensão da evolução temporal dos usos da terra nos últimos 30 anos (1985 a 2015); 2) prever cenários futuros dos usos da terra da ZA para os próximos 15 anos (2030), envolvendo a participação das comunidades do entorno no processo; 3) diagnosticar a situação atual da fragmentação florestal da ZA e propor alternativas de manejo para a melhoria da conectividade entre as áreas, visando à melhoria da conservação regional. Considerando estes objetivos, a tese foi estruturada em dois artigos: o primeiro, com estudo do passado ao presente (1985 a 2015), sobre as mudanças da paisagem ao longo dos últimos 30 anos e o segundo com cenários futuros do que pode acontecer se continuar assim, adicionada a uma visão sobre a fragmentação florestal da ZA, para melhoria da conservação local como medida para remediar essas previsões.

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ARTICLE 1 - A MULTISCALE ANALYSIS OF LAND USE DYNAMICS IN THE BUFFER ZONE OF RIO DOCE STATE PARK

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Abstract

This paper uses a multiscale approach for assessing landscape changes in the Rio Doce State Park (PERD), Minas Gerais, Brazil. In this paper we assess land use changes over a 30 year period in the total area of municipalities and in the area of PERD buffer zone. Our results show that over the last 30 years, while inside the park landscape changes were minimal, in the park buffer zone human induced changes are steadily rising due to an increase in the planting of eucalyptus and the spread of urban areas that grew 4% and 1.9% respectively. Agricultural land was reduced by 6.35% while there was an increase in native forests from 40.588 ha in 1985 to 45.690 ha in 2015. The analysis of human impacts in the study area delivers very different results when varying the pixel size from 25 ha (500x500 meters) to 900 m² (30x30 meters). The former shows a very high level of human influence while the latter reveals small but vital patches of native forest offering opportunities for sustainable natural resource management in this critical biome. Our work stresses the importance of better targeting policy making and land use management of buffer zones of protected areas as they suffer from many development pressures and often experience contradictory policy frameworks which encourage a clash between both biodiversity conservation and agro husbandry production.

Keywords: landscape ecology; anthropomorphic land use change; GIS; environmental management; Rio Doce State Park.

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1. Introduction

Landscape patterns, as described by composition and configuration of the mosaic of land uses, are associated to multiple ecosystem services and functions such provisioning, regulating, and cultural (Li & Wu, 2004; Uuemma, 2013). Landscape composition and configuration are permanently changing as land mosaics are in a constant shift (Antrop, 2005). The peace and rate of landscape change is associated to gains and losses of Ecosystems Services (ES) and the benefits they provide to humankind (Costanza & Daly, 1992; Costanza et al., 1992; De Groot et al., 2002; Liu et al., 2009).

Ecosystem services secure our foundations of life and are associated with human wellbeing (Millennium Ecosystem Assessment, 2005; Balvanera et al., 2012). Major land use change around the globe vary from deforestation (Davis & Petersen, 2018; Franklin Jr. & Pindyck, 2018), for this reason, it should be emphasized the great importance of the presence of conservation units and the protection of local biodiversity, thus protecting forests and water bodies, which constantly suffer anthropogenic impacts; urbanization (Kamusoko et al., 2009); land use intensification (Villa et al., 2018; Adhikari & Hansen, 2018) but also land abandonment (Van Der Zanden et al., 2018).

A recurrent trend associated to deforestation and urbanization is landscape fragmentation and decreased ecosystem stability where anthropic elements and structures have been created into original pristine and “ecological” landscapes (Su et al., 2014; Zhou et al., 2015). As a result, many ecological and environmental problems have worsened, such as global climate change (Kalnay & Cai, 2003), urban flooding (Huong & Pathirana, 2013), surface water pollution (Ren et al., 2003). Therefore, it is important to determine the effects of land use change on ecosystems and to quantify the relationships between land dynamics and ecosystem services. This knowledge can improve urban planning and policy making for sustainable urban development (Solovjova, 1999; Cen et al., 2015).

Key trends of landscape change in the tropics are land intensification and urbanization (Reed et al., 2016) where natural areas are increasingly giving way to urbanized areas and agricultural uses. This replacement of the natural by anthropic land uses brings major challenges to environmental planning and management in the tropics (Lenzi, 2006; Ishizawa, 2017).

Brazil is known for its climatic variety, richness of environmental resources and for being one of greatest biological diversity hotspots of the planet (Myers et al., 2000; Pimm &

Raven, 2000). The conservation of such resources is nevertheless very challenging (ONU, 2011). In addition to well-known politically induced pressures of an emerging economy, Brazil needs to be competitive in world markets. Brazil has embarked on intensive development initiatives and policies to produce food (OCDE-FAO, 2015), fibers (Brasil, 2012) and energy (Bronzatti & Neto, 2008). The creation of protected areas is well underway but there is still the need to better frame policies able to gear away from unfavorable trends such as deforestation. The safeguarding of protected areas and their surroundings, present many weaknesses (SNUC, 2011; WWF, 2017).

A major challenge is to reconcile protection of natural assets while enhancing the livelihoods of communities occupying lands close to protected areas. Brazil has experimented with promising public policies aimed at sustainable local development and nature conservation through Payment for Ecosystem Services (PES) programs and inovative intergovernmental fiscal transfers ("Ecological *ICMS*") (Bernardes, 1999; Ring, 2008). The operational success of PES and E-ICMS payments rely on how well the benefits of such payments are understood and appreciated by citizens, and how in turn ICMS revenues are allocated by local government (May et al., 2002). Moreover, the funding critically depends on the good conservation status of these protected areas, which are represented by permanent protection areas (APPs) and legal reserves. Thus, a key issue is to monitor the level of anthropic alteration in protected areas and their surrondings.

Atlantic forest is one of the most threatened biomes in the world and still the data set for monitoring forest recovery is poorly detailed when compared for example to the Amazon region. One of the biggest remnants of Atlantic forest in Minas Gerais is the Rio Doce State Park / PERD (IEF, 1994; 2002a).

The main goals of this study are: 1) to characterize the socio-economic dynamics of the municipalities surrounding the area of PERD and cluster them according to their socio-economies, 2) to map land use and human intervention at both regional (16 municipalities surrounding the park) and local scales (10 km buffer zone around PERD), and 3) to analyze the dynamics of land use changes over the period 1985 to 2015 in the 10 km buffer zone of the PERD. This paper provides an analysis of the landscape dynamics offering an important tool for monitoring landscape changes for the future based on past data.

2. Case study and Methods

2.1 Study Area

The Rio Doce State Park (coordinates: 19º42’23” S and 42º34’33” W – Datum WGS 84 / 23 S) has an area of 35.976,43 ha (IEF, 2002a) and covers part of the municipalities of Marliéria, Timóteo and Dionísio (**Figure 1 – Total area of municipalities and Buffer Zone**). Its water system consists of about 50 lakes (6% of its area – IEF, 1994). The northwest boundary is naturally made by the Piracicaba River and to the east by the Doce river (**Figure 1 - PERD**). It borders urban centers, agro-pastoral areas and extensive eucalyptus plantations, mainly to the east and south. In general, most of the water bodies that make up the lake system have suffered some kind of adverse impact, either by excessive water use or by modifying the landscape. Only the lakes inside the park are wholly preserved from anthropogenic impacts.

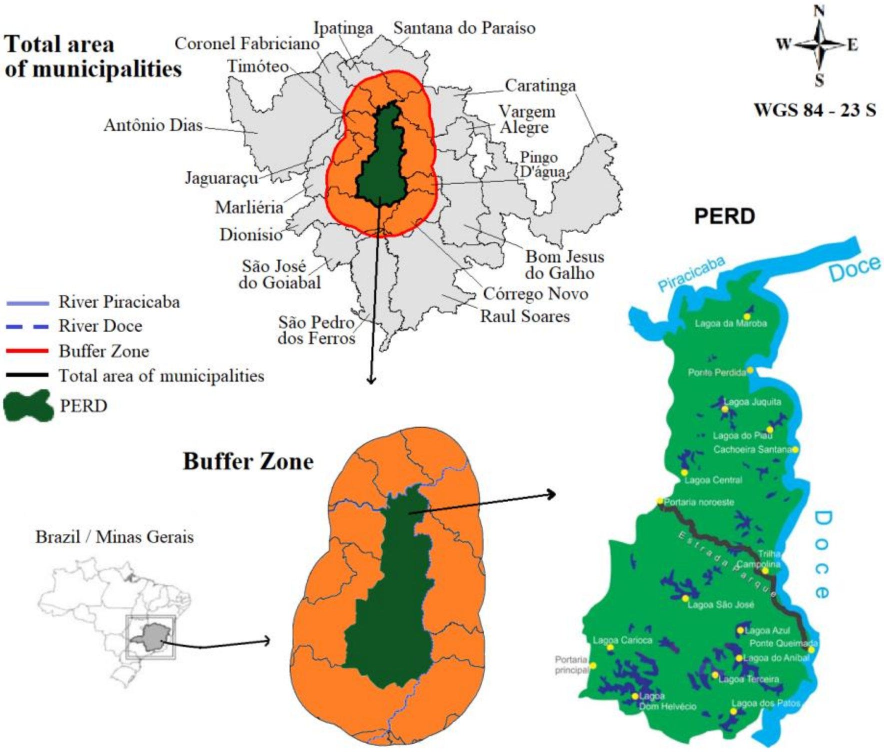


Figure 1. Study area: Rio Doce State Park / MG and municipalities that cover its territorial areas and its buffer zone.

The total area occupied by the 16 municipalities around the PERD is 623.784,20 ha while its 10 km buffer zone area occupies 128.893,36 ha. Our study comprised the analysis of landscape dynamics both for the 10 km buffer (**Figure 1 – Buffer Zone**) and for the total area of the 16 municipalities surrounding the Park (**Figure 1 – Total area of municipalities**).

Established in 1944 the Rio Doce State Park is located in the eastern region of the State of Minas Gerais, the largest continuous surface of preserved Atlantic Forest (Ribeiro et al., 2009). It is therefore considered one of the most important areas for biodiversity, by the fact of covering high diversity of fauna and flora, in addition to species with risk of extinction (Myers et al., 2000). The Park is the third largest lake system in Brazil (behind the Amazonian and Pantanal basins) from which local communities hugely benefit from ecosystem services such as water regulation and culturally rich biodiversity, and its buffer zone also exhibits a great range of rich natural environments.

The buffer zone of PERD is characterized by a great diversity of socio-economic activities. In addition to the "ancient traditional" activities such as mining and steel industry, the region is well known as steel valley - Vale do Aço (Veloso, et al., 1991; CBH-DOCE, 2014), new activities have recently emerged such as a pulp industry encouraging extensive monocultures of eucalyptus (*Eucalyptus spp)* and sugarcane (*Saccharum officinarum).* Associated population and industrial growth bring many pressures to regional aquatic ecosystems, suppressing riparian forest, increasing sedimentation, and disrupting the watershed as a whole (Maillard, et al., 2012).

Major environmental problems of these areas are: the embankment of river banks, canals and lakes; the burning of vegetation that precedes the introduction of species such as eucalyptus and the harvesting of sugarcane; the release of untreated domestic effluents, and sedimentation of the basin's water beds (IEF, 2002a; Peixoto, 2012).

All the economic activities occurring in the buffer zone of PERD are drivers of land use change that operate at multiple scales. Notably the increase in areas of eucalyptus and sugar cane are driven by macroeconomics that operates at different levels of governance from international to local. Recognition of the importance of scale in environmental assessments has grown considerably over the past decade. The geographical approach seeks to understand the structural and functional modifications of the land use mosaic as a whole, explicitly incorporating all the complexity of the spatial interrelations of land uses, both natural and human caused (Metzger, 2001). However, analyzing the land use dynamics in the Atlantic forest biomes is very challenging. There are different broad scale analysis datasets such as MAPBIOMAS at resolution 1:100.000 (MAPBIOMAS, 2018) and 25 ha pixel (500x500 meters - Soares-filho et al., 2016) but for multi temporal and finer scale analysis of land use change as required to map small plots of Atlantic forest remnants data is clearly missing.

2.2 Methodology

This research was divided in 6 stages, (**Figure 2**) as follows: bibliographic review on historical data and the occupation patterns of the study area. Based on the socio-economic data of the 16 municipalities surrounding PERD by the Brazilian Institute of Geography and Statistical (IBGE, 2015) we performed a principal components analysis (PCA) and cluster analysis (CA) for grouping the municipalities according to socio-economic dynamics (Urban Population, Rural Population, Demographic Density, Human Development Index, Basic Education Development Index and Sectors of the economy highlighted) in SPSS (IBM, 2010).

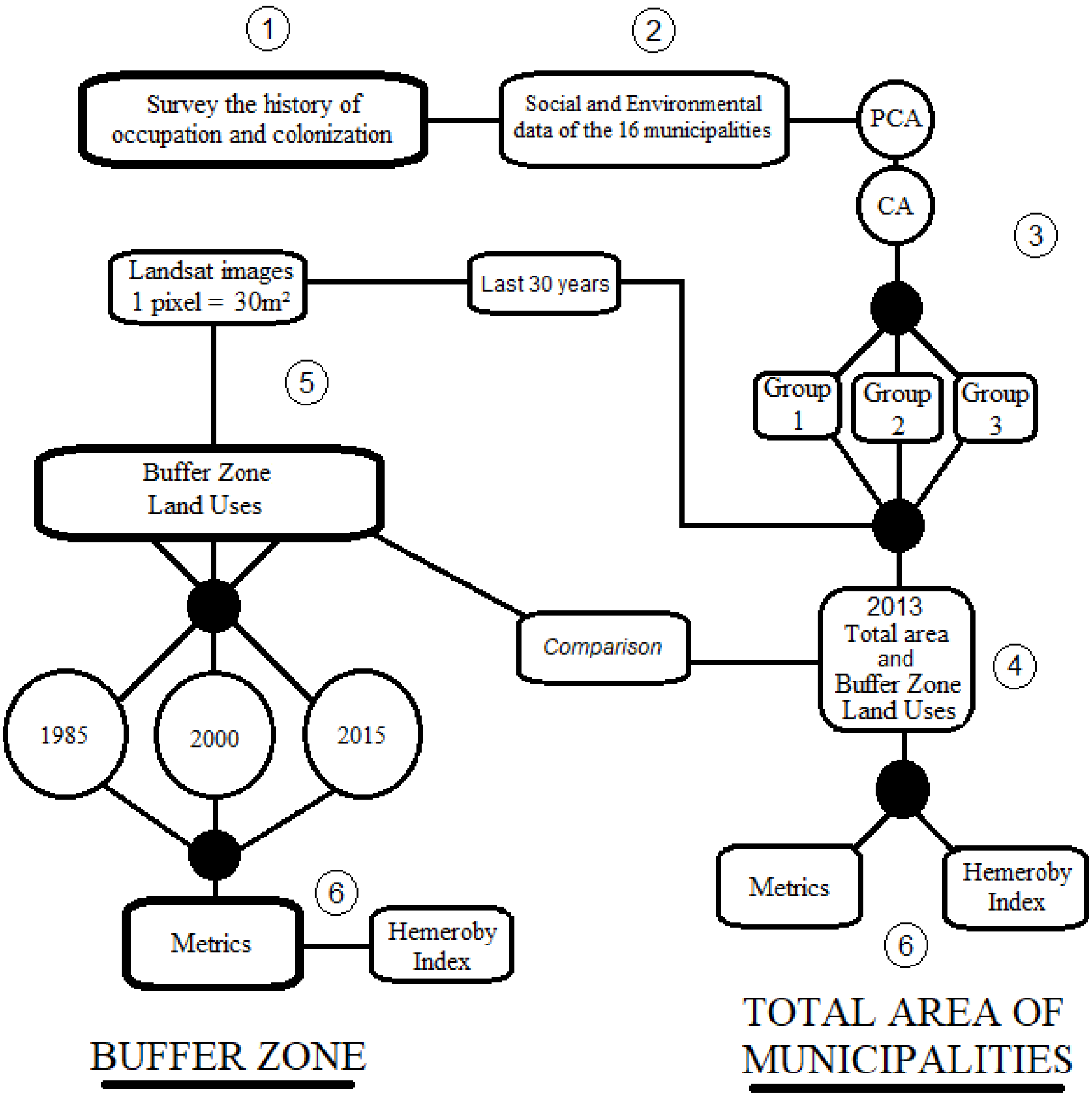


Figure 2. Flowchart of the methodological steps of study.

We applied socioeconomic variables such as Total Population, Urban Population, Rural Population, Demographic Density, Human Development Index, Basic Education Development Index and Sector of Economy into a Principal Component Analysis (PCA) and extracted 3 principal components that explained 75 % of the variability in the data set. Consequently we developed the principal axis to separate the 16 municipalities in 3 groups (K-mean) with similar characteristics.

This snapshot analysis of the total area of municipalities provided a perspective of changing land use in the area (year 2013). This analysis was conducted at a resolution of 25 ha (500x500 meters - CSR/UFMG, Soares-Filho et al., 2016) per pixel using the only dataset available that disaggregates agriculture land into different crop systems. This analysis allowed classification in 6 types of land cover, covering anthropic altered and natural classes, presented in **Table 1** below.

Table 1. Land uses of the 16 municipalities total area, PERD and buffer zone.

Natural	
Water	river, lakes, ponds and water bodies
Forest	native forest
Anthropic	
Urban	urban centers and districts
Forestry	eucalyptus
Pasture	low vegetation and for livestock
Agriculture	soybean, sugarcane, maize, rice, beans, coffee, orange, cassava and banana

To analysis of land use data, we used ArcGis 10.22 (ESRI, 2013) and finer resolution land use LANDSAT 5/7/8 images covering the last 30 years (1985, 2000 and 2015 – buffer zone), all of them taken in July for temporal standardization (INPE, 2015; Earth Explorer, 2015). Only LANDSAT images were used to standardize the analysis, because old years only exist for these images. The images were acquired already orthorectified (Earth Explorer, 2015; INPE, 2015) and their differences according to the years are due to the quality of landscape identification, where in 1985 the image presents confusing aspects due to the low precision of the satellites, already the current ones have better quality. This analysis allowed classification in 6 types of land cover too, covering anthropic altered and natural classes, presented in **Table 1**. Exclusively for the land uses analyses inside of the PERD, the term *Bare Soil* is classified for sites without vegetation.

Our classification aimed at distinguishing amongst anthropic altered and natural land classes. First, a supervised classification was made to understand the entire study area (which obtained an accuracy of 86.72%) and then, due to notification of the accuracy, an unsupervised, where they were manually corrected and analyzed using Google Earth. A random validation points are made with Google Earth (2015) and ArcGis, where in the field have been proven (the hard-to-reach points were verified by recognition on Google Earth itself). For a better proof of land uses, the land use patterns (shapes) of the companies Cenibra and AcellorMital were acquired, mainly to prove the forestry areas and thus not to confuse the classification with the forest areas.

The next step of the study was to elaborate the *Hemeroby index* (a measure of human induced land use changes) and the *land use metrics* of the groups of municipalities at regional and local scales. The *Hemeroby index* is widely used to report the progression of the anthropic altered land uses over the natural (Kiedrzynska et al., 2014; Fushita et al., 2017). We used this index for assessing the human alteration of the area over the last 30 years of study (1985 to 2015) both for PERD and its buffer zone. This approach followed other Brazilian studies and was adapted to the study region (Belem & Nucci, 2011). As shown in **Figure 3**, this approach is a reclassification of land uses based on an anthropomorphic measure.

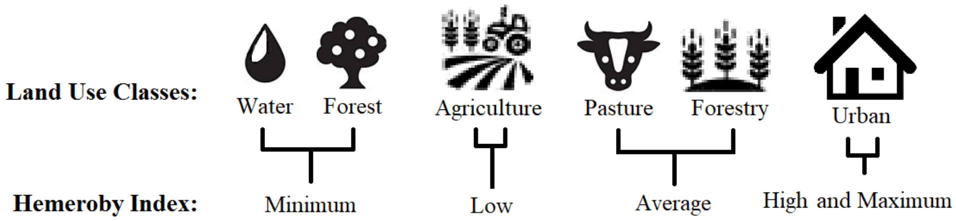


Figure 3. Land Uses and Hemeroby Index of each study class.

Minimum Hemeroby was assigned to remaining native vegetation and aquatic environments such as rivers, lakes, reservoirs and flooded areas; *Low* Hemeroby, were assigned to areas modified by humans, with fragmented patches of native and altered vegetation occurring in the form of forests and / or abandoned land; and the arboreal and shrub vegetation that are slightly spaced, which allows the development of herbaceous species. Its regional presence is characterized, in addition to these natural features, by the presence of family farming as well as to sugarcane plantations. *Average* Hemeroby class was assigned to pastures areas, areas of eucalyptus and areas of exposed soils classified with high degree of human intervention. Agricultural use particularly intensive management is also present in the study area often linked to soil erosion and disruption of the hydrological cycle. *High* and *Maximum* Hemeroby classes are associated with urban areas in the buffer zone mainly located in the north / northwest of the PERD, represented by great population density, buildings, avenues, tunnels, bridges, industries and steel mills.

Fragstats 4.2 software (UMass, 2015) was used for the analysis of total area of municipalities and buffer zone *land use metrics*. For the 3 groups of municipalities we calculated, for each land cover class, a set of simple and straightforward interpretation metrics such as Mean Area of the patches (AREA_MN) and the area of Largest Patch (LPI). We also used other five metrics such as Number of Patches (NP), Euclidian Nearest Neighbor Distance (ENN_MN and ENN_CV), Connectance Index (CONNECT) and Edge Density (ED) aiming at assessing fragmentation. A distance of 60 m was used as edge width as this represents the living area of jaguars (these from the border means that the fragment becomes suitable for housing and passage for large mammals and the choice of this animal is due to the fact that it is the largest in the region and that it is most at risk of extinction). These metrics were selected for ease of interpretation and for their relationship with sustainability (Botequilha Leitão & Ahern, 2002).

3. Results and Discussions

3.1 The socio-economy of the municipalities surrounding PERD

After exploring the variability of socio-economic data by performing a Principal Component Analysis (PCA) and grouping the 16 municipalities surrounding PERD into 3 clusters (K-means), we were able to map contrasting socio-economic dynamics in the region (**Figure 4**).

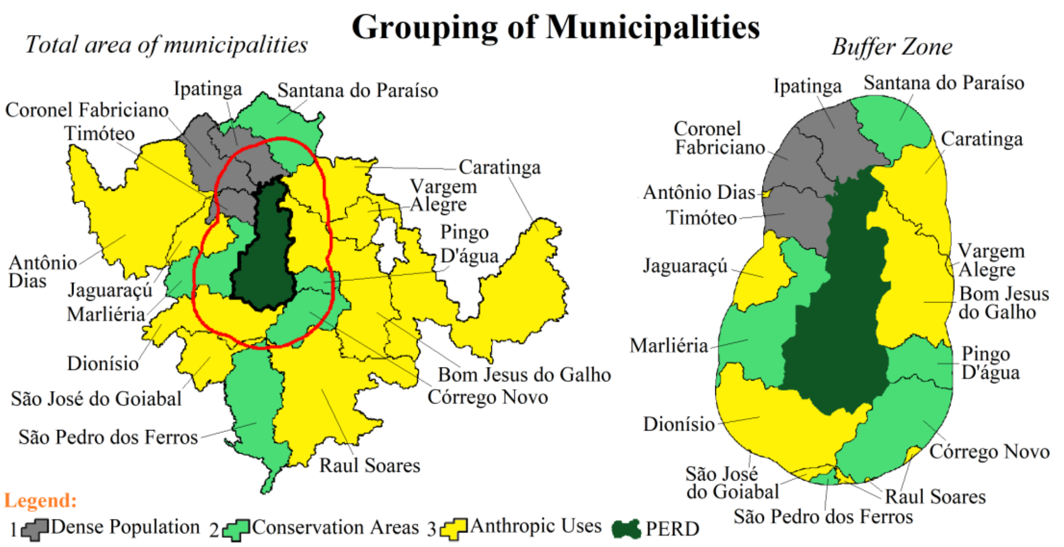


Figure 4. Clustering of municipalities in the Rio Doce State Park/MG and its buffer zone.

In *Group 1* were clustered municipalities whose socio-economic characteristics were mainly of urban centers (high population's density – Ipatinga, Coronel Fabriciano and Timóteo) and where the principal sectors of economy are industry and services. In *Group 2* were clustered those municipalities whose socio-economies were of remote rural areas with land uses more associated with conservation (Santana do Paraíso, Marliéria, Pingo D'água, Córrego Novo and São Pedro dos Ferros). Finally, *Group 3* is composed of municipalities (Antônio Dias, Jaguaraçu, Dionísio, São José do Goiabal, Caratinga, Vargem Alegre, Bom Jesus do Galho and Raul Soares) with rural economies focusing on intensive forestry and agriculture.

These three major clusters can therefore be associated with urbanization, conservation or land use intensification, respectively. We also note that populations have been increasing in all clusters with the lowest population density in the intensive land use cluster. Despite not having a growing economy (because it depends almost exclusively on the handling and production of local forestry and the company ArcelorMittal has closed) *Group 2* holds the highest human development index, because it has good schools and a lot of investment in education (**Figure 5 -** IBGE, 2015).

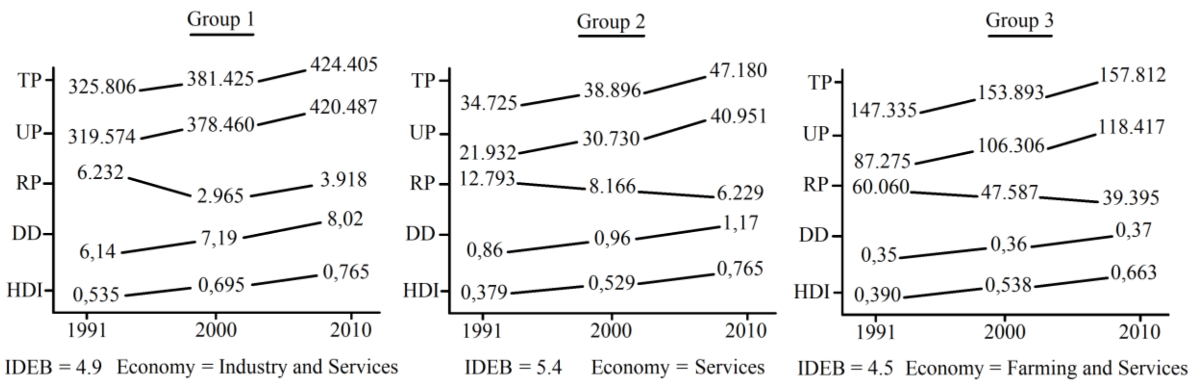
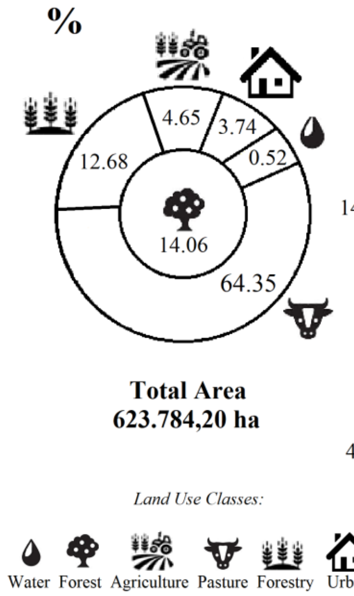


Figure 5. Social metrics – IBGE, 2015. Legend: TP = Total Population, UP = Urban Population, RP = Rural Population, DD = Demographic Density, HDI = Human Development Index, IDEB = Basic Education Development Index and Sectors of the economy highlighted.

3.2 A snapshot at the total area of municipalities (year 2013)

An analysis of the land uses of the total area of the municipalities (regional scale) is represented in **Figures 6 and 7**. Native *Forest* and *Water* occupy an area of 79.426,35 ha (14.06%) and 2.976,28 ha (0.52%), respectively. Of the human use classes, *Pasture* occupies the largest area, in total 410.448,52 ha (64.35%); *Forestry* is also representative in the region, with a total area of 82.537,81 ha (12.68%); *Urban* with 23.038,71 ha (3.74%) and *Agriculture* with a total area of 25.356,53 ha (4.65%).



Group 1 53.051,70 ha	CA	MN	LPI	%
Water	25,04	25,04	25,04	0.04
Urban	15.330,80	2.190,11	5.799,98	28.90
Forest	6.211,67	100,18	4.637,35	11.71
Agriculture	366,15	17,43	25,00	0.69
Pasture	14.230,72	153,01	5.194,71	26.82
Forestry	16.887,32	1.196,97	13.405,28	31.84

Group 2 149.657,40 ha	CA	MN	LPI	%
Water	1.624,47	81,22	434,71	1.08
Urban	1.518,39	138,03	698,05	1.01
Forest	36.990,15	132,58	27.604,75	24.72
Agriculture	5.136,05	65,01	1.195,98	3.43
Pasture	86.135,68	435,02	31.080,45	57.56
Forestry	18.252,66	180,95	4.832,51	12.20

Group 3 421.075,10 ha	CA	MN	LPI	%
Water	1.326,77	73,70	304,45	0.31
Urban	6.189,52	150,96	2.471,38	1.47
Forest	36.224,53	38,05	986,37	8.60
Agriculture	19.854,33	35,77	549,36	4.71
Pasture	310.082,12	701,56	62.958,68	73.65
Forestry	47.397,83	262,65	14.955,78	11.26

Figure 6. Percentage of each land use class (total areas and by groups) and representation of the Total Land Cover Areas (CA), Mean Areas (MN) and Largest Patch Index (LPI) by groups (sum of each land use of the three groups = total area of each land use) for the municipalities total area (year 2013).

As can be seen (**Figures 6 and 7**), while *Group 1* has a large urban area, *Group 2* has a larger forest area and *Group 3* has a greater presence of human based uses.

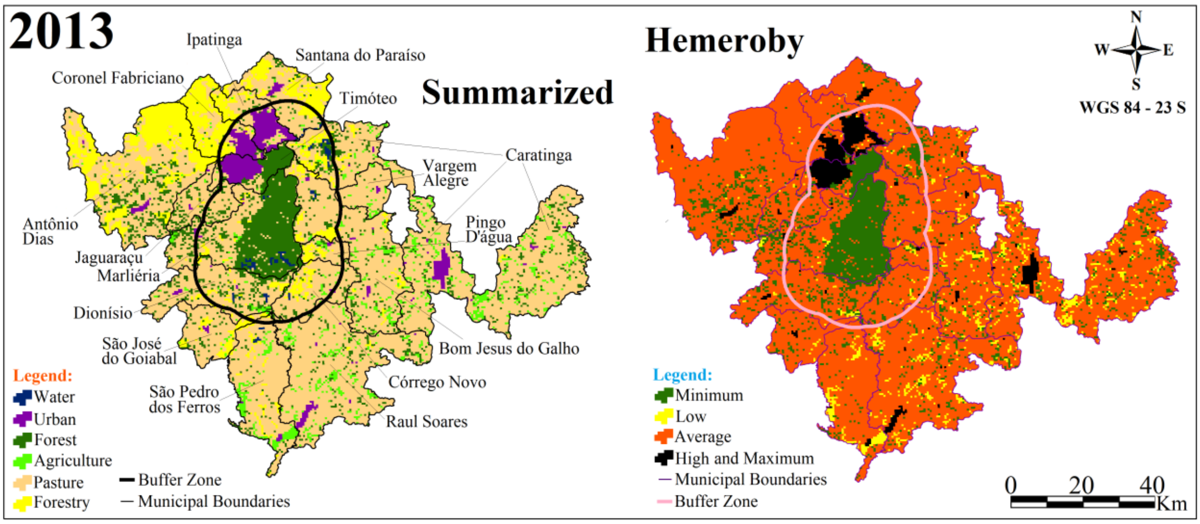


Figure 7. Summarized land uses and Hemeroby Index of the total area of municipalities with identification of PERD and buffer zone for the year 2013.

As shown in **Figures 6 and 7**, the anthropic altered level of the study area is high (85.42%) with predominance of *Pasture*. *Pasture* is one of the land uses that is highly associated to deforestation (Schielein and Börner, 2018). *Forestry* is also abundant in the region (12.68%), mainly in the northern region of the study area in Coronel Fabriciano and Ipatinga (predominantly urban), Antônio Dias (intensive land use) and Santana do Paraíso (conservation cluster). In these areas eucalyptus is the dominant biome which in turn raises multiple pressures in the region.

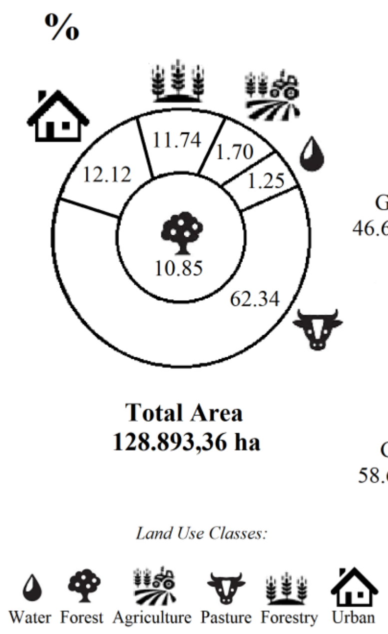
Agriculture, despite occupying 4.65% of the whole area, holds the smaller patches in the 3 clusters (mean area of 17,43 ha, 65,01 ha and 35,77 ha, respectively). This is abundant in São Pedro dos Ferros, that produces sugarcane to be processed locally (sugar refinery). Sugarcane is one of the crops that has growing steadily in Brazil due to its increasing land use rent, but creates well known environmental problems such as fire. The bigger urban areas are known as steel valley because they host important metal industries.

Using this 25 ha pixel we see a reduced number of patches of native *Forest* that are mainly located inside protected areas such Rio Doce State Park (PERD), environmental protection areas (APAs) and RPPNs (notably the reserve Feliciano Miguel Abdala in Caratinga). Outside protected areas the patches of native forests are very small (the majority only 1 pixel).

Altogether this makes the Hemeroby Index (**Figure 7**) vary from *Average* to *High* and *Maximum* as land covers mapped were of *Pasture*, *Forestry* and *Urban*. When using this data set the overall picture is alarming from a biodiversity viewpoint due its proximity with PERD, the biggest remnant of Atlantic forests in the Minas Gerais state. The combined effect of both growing urbanization pressures and land use intensification raises serious concerns over the integrity of biodiversity and the provision of ecosystem services. Similar results of human induced pressures into buffer zones of parks were found in other Brazilian states such as Mato Grosso (São Félix do Araguaia), São Paulo (Rio Mogi-Guaçu catchments) and Rio Grande do Sul (Rio Pardo Catchement) (Dos Santos, 2011; Fushita, 2011; Marques, 2012).

3.3 A snapshot at the buffer zone (reference year 2013)

Following the same pattern as described for the total area of the 16 municipalities, in the 10 km PERD buffer zone (**Figure 8**).



Group 1 23.616,93 ha	CA	MN	LPI	%
Water	25,04	25,04	25,04	0.10
Urban	15.089,83	5.029,94	14.737,22	63.91
Forest	1.063,52	29,54	141,47	4.50
Agriculture	172,96	21,62	24,99	0.73
Pasture	5.882,28	125,15	2.361,22	24.91
Forestry	1.383,30	197,37	1.232,71	5.85

Group 2 46.611,98 ha	CA	MN	LPI	%
Water	269,54	38,50	76,67	0.58
Urban	365,12	60,85	117,34	0.78
Forest	4.833,37	33,18	349,91	10.37
Agriculture	991,93	30,05	124,99	2.13
Pasture	34.222,45	543,21	30.259,96	73.42
Forestry	5.929,57	179,68	1.164,59	12.72

Group 3 58.664,45 ha	CA	MN	LPI	%
Water	1.321,74	73,43	304,45	2.25
Urban	175,22	29,20	100,00	0.30
Forest	8.089,64	44,85	560,20	13.79
Agriculture	1.027,78	31,14	254,29	1.75
Pasture	40.247,14	638,84	38.236,43	68.61
Forestry	7.802,93	195,07	1.378,21	13.30

Figure 8. Percentage of each land use class (total areas and by groups) and representation of the Total Land Cover Areas (CA), Mean Areas (MN) and Largest Patch Index (LPI) by groups (sum of each land use of the three groups = total area of each land use) for the PERD buffer zone (total area of municipalities clip - year 2013).

Pasture still occupies the largest area, in total 80.351,87 ha (62.34%); *Forestry* occupies 15.115,80 ha (11.74%), *Urban* occupies 15.630,17 ha (12.12%) and *Agriculture* occupies 2.192,67 ha (1.70%). *Forest* and *Water* occupy only 13.986,53 ha (10.85%) and 1.616,32 ha (1.25%) respectively (**Figures 8 and 9**).

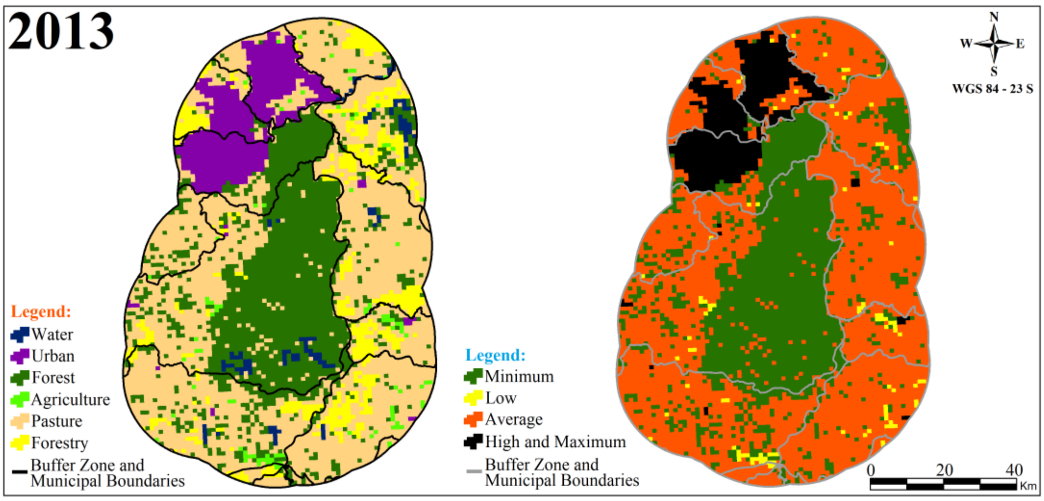


Figure 9. Summarized land uses and Hemeroby Index of the PERD buffer zone (total area of municipalities clip - year 2013).

This result shows that using the same dataset of 25 ha pixel (500x500 meters), even in the areas closest to the park, there are high level of anthropic altered land uses with *Pasture*, *Forestry* and *Urban* representing 86.2% of the 10 km buffer zone of the park.

3.4 Landscape dynamics over a 30 year period inside PERD (1985-2015)

From 1985 to 2000, PERD had 1.225,38 ha (3.40%) of anthropic altered areas, represented by *Urban* and *Bare Soil*. From 2000 to 2015 anthropic altered uses decreased to 244,62 ha (0.67%), where *Urban* slightly grew and *Bare Soil* has been reduced (compared to 1985 – **Figures 10 and 11**).

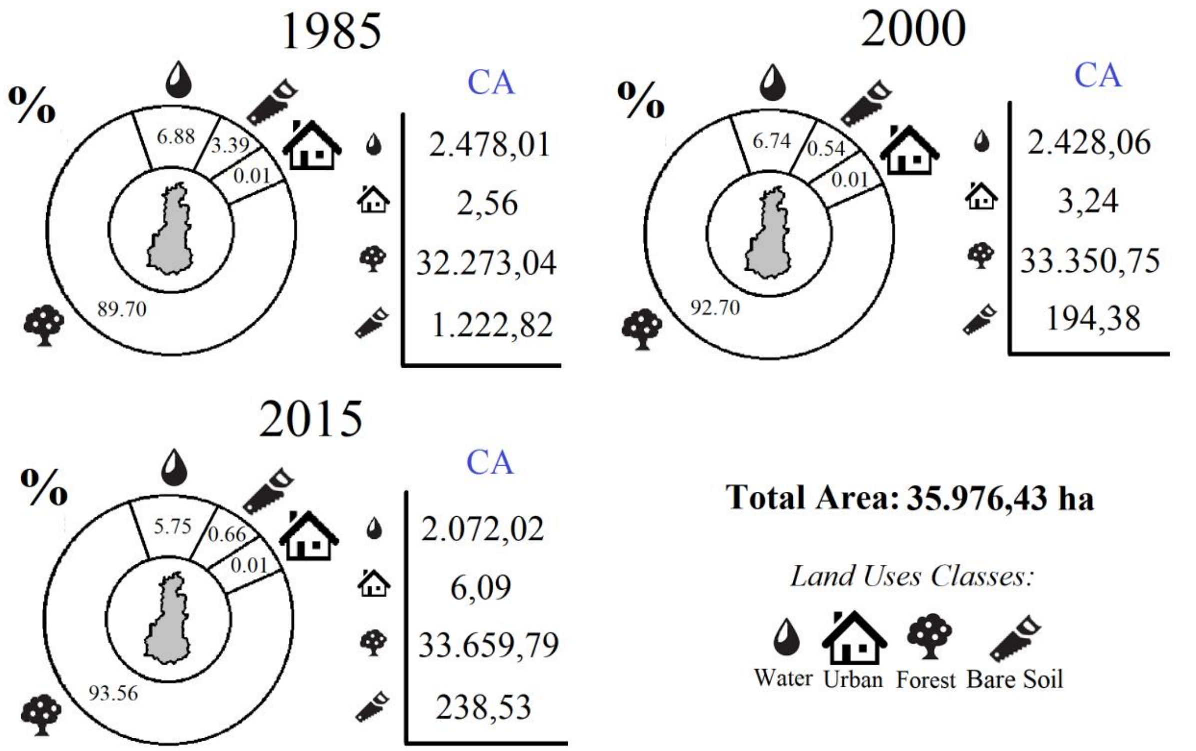


Figure 10. Percentage of each land use class (total area) and representation of the Total Land Cover Areas (CA) for the PERD.

Native *Forest* areas slightly increased from 32.273,04 ha (89.70%) in 1985 to 33.659,79 ha (93.56%) in 2015. The *Water* class decreased (it is believed that due to climatic reasons) from 2.478,01 ha (6.88%) in 1985 to 2.072,02 ha (5.75%) in 2015 (**Figures 10 and 11**).

These land use transitions from *Bare Soil* to native *Forest* likely reflect the successional regrowth of native *Forest*. The increase in urban areas can be explained by the creation of infrastructures of the park to receive tourists, administrative areas and research buildings and labs (IEF, 2002b).

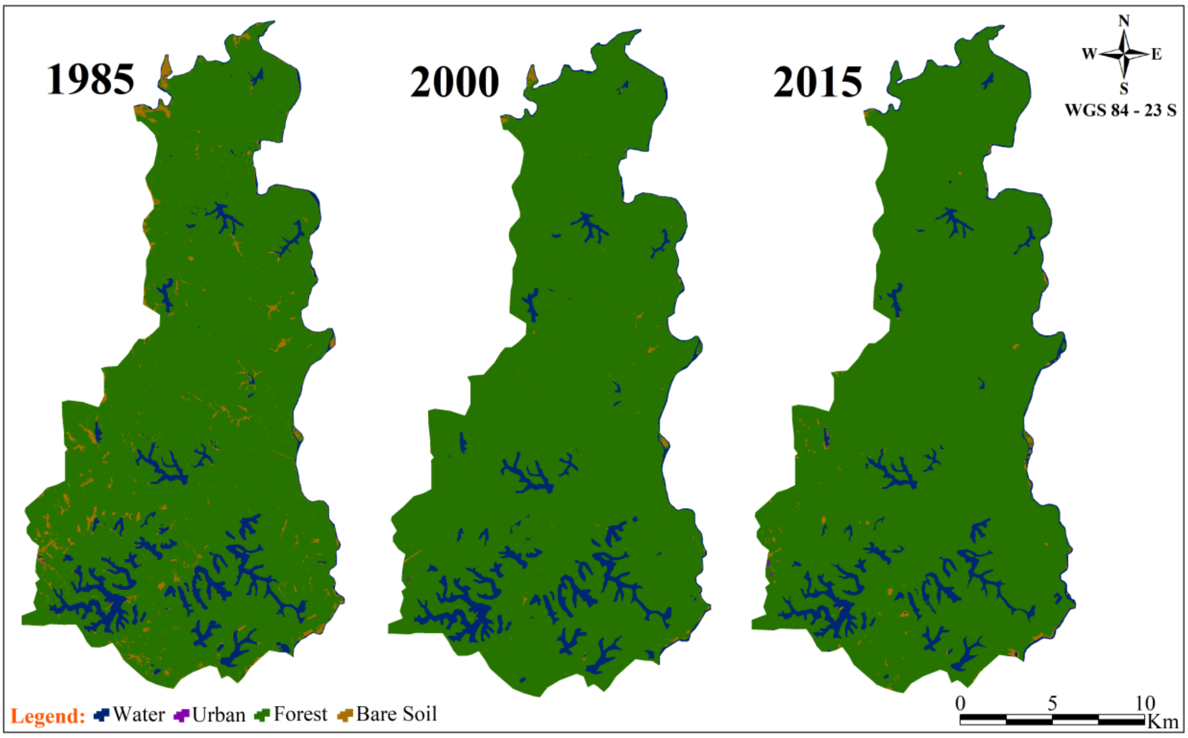


Figure 11. Land uses classes of the PERD identified for the years 1985, 2000 and 2015 by classification of the LANDSAT-5/7/8 images.

In 2010, PERD was classified as a RAMSAR site (IEF, 2017) due to its lakes and riverine systems of very important conservation value. Nevertheless, as our study shows, the water bodies inside the park are decreasing. This trend was also noticed in other studies in the study area (Maillard et al., 2012).

3.5 Landscape dynamics within the 10 km Buffer Zone over a 30 year period (1985-2015)

Land use dynamics over the 30 year period in the 10 km of PERD buffer zone are shown in the **Figures 12, 13, 14 and 15**. Native *Forest* ranged from 40.588,48 ha (31.50%), 60.312,40 ha (46.40%) to 45.690,38 ha (35.46%), in 1985, 2000 and 2015, respectively. *Water* occupied 4.559,77 ha (3.53%) in 1985, 5.543,58 ha (4.30%) in 2000 and 5.552,99 ha (4.31%) in 2015 (**Supplementary Figure S1**).

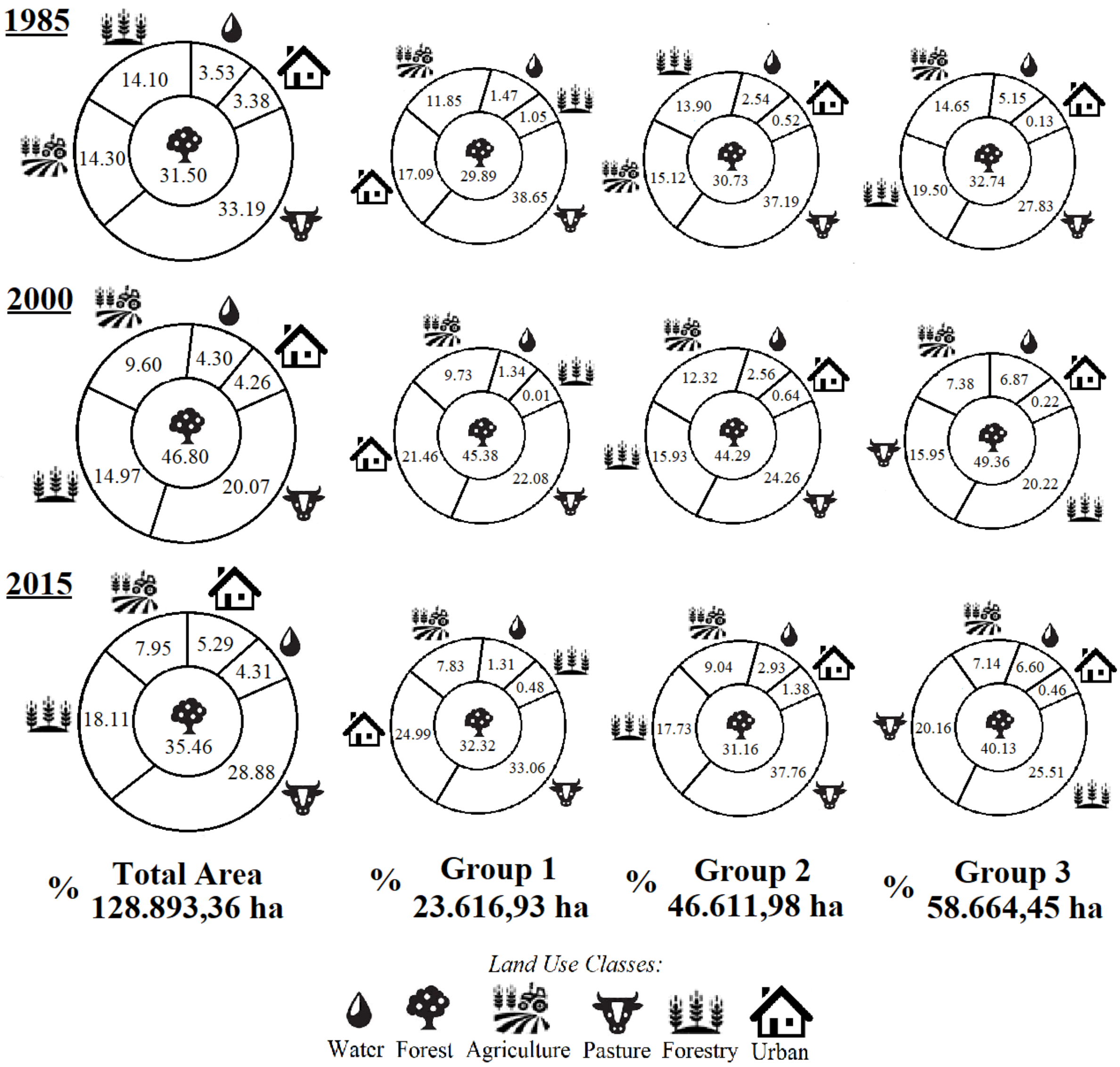


Figure 12. Representation of total areas in percentage of each land use class in the 3 groups of municipalities of the PERD buffer zone for the years 1985, 2000 and 2015.

From the anthropic altered land uses, both urban and forestry grew over the 30 year period. *Urban* grew from 4.360,80 ha (3.38%) in 1985 to 6.817,71 ha (5.29%) in 2015 while *Forestry* grew from 18.164,79 ha (14.10%) in 1985 to 23.345,21 ha (18.11%) in 2015. *Agriculture* decreased occupying 18.439,17 ha (14.30%) of the area in 1985 to 10.252,53 ha (7.95%) in 2015. *Pasture* also decreased from 42.780,35 ha (33.19%) in 1985 to 37.234,54 ha (28.88%) in 2015.

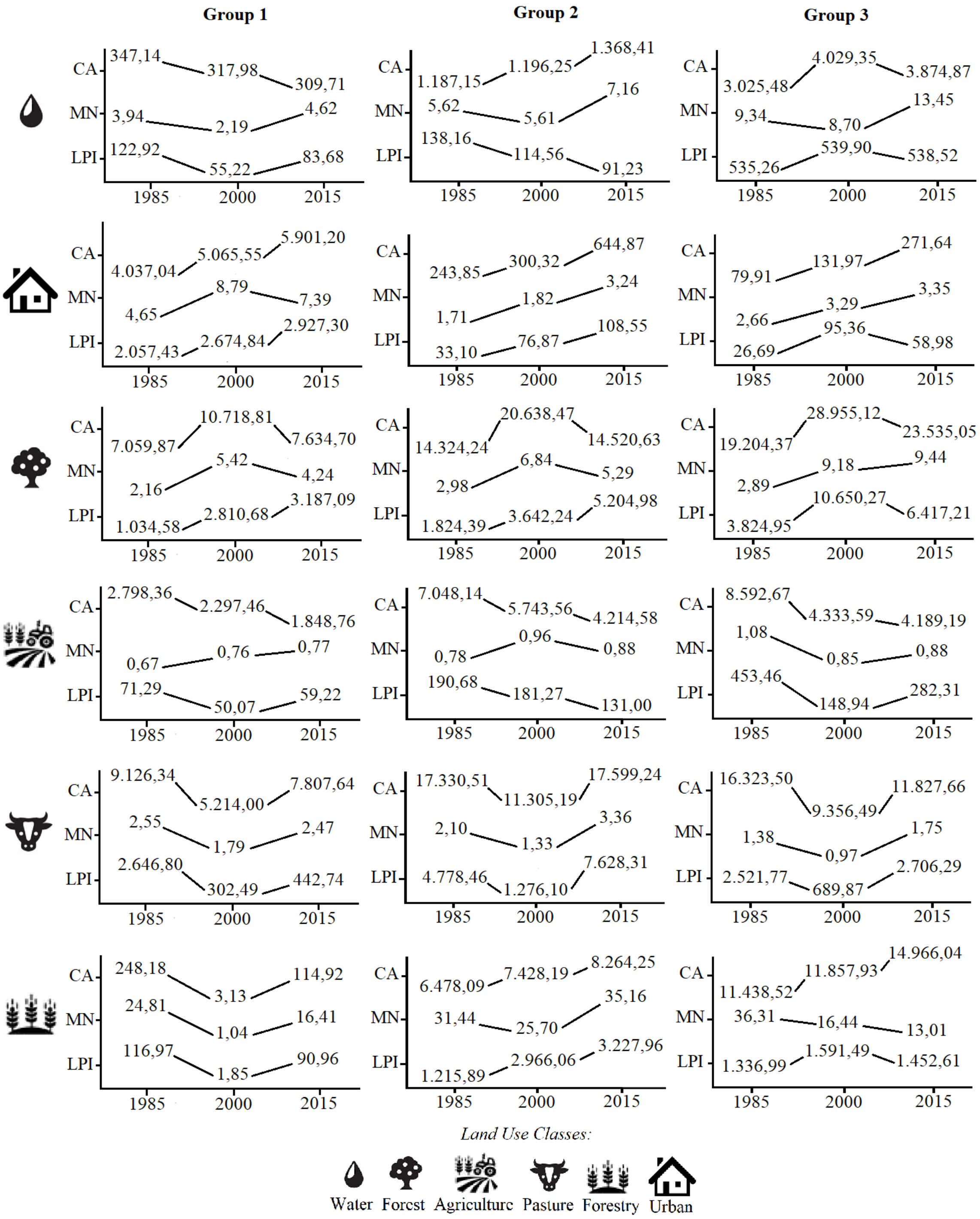


Figure 13. Total Land Class Areas (CA), Mean Areas (MN) and Largest Patch Index (LPI) of each class in the 3 groups of municipalities (sum of each land use of the three groups = total area of each land use) of the PERD buffer zone for the years 1985, 2000 and 2015.

In the PERD buffer zone native *Forest* grew in the three clusters of municipalities, altogether with a slight decrease of *Pasture* in the year 2015. This is reassuring for the conservation efforts already in place. On the other hand *Forestry* increased over the period, while *Agriculture*, particularly family farming, decreased.

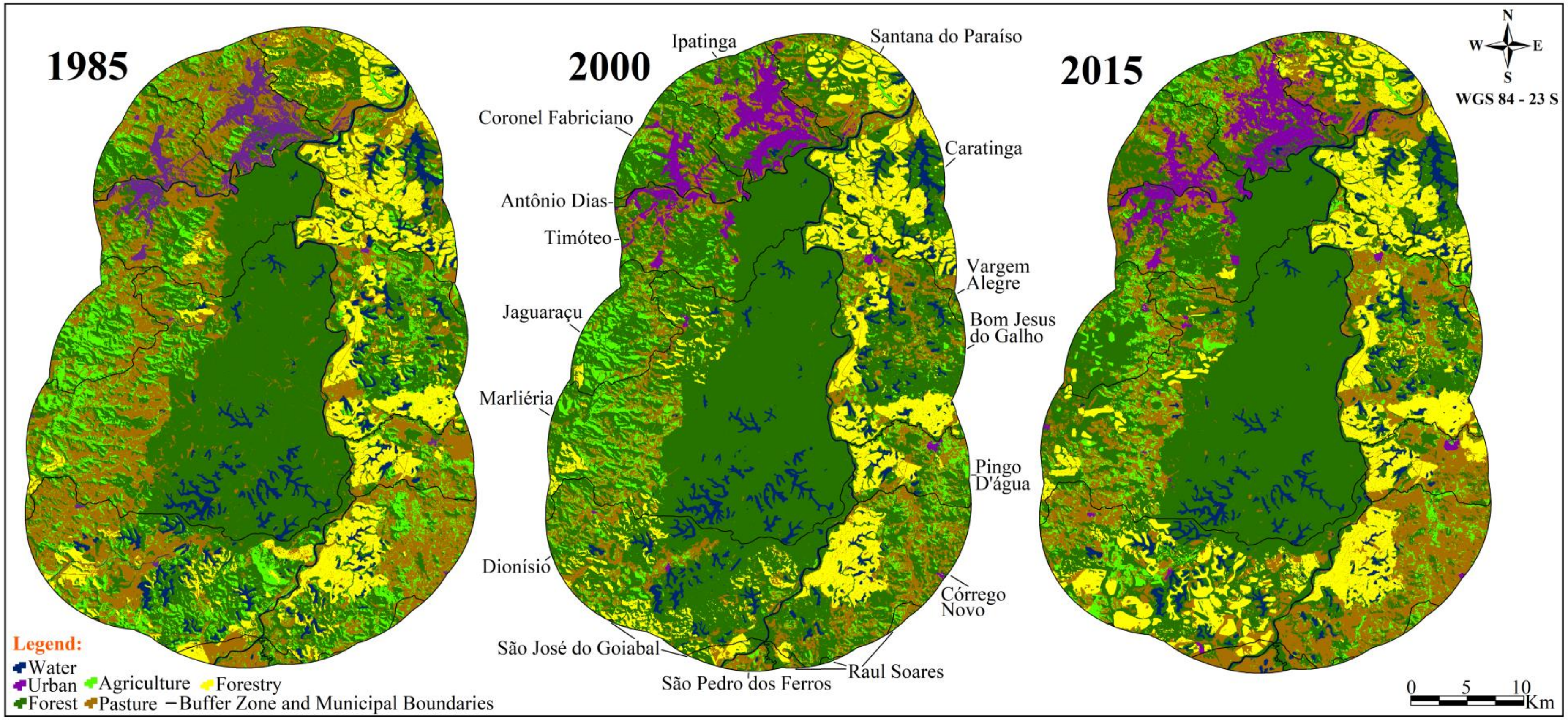


Figure 14. Land uses classes of the PERD buffer zone identified for the years 1985, 2000 and 2015 by classification of the LANDSAT-5/7/8 images, according to the municipal boundaries.

We can also highlight the presence of two Environmental Preservation Areas (EPA): Jaguaraçu, created in 1998 and Jacroá in 2001, located respectively in the western part of the PERD in the municipalities of Jaguaraçu and Marliéria. Therefore, the reason for the growth of the Forest areas from 2000 to 2015 in these places, since these areas are dedicated to preservation and conservation of wildlife (APA do Jacroá, 2008; APA Jaguaraçu, 2008).

As for the *Water* and water bodies, our results show a slight increase of the water bodies in *Group 2*. Despite the growing trends for urban land uses, which demand higher water consumption, as well as water shortages in latter in the year 2015, our results reports the drop in groups *1* and *3*, more urban and more anthropic. These slight variations across the period also can be associated to fluctuations in the rainfall of the region and to the quality of the images. The river and lakes borders from the LANDSAT in the 80s were much more difficult to classify whereas the most recent LANDSAT images from 2000 and 2015 made river and lake borders easier to classify.

For the anthropic altered uses, *Agriculture* has reduced in size being replaced by eucalyptus monoculture (*Forestry*), because it generates a higher income and is easier to manage. However, its introduction causes the rapid advances in soil degradation and deteriorating regional conservation (Vital, 2007; Mosca, 2008; Rezende, et al., 2013). In the buffer zone, in addition to eucalyptus, another monoculture, the sugar cane, is also extensively expanding. In sugar cane management fire is used during its cut. This can generate fires in buffer zones, with adverse consequences for biodiversity (Aguiar et al., 2009; Aguiar & Souza, 2014).

Pasture covers extensive areas in the total area of municipalities and in the PERD buffer zone. *Forest* initially increased in size from 1985 to 2000, but in the last fifteen years this has reduced. A soil that has been used as *Pasture* for a long time becomes difficult for the growth of crops or for reforestation because it becomes exposed and degraded, thus losing its native flora (Dias-Filho, 2014; Macedo & Zimmer, 2018).

Analyzing the entire anthropic altered uses (**Figure 15** – Hemeroby Index), the *Forestry* stands out as the most damaging for conservation. The land use of *Forestry* has gradually increased over the 30 years of study, replacing *Agriculture* and *Pasture* often in conjunction with sugar cane (Guilardi & Ronquim, 2015). Because of the high demand for eucalyptus, planting of eucalyptus is possible on poor soil without large costs, and can be introduced together with cattle breeding (EMBRAPA, 2004). Sometimes eucalyptus are planted near the native Forest and gradually occupy their spaces, as already mentioned in our various study sites, which is of concern to local conservation (Viana, 2004; Carriello & Vicens, 2011; Wicke et al., 2014).

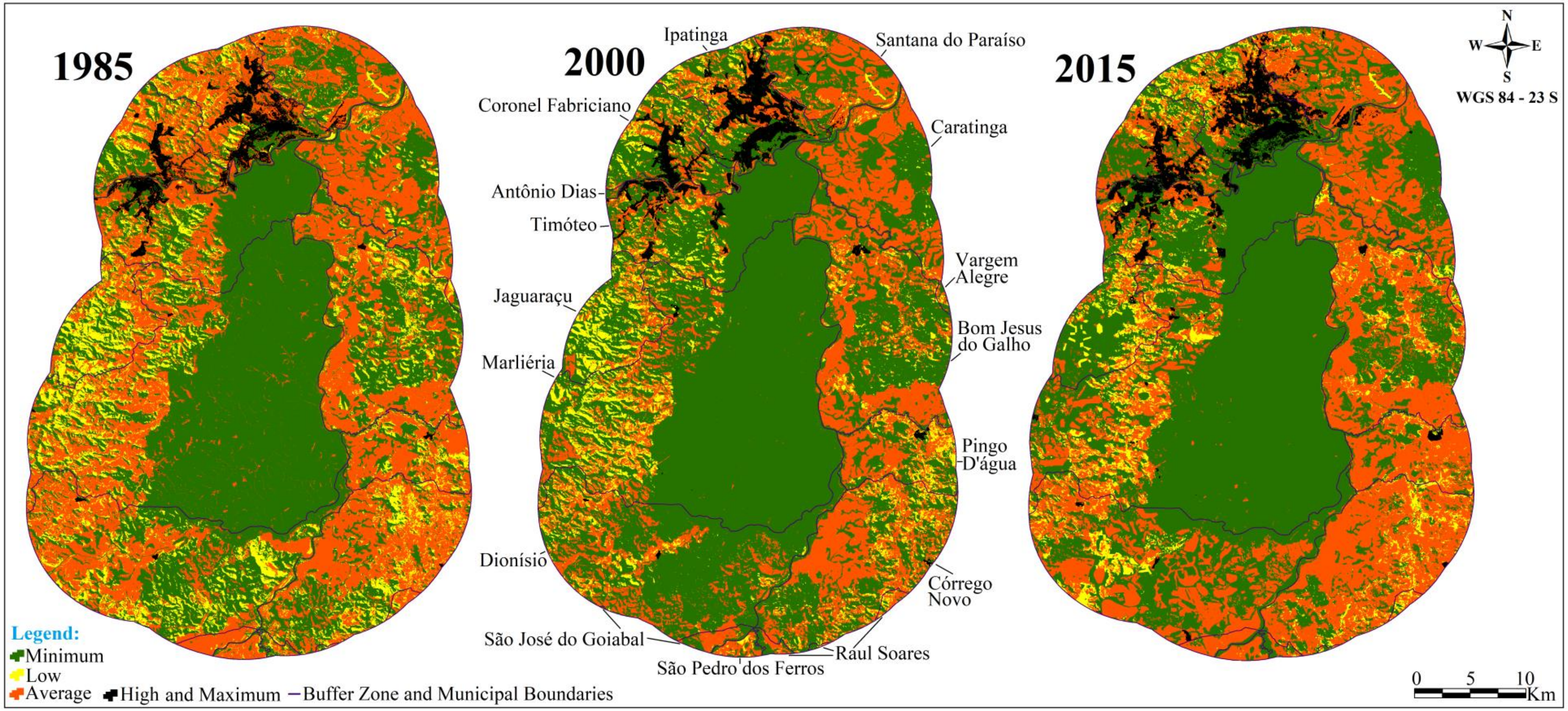


Figure 15. Hemeroby Index of the PERD buffer zone identified for the years 1985, 2000 and 2015 by classification of the LANDSAT-5/7/8 images, according to the municipal boundaries.

Urban areas are also very representative in the region of the valley of steel with the largest urban centers located in the PERD buffer zone. These urban centers continue to grow (global trend – Millennium Ecosystem Assessment, 2005), using areas close to the Conservation Areas and contributing to their degradation (Melo, 2001; PELD, 2018). Recent and unpublished studies showed that urban developers claimed not to know of the high conservation values in their midst. The proposal of an environmental education project in partnership with the park administration may help to enlighten this ignorance.

Our results support the findings by Molin et al. (2017), that report loss of native *Forest*, and growth of *Forestry* in tropical landscapes. Also Lira et al. (2012) reported forest fragmentation, and estimated future changes that may affect the conservation of species in this already threatened biome. This work also shows that some landscapes in the Atlantic Forest seem to be beginning to experience a process of *Forest* transition (Mather & Needle, 1998; Mather, 1992; 2004), which could be of great importance for the conservation of biodiversity, since young secondary *Forest* can contribute to the reduction of isolation between fragments and may also sustain a significant amount of biodiversity.

Analyzing the general aspect of the study, we found that the main socio-economic characteristics of the study area are urbanization, land use intensification and conservation (**Figure 4**) and a systematic variation in land uses, because of the general increase in anthropic altered uses in all three groups of municipalities regardless of their characteristics and socio-economic conditions. We therefore used the set of metrics selected by Leitão & Ahern (2002), which associate Large Patch Index (LPI), Mean Area (MN) and Class Area (CA) in the evaluation of landscape sustainability.

Our results also show that while the Hemeroby index as calculated to the 25 ha (500x500 meters) pixel size data set is *Average* to *High* and *Maximum* (**Figures 6 to 9**), a more refined pixel of 900 m² (30x30 meters) gives a very different picture showing promising patches, still connecting native *Forest* fragments. Reforestation techniques can be implemented and thus ecological corridors can be formed, contributing to the conservation of regional biodiversity (**Figures 10 to 15 and S1**).

3.5.1 Forest fragmentation of the PERD buffer zone – year 2015

For a better perspective on the current fragmentation of native *Forest* in the PERD buffer zone, a new set of landscape metrics were calculated. This data is also created to support forthcoming plans from the Park to create ecological corridors for large animals such as jaguars and tapirs in future research.

The vast majority of the patches (6.227 fragments) representing 3.84% below 2 ha is notified (calculating by Fragstats 4.2). The presence of a large number of fragments of small size is important because they represent remnants of native *Forest* that can serve as "stepping stones", that is, points of support for animal displacement. It is important to find ways to interconnect these small patches to bigger patches in order to increase connectivity.

The native forest fragments from 2 to 50 ha are totaling 5.665,40 ha (673 fragments), concentrated in the south/southeast part of the Park are the most suitable for environmental conservation proposals, because they have more round areas, less human interference and edge effects, aspects considered by several authors as appropriate for the connective purpose (Saito et al., 2016; Umeda et al., 2015; Dos Santos et al., 2016; Blumenfeld et al., 2016; Nascimento & Laurance, 2006; Oliveira et al., 2015; Penido et al., 2015).

The larger ones of 50 to 500+ ha (69 fragments) have a total area of 38.267,44 ha, representing 83.77% of the buffer zone native forest, which demonstrates the presence of larger and more conserved areas around the PERD, essential for the movement of large terrestrial animals present in the region.

In relation to fragmentation metrics (**Table 2**), the average distance between the nearest neighbor (*ENN_MN* = 95,16 meters*)* indicates high connectivity between fragments, although there is a large variation between them (*ENN_CV* = 61.68%). This connectivity levels enables the creation of ecological corridors, which may promote inter-species exchange and improve gene flow.

Table 2. Metrics on the *Forest* fragmentation of the PERD buffer zone for the year 2015.

Fragmentation Metrics	Values Obtained
ENN_MN	95,16
ENN_CV (%)	61.68%
ED	61,63
CONNECT	0,1

Legend: ENN = Euclidian Nearest Neighbor Distance, ED = Edge Density, CONNECT = Connectance Index.

On the other hand, the *Edge Density* (ED = 61,63) indicates a high possibility of alteration in the structure of the communities and in the abiotic factors (solar radiation, soil moisture, winds, nutrient concentration, etc.) determined by the formation of the *Forest* edge. This is worrying, because the near presence of a border can change the density and composition of species, and interfere in the interactions between species and selected communities (Laurance et al., 2002; Scariot et al., 2003; Geneletti, 2004; Ribeiro & Marques, 2005; Rodrigues & Nascimento, 2006; Muchailh, 2007; Vidal et al., 2007; Lang & Blaschke, 2009; Lima & Rocha, 2011).

The CONNECT (Connectance Index) computed the connectivity of the fragments using a limit distance of 60m, which represents low insulation, a viable distance for the movement of local terrestrial fauna without much human interference (Almeida, 2008; Da Silva & Souza, 2014). The resulting value was very close to zero (0,1), which means a high rate of connectivity between *Forest* fragments to facilitate the movements of the local fauna.

Therefore, while on the regional scale the prospects for sustainable land use around the PERD appeared to be very low, analysis at the local scale reveals the possibility of using strategies/techniques (natural or artificial stepping stones, such as perches, in addition to reforestation, etc.) to recreate the connectivity between *Forest* remnants and to reduce the edge effect. In this particular case, as the connectivity between fragments was high, the proposal of ecological corridors seems encouraging.

Our results have several implications for the wider landscapes and for the sustainability debate. Our study suggests that it is possible to identify associations between landscape metrics and characteristics of forests (Ribeiro & Lovet, 2009) and that the calculation of metrics for individual land uses and their association with human induced impacts (Hemeroby Index) can help informing policy making.

4. Conclusions

In countries such as Brazil with huge continental areas methodologies as proposed here can be of value due to its efficiencies and cost effectiveness. Nevertheless, the land use data has to be at an appropriate resolution. While our results from the 25 ha (500x500 meters) pixel size analysis revealed a very scary picture, the 900 m² analysis pixel size (30x30 meters) suggests that it may still be possible to reverse the unfavorable effects of Atlantic forests deforestation.

The data obtained in this study, besides updating the information about the buffer zone of the Park, is of fundamental importance for managers, as this will buttress the review the management plan for PERD and its surroundings. Because our analysis was conducted through a Long-Term Research Program (LTRP) it can also help to design strategies to recover fragments of forests and degraded land. This is particularly helpful for it can provide the basis of discussions with the local communities involved. Using the results of this work the updating of the park management plan can propose in situ actions to overcome fragmentation and help to achieve specific land use conservation targets (for example using landscape metric such as ENN working with communities and local governmental bodies targeting a specific connectivity value for the next 15 years).

This study conducted in PERD and the buffer zone will help environmental managers to know how land uses are changing from natural to man-made in the areas of their municipalities. Armed with this knowledge, solutions can be proposed for the improvement of these areas aiming at local environmental conservation, such as the application of techniques to recover the forest fragments and to restore degraded areas.

For the recovery of degraded areas, reforestation can be carried out with local native species, techniques attractive to the fauna, such as the use of natural perches for the passage of birds through the site and, thus, the deposition of seeds in the depleted soil. There is still a great number of seed dispersal animals such as jaguar (*Panthera onca*) and tapir (*Tapirus terrestris)* whose secure movement in and around the Park avoiding conflicts with the population and farmers, could lead to a renaissance in the future sustainable management of a World Heritage Park. We feel that we have created the basis for hope for the sustainable restoration of this very special site. But of course the fundamental hostilities of the socio-economic dynamics of land use conversion, and the weak and contradictory regulatory regimes at all levels of government must also be firmly addressed if the kind of contribution we offer here is to have any lasting traction.

In addition to all the data provided in this article, it will be fundamental for the development of the next researches, which will be the basis for future scenarios of the land uses of the buffer zone, as well as proposals to create ecological corridors aiming at environmental conservation and a fundamental aid for the updating of the management plan of the conservation unit.

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7. Appendix

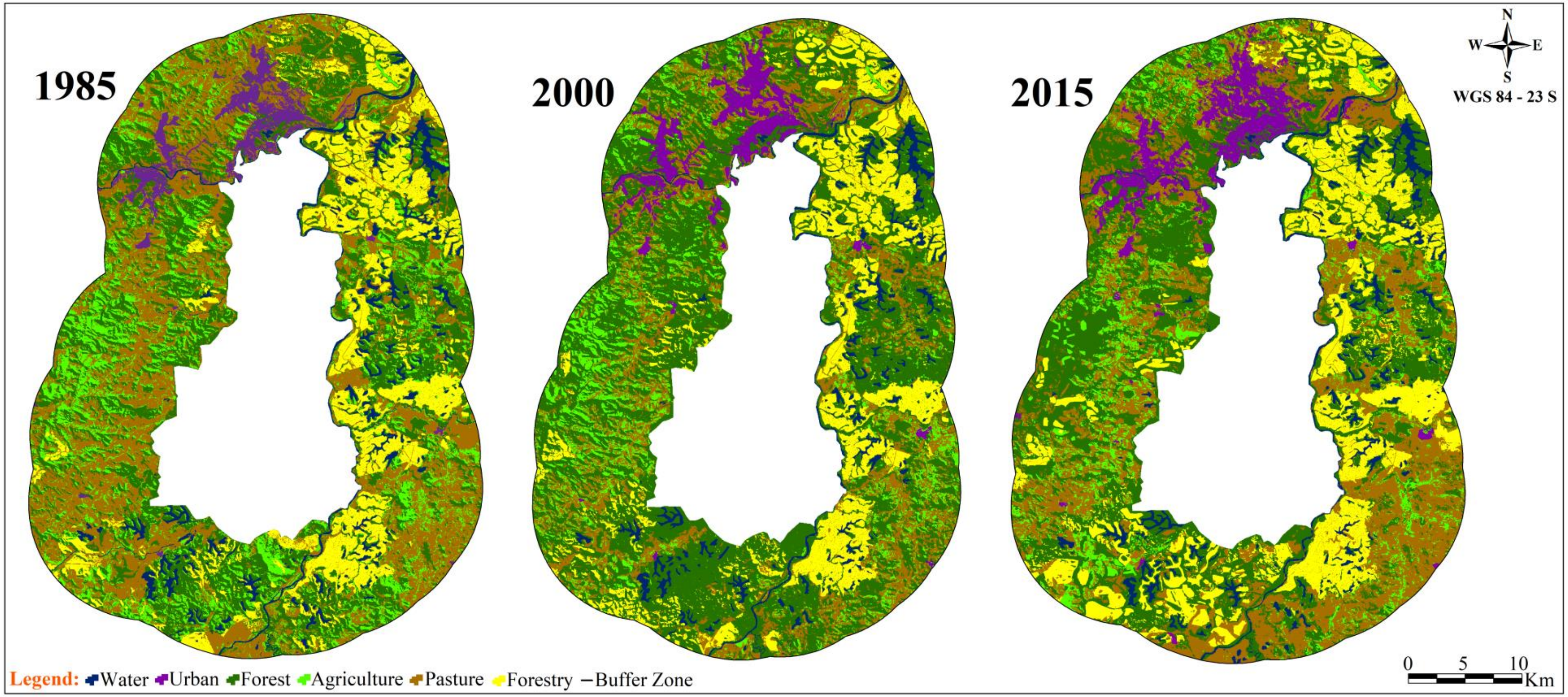

Figure S1. Land uses classes of the PERD buffer zone identified for the years 1985, 2000 and 2015 by classification of the LANDSAT-5/7/8 images.

ARTICLE 2 - RIO DOCE STATE PARK BUFFER ZONE: WHAT WILL CHANGE IN 2030?

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Abstract

The environment is dynamic and changes over time. So, it is necessary to understand the importance of landscapes that make up the environment, for a broader vision of time and space, so that it is perceived that each part of the territory has answers to environmental changes and land uses. This paper uses a multiscale approach in the Rio Doce State Park (PERD), localized in Minas Gerais, Brasil, based on a previous study of the land use evolution of the last 30 years (1985-2015) of the total area of municipalities and with greater refinement for the PERD buffer zone, preparing a future scenario for the next 15 years (2030). In order to cover a greater range of information and involvement of the community living in the study area, workshops were conducted involving the population, environmental managers and operating companies, as well as the PERD itself. With this in mind, it was sought to generate a greater involvement among all the categories, showing how it could be in the future, in contrast to interactions and dialogues with the preparation of a proposal planning of all involved to define how everyone can help so that the environmental directions for the future can be positive.

Keywords: landscape ecology; environmental management; future predictions; surrounding communities; Rio Doce State Park.

1. Introduction

The environment is dynamic and as a whole changes over time. Santos (2007) emphasizes that the history of the planet is constituted by constant transformations, which show a succession of states that are changing a landscape. At the present time, it is perceived that the environmental issue is on the rise. There is much talk about this subject, the search for sustainable development, which does not only take into account economic and social aspects, but also preservation of the environment.

Ecosystems provide a large number of services for the benefit of humankind (Costanza & Daly, 1992; De Groot et al., 2002; Liu et al., 2009). Such ecosystem services secure our foundations of life and ensure its quality, by providing food, the basis for tourism and culture, or protection against soil erosion (Millennium Ecosystem Assessment, 2005). However our landscapes are being transformed ever more quickly (Antrop, 2005; Haase et al., 2007). The reasons for this include the overuse of non-renewable energy sources, intensification of agriculture, demographic changes, the urban expansion and highways.

The definition of sustainable development presented in the Bruntland Commission report included the maintenance of economic growth and progress and the protection of the environment for the use of future generations (United Nations General Assembly, 1987, p.43). Therefore, sustainable development can only be achieved if we consider economic, social and environmental aspects during decision-making processes. However, in the process of development of humanity, part of the natural areas were transformed into urban centers and planting areas, both growing steadily. This replacement of the natural elements by human enterprises results in the degradation of the environment (Lenzi, 2006).

Urbanization has profoundly changed land use around the globe (Yue et al., 2003; Kamusoko et al., 2009). Notable landscape fragmentation and decreased ecosystem stability have become common as various anthropic elements and structures have been created in original ecological landscapes (Su et al., 2013; Zhou et al., 2014). As a result, many ecological and environmental problems have worsened, such as global climate change (Kalnay & Cai, 2003), urban flooding (Huong & Pathirana, 2013), surface water pollution (Ren et al., 2003).

Therefore, it is important to determine the effects of urban land use change on ecosystems and quantify the relationships between urban land dynamics and ecological security. This knowledge can improve urban planning and policy making for sustainable urban development (Solovjova, 1999; Cen et al., 2015). Ecological security was first proposed by the government of the United States (Ezeonu & Ezeonu, 2000) and it included natural, economic, and socio-ecological security, as well as human well-being (Costanza et al., 1992; Carr Edward, 2002).

Knowledge of the mosaic of landscapes that make up the environment is necessary so that one can understand, and even predict, how each part will respond to environmental and land-use changes. This will help in the planning, application and development of technologies that contribute to the environmental preservation of the changes promoted by human activities.

One of the tools that has been used in research of this nature is the Geographic Information Systems (GIS) that can help in the identification of negative environmental impacts in protected areas (Lang & Blaschke, 2009). The use of models allows the simulation of different scenarios around the Conservation Units, which may help in the planning and definition of public policies in areas with greater pressure on natural resources.

On the base of scenarios, it is possible to identify what these developments will be like for certain ecosystem services, and how humankind can intervene in a directive manner! (Carpenter et al., 2006; TEEB, 2009; Rosenberg et al., 2014). The scenario technique could function as a bridge concept for interdisciplinary work in research of the human-environment relationship (Santelmann et al., 2004) and is considered an approach to addressing the question of sustainability (Walz et al., 2007), since the assessment of intergenerational justice requires a plausible view into the future, involving, among other things, an investigation of long-term developments.

Scenarios are defined as simplified descriptions of what may occur in the future in the areas analyzed, based on a set of assumptions on the key driving forces and changes (Millennium Ecosystem Assessment, 2005). Alcamo (2008) states: "A scenario is a description of what the future will look like on the basis of if-then statements, and is typically based on a representation of the initial situation and the description of key driving forces and changes, which will lead toward a certain future condition." Or, to put it more simply: "Scenarios are hypothetical results of events which are designed to highlight the consequences of certain decisions" (Rotmans et al., 2000).

The main goal of this study is predict for the next 15 years, scenarios of possible changes in the PERD buffer zone through a dynamic landscape analysis and using a multiscale approach in the total area of the municipalities around the PERD and its buffer zone. This paper provides an analysis of the landscape dynamics thus can be an important tool for monitoring landscape changes in the future and will be made available to environmental managers, population and researchers of the whole regional area for the knowledge and better application of proposals for a better environmental conservation.

2. Case study and Methods

2.1 Study Area

The Rio Doce State Park (35.976 ha - IEF, 1994; 2002) is located in the eastern region of the Minas Gerais State **(Figure 1 – Total area of municipalities and Buffer Zone)**, and represents the largest continuous surface of preserved Atlantic Forest (Ribeiro et al., 2009). It is therefore considered one of the most important areas for biodiversity (Myers et al., 2000). The Park is the third largest lake system in Brazil (behind the Amazonian and Pantanal basins). Its water system consists of about 50 lakes (6% of its area). The northwest boundary is naturally made by the Piracicaba river and the east by the Doce river (**Figure 1 - PERD**).

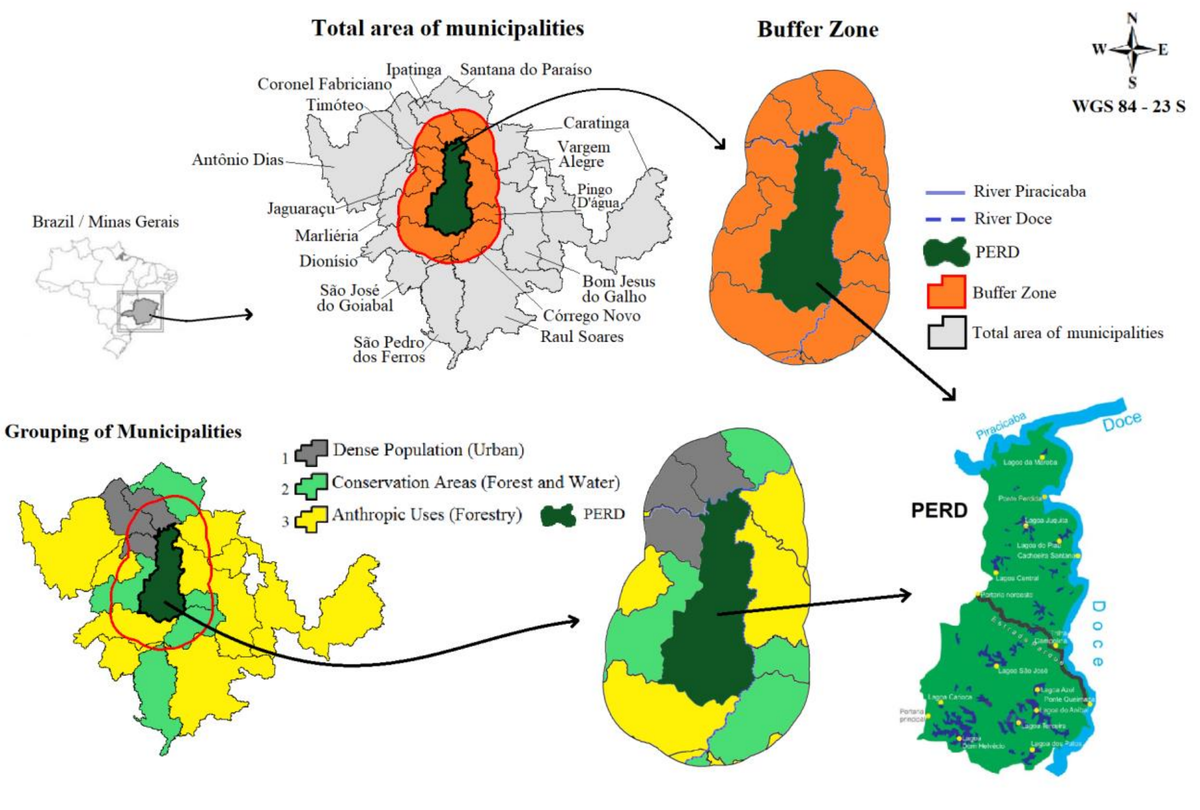


Figure 1. Location of the study area of the Rio Doce State Park/MG, its buffer zone and municipalities that cover its territorial areas, highlighting the 3 groups of municipalities (figure based on data from previous study by Oliveira et al., 2019).

According to Oliveira et al., 2019, the Park borders with urban centers, agropastoral areas and extensive eucalyptus plantations, mainly to the east and south. In general, most of the water bodies that make up the lake system have suffered some kind of impact, either by using water or by modifying the landscape. Lakes preserved are located inside the park only while those in their buffer zone suffer direct anthropic impacts (Oliveira et al., 2019).

Our study comprised a multi-scale analysis of the total area of the 16 municipalities surrounding the Park with 623.784,20 ha and the PERD buffer zone with 128.893,36 ha (**Figure 1- Total area of municipalities and Buffer Zone**).

The municipalities were grouped according to their characteristics: *Group 1* - Dense Population (3 municipalities), *Group 2* - Most Conserved (5 municipalities) and *Group 3* - More Anthropized (8 municipalities) (**Figure 1 - Grouping of Municipalities**). According to statistics from the Brazilian Institute of Geography and Statistics (IBGE, 2015), the four main municipalities hold in 2015, a total of approximately 485.584 inhabitants.

2.2 Methodology

The study was divided in two stages, Total area of the 16 municipalities and PERD Buffer Zone (**Figure 2**) as follows: The first step was to group the maps already made by the authors themselves, referring to the same area of study, the evolution of the landscape from 1985 to 2015 (30 years before) to the Rio Doce State Park and its buffer zone and for the year 2013 with representation of the total area of the 16 municipalities that are part of the PERD buffer zone (Oliveira et al., 2019).

This step was analyzed the land cover, represented by the Anthropic and Natural classes. For the "Anthropic class" four types of land use were identified: Urban, Agriculture, Pasture and Forestry. For the "Natural class" were considered the Forest and Water.

In sequence, in the second step was elaborated for the PERD buffer zone a scenario prediction of land use and metrics for the year 2030, in order to allow an analysis and comparison with a study for the same year 2030, of the total area of the 16 municipalities, carried out by the Remote Sensing Center of UFMG (Soares-Filho et al., 2016).

The Dinamica EGO software (CSR/UFMG, 2018) was used and for the interpolation of the future scenarios the following data: total land uses (1985-2000-2015), areas of forest (previous data and shapes of local business areas), pasture and bare soil, agriculture, forestry (including the shapes of Cenibra and Arcelor Mittal), urban, rivers, lakes (also islands and bodies of water), highways, railways, unpaved roads, urban areas, districts, landing areas, land maps, relief, weather and APPs.

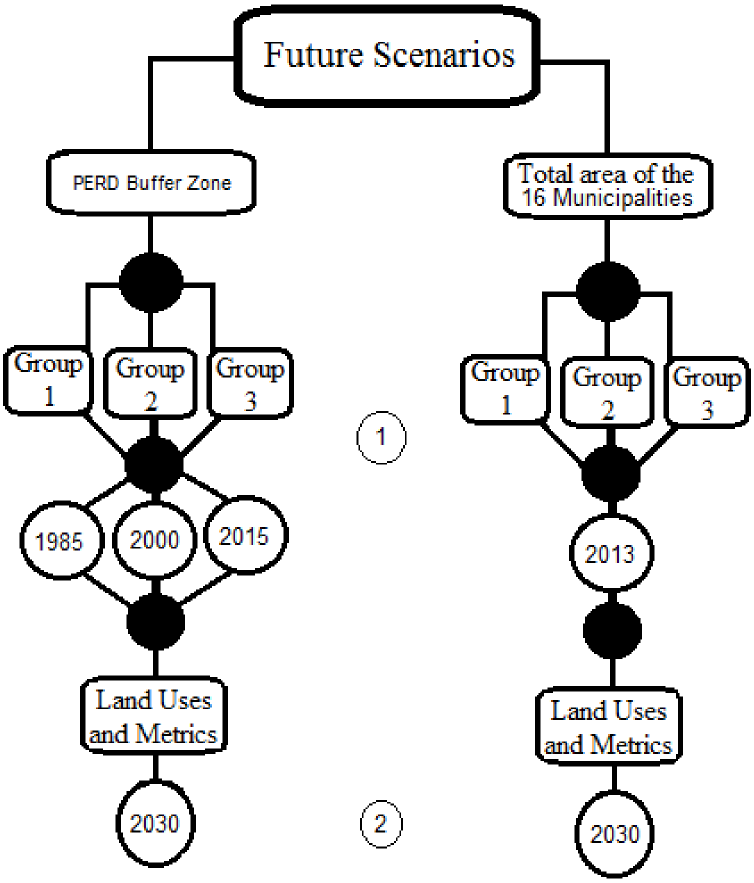


Figure 2. Flowchart of the methodological steps of study.

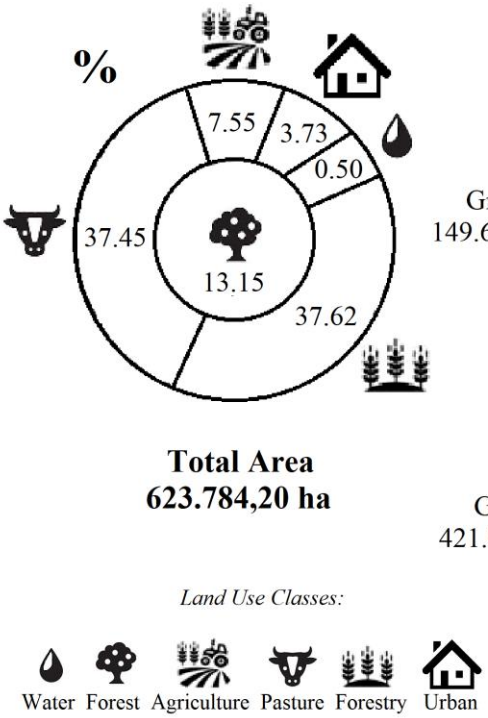
All the material produced will be made available to the manager of PERD as a subsidy for analysis and development of proposals that aim at effective action in the conservation of regional biodiversity. Based on these thematic maps, will be discussed (workshops) how new directions can be taken in the face of environmental conservation and the anthropic environments that are present in the region of the buffer zone.

3. Results and Discussions

3.1 A snapshot at the total area of municipalities (year 2030)

An analysis of the land uses of the total area of the municipalities is represented for the year 2030 the in **Figures 3 and 4**, where they are presented their percentages of territorial areas (total areas and by groups), cover areas and landscape metrics.

For the anthropic environment, *Pasture* and *Forestry* occupy a large area, totaling 233.603,07 ha (37.45%) and 234.690,38 ha (37.62%) respectively. *Urban* and *Agriculture* are less representative in terms of occupied area: 23.274,84 ha (3.73%) and 47.084,10 ha (7.55%). As for the natural environment, *Forest* and *Water* have an area of only 82.019,91 ha (13.15%) and 3.111,90 ha (0.50%), respectively.



Group 1 53.051,70 ha	CA	MN	LPI	%
Water	25,00	25,00	25,00	0.04
Urban	15.454,77	5.151,59	15.035,09	29.13
Forest	6.333,45	126,66	4.700,73	11.94
Agriculture	805,95	26,86	74,99	1.52
Pasture	2.634,69	47,04	356,45	4.96
Forestry	27.797,84	1.310,39	24.881,34	52.41

Group 2 149.657,40 ha	CA	MN	LPI	%
Water	1.709,86	85,49	434,71	1.14
Urban	1.520,28	190,03	681,96	1.01
Forest	37.712,41	149,06	27.614,52	25.20
Agriculture	15.162,16	36,98	1.143,62	10.13
Pasture	43.889,86	136,30	8.047,59	29.32
Forestry	49.662,83	287,99	19.955,39	33.20

Group 3 421.075,10 ha	CA	MN	LPI	%
Water	1.377,04	86,06	304,45	0.33
Urban	6.299,79	174,99	2.509,62	1.49
Forest	37.974,05	41,59	988,32	9.02
Agriculture	31.115,99	31,46	364,62	7.39
Pasture	187.078,52	305,68	65.922,17	44.43
Forestry	157.229,71	593,83	63.653,22	37.34

Figure 3. Percentage of each land use class (total areas and by groups) and representation of the Total Land Cover Areas (CA), Mean Areas (MN) and Largest Patch Index (LPI) by groups (sum of each land use of the three groups = total area of each land use) for the year 2030.

As we can see in the areas and percentages by groups for 2030 (**Figures 3 and 4**), their characteristics are correlated to the year 2013 exemplified in Oliveira et al. (2019), where *Group 1* has a large urban area, *Group 2* has a larger forest area and *Group 3* has a greater presence of anthropic uses.

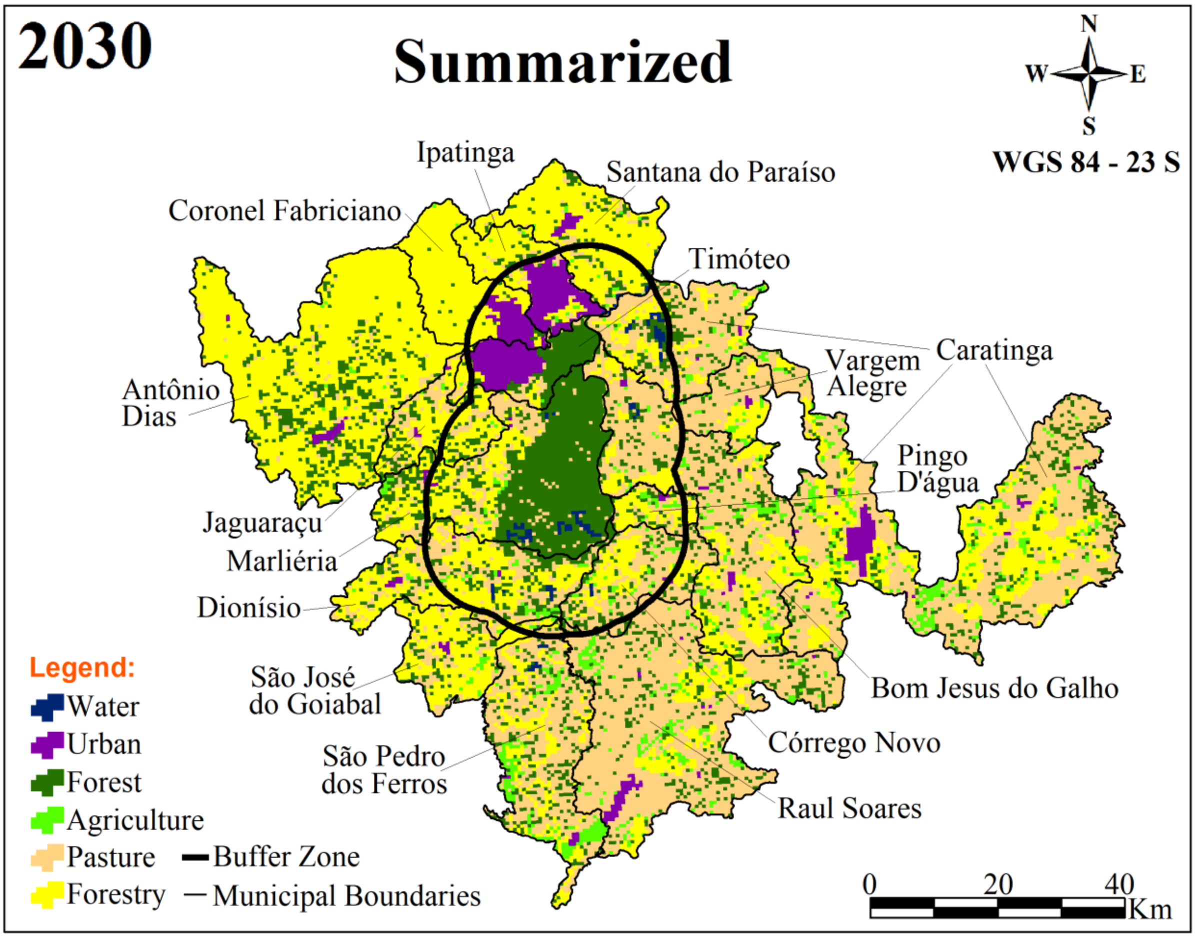


Figure 4. Summarized land uses of the total area of municipalities with identification of PERD and buffer zone for the year 2030.

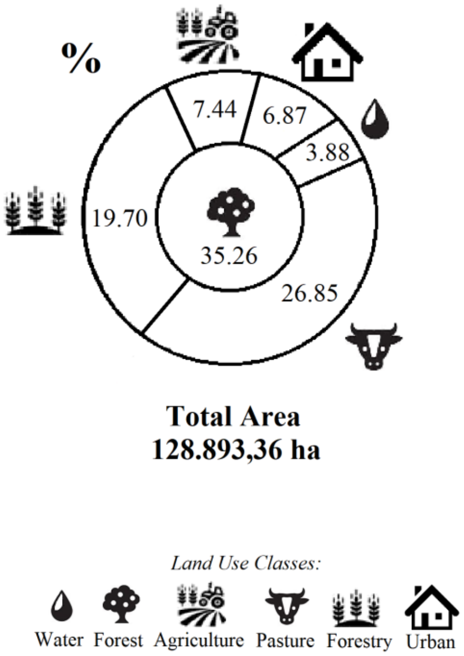
The scenario for 2030, compared to 2013 (Oliveira et al., 2019), for the anthropized areas is that there will be a reduction of about half the area occupied by *Pasture* (from 410.448,52 ha to 233.603,07 ha) in the three groups, while the *Forestry* area will increase greatly (3x). *Agriculture* will significantly increase its occupancy mainly in groups 2 and 3 and *Urban* will grow slightly, mainly in group 1, as expected for the region. As for natural uses, *Forest* and *Water* will show a small increase, despite anthropic pressures, probably due to the consolidated regional conservation strategies.

3.2 Landscape dynamics in the Buffer Zone

3.2.1 Future Scenarios for the next 15 years (2030)

The prediction of future land use scenarios (the next 15 years) in the 10 km buffer zone of the Park are shown in the **Figures 5, 6 and S1**. According to the current area 2015

(Oliveira et al., 2019) and comparing with the future forecast of 2030, to the natural areas, native *Forest* will present an area of 45.439,94 ha (35.26%), thus reducing the area in 250,44 ha and the *Water* occupied 5.007,85 ha (3.88%), showing a fall in 545,14 ha in the areas of regional water bodies.



Group 1 23.616,93 ha	CA	MN	LPI	%
Water	273,19	1,69	40,66	1.15
Urban	7.729,04	13,06	3.936,58	32.73
Forest	10.990,55	6,36	4.087,54	46.54
Agriculture	2.456,82	1,12	500,64	10.40
Pasture	2.155,93	0,73	183,33	9.13
Forestry	11,40	0,31	3,62	0.05

Group 2 46.611,98 ha	CA	MN	LPI	%
Water	1.178,93	3,67	84,82	2.53
Urban	786,70	4,28	165,59	1.68
Forest	15.390,36	7,78	13.046,66	33.02
Agriculture	4.371,88	1,52	1.221,36	9.38
Pasture	17.493,50	3,33	13.322,57	37.54
Forestry	7.390,61	8,77	3.420,82	15.85

Group 3 58.664,45 ha	CA	MN	LPI	%
Water	3.555,73	4,64	275,46	6.06
Urban	347,33	2,20	26,69	0.59
Forest	19.059,03	4,62	6.289,17	32.49
Agriculture	2.762,62	0,71	297,52	4.71
Pasture	14.954,13	1,79	4.604,49	25.49
Forestry	17.985,61	12,35	5.746,03	30.66

Figure 5. Percentage of each land use class (total areas and by groups) and representation of the Total Land Cover Areas (CA), Mean Areas (MN) and Largest Patch Index (LPI) by groups (sum of each land use of the three groups = total area of each land use) for the PERD buffer zone (year 2030).
.

Over the next 15 years, *Urban* and *Forestry* areas will continue to grow and occupy large spaces due to the greatly increasing regional anthropogenic use, with respective areas of 8.863,07 ha and 25.387,62 ha, estimating a forecast growth of approximately 2.045 ha for each use over the next 15 years. On the other hand, the areas of *Agriculture* and *Pasture* will decrease 661,21 ha and 2.630,98 ha, respectively, however, it is noted that it will not be due to the natural increase, since they will be replaced by the anthropic uses previously mentioned.

In the PERD buffer zone, the changes in the area of native *Forest* varied between the three groups: in groups 1 (urban) and 2 (more conserved) the forecast is a growth of 3.355,85 ha and 869,73 ha, respectively, a result expected only for group 2. In group 3 (most anthropic) the native *Forest* area is expected to be reduced by 4.476,02 ha, reducing it to an area still smaller than that reported for 1985 (Oliveira et al., 2019), where it was extremely degraded.

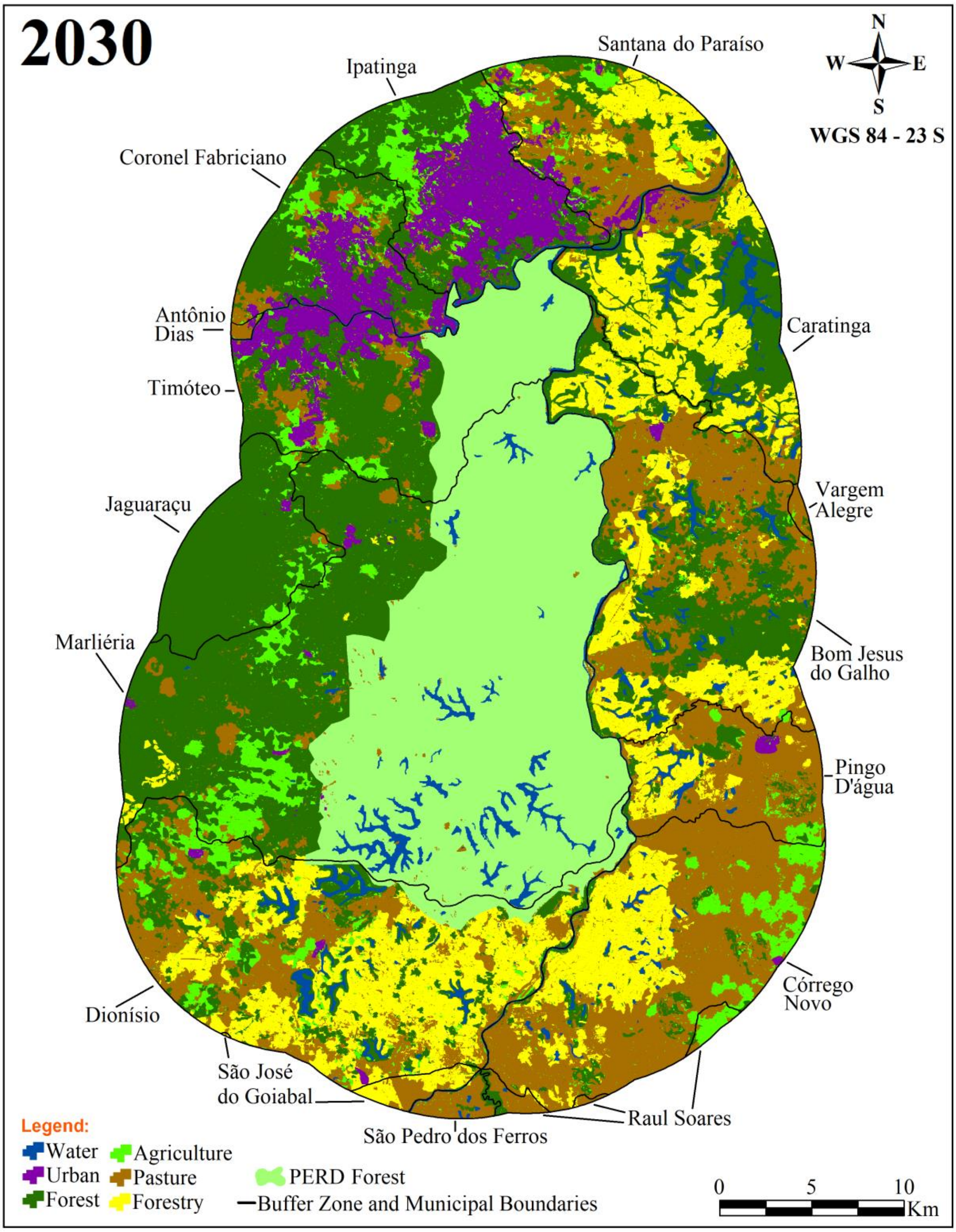


Figure 6. Land uses classes of the PERD buffer zone predicted for the year 2030 by classification of the Dinamica EGO, according to the municipal boundaries.

In relation to *Forest* areas, it is interesting to highlight the increase in the more urbanized areas and a greater concentration on the western side of the buffer zone. The presence of two Environmental Preservation Areas (EPA): Jaguaraçu, and Jacroá, located respectively in the municipalities of Jaguaraçu and Marliéria. Therefore, the reason for the growth of the *Forest* areas it's because these areas are dedicated to preservation and conservation of wildlife (APA do Jacroá, 2008; APA Jaguaraçu, 2008).

In addition, for the municipalities of Pingo D'água and Córrego Novo, which are considered to be the most conserved in previous years, a loss of *Forest* areas and an increase in *Pasture* areas is foreseen (which underlines the great importance of the creation of ecological corridors and the use of management techniques to improve the situation in this area).

Regarding *Water*, the results show a slight reduction of water bodies in the buffer zone of the PERD, which may be associated to the expansion of urban centers, which will require a greater consumption of this resource, and the water crisis experienced in 2015 as result of climate change and anthropogenic pressures (Marengo, 2008; FMA, 2018; WWAP, 2018; Oliveira et al., 2019).

For the anthropic uses, *Agriculture* will lose in total areas and will be concentrated to larger fragments, and what is suggested is the arrival of sugarcane and a concern with the handling of fire during its cut. This can generate fires in buffer areas, with adverse consequences for biodiversity (Santaella & Paes, 1995; Aguiar et al., 2009; Ronquim, 2010; Aguiar & Souza, 2014).

In this region the family farming in smaller areas will resist (Ribeiro et al., 2007; EMATER/MG, 2014; PPAG, 2017), but the medium-sized areas will be replaced by *Forestry* (eucalyptus monoculture), that generates a higher income and is easier to manage (Motta et al., 2010). However, its introduction causes rapid soil degradation and compromises regional conservation (Vital, 2007; Mosca, 2008; Rezende et al., 2011; Rezende, et al., 2013).

Pasture will cover extensive areas at the total area of municipalities and in the PERD buffer zone. A soil that has been used as pasture for a long time becomes inadequate for planting or for reforestation because it loses their characteristics and needs great improvements (Peron & Evangelista, 2004; Zanine et al., 2005; Dias-Filho, 2014; Freitas et al., 2016; Macedo & Zimmer, 2018). *Pastures* cause great forest fragmentation mainly in the eastern part of the buffer zone, making these forests fragments to lose more and more the connectivity, implying in this way the urgency to create corridors and management techniques to improve local conservation (Da Silva & Souza 2014; Gerhardt, 2014; Souza et al., 2014; Saito et al., 2016; Lima, 2017).

In this region, the *Forestry* stands out as the most damaging activity for conservation and has gradually expanded over the past 30 years (Oliveira et al., 2019), replacing mainly *Agriculture* and *Pasture* areas. Planting eucalyptus is possible on poor soil without large costs (EMBRAPA, 2004; Motta et al., 2010) and having large areas in the buffer zone with the presence of *Pasture*, makes everything favorable to this increase every year.

In the region of the valley of steel *Urban* areas are also very representative with three largest urban centers in the buffer zone. As a global trend, these urban centers continue expanding and their population increasing (Millennium Ecosystem Assessment, 2005; ONU, 2014), with studies indicating that the children's are increasingly disengaged to the surrounding environment (Zulauf, 2000; Silva, 2012; Telles & Silva, 2012) and its proximity areas to the park contributes increasingly to local environmental degradation (Melo, 2001; PELD, 2018), which makes urban areas an important focus to change the future of this region, with environmental education and improved environmental management.

4. Conclusions

With the finalization and analysis of the study it can be observed that the buffer zone of the Rio Doce State Park suffers with the advance of the anthropic over the natural, for all four types of land uses present in the region: the three large urban centers (*Urban*); the sugar cane and the danger with the fire in the process of cutting (*Agriculture*); the presence of large areas of *Pasture*, where in addition to the areas undergo degradation by the presence of livestock, they also suffer with the abandonments; besides the strong presence of *Forestry*, which increasingly takes up space of the other uses throughout the buffer zone.

As notified, strong interactions of the population with the managers and companies in the region are necessary for the improvement of regional environmental conservation, seeking a better sustainable development, thus increasing the social condition of each municipality present around the Park. In many rural areas around the PERD, many people have never been or do not even know about this UC. To improve this situation, the communities around the PERD were invited to participate in workshops where the land use situation will be presented and discussed and the solutions will be sought. With the completion of the studies in development and workshops held, all the material will be unified to make it available to the community and scientifically.

All the data obtained will be made available to the municipal managers and to the PERD administration, as contribution to the reformulation / elaboration of management plans and to the proposal of public policies that aim at the regional conservation.

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7. Appendix

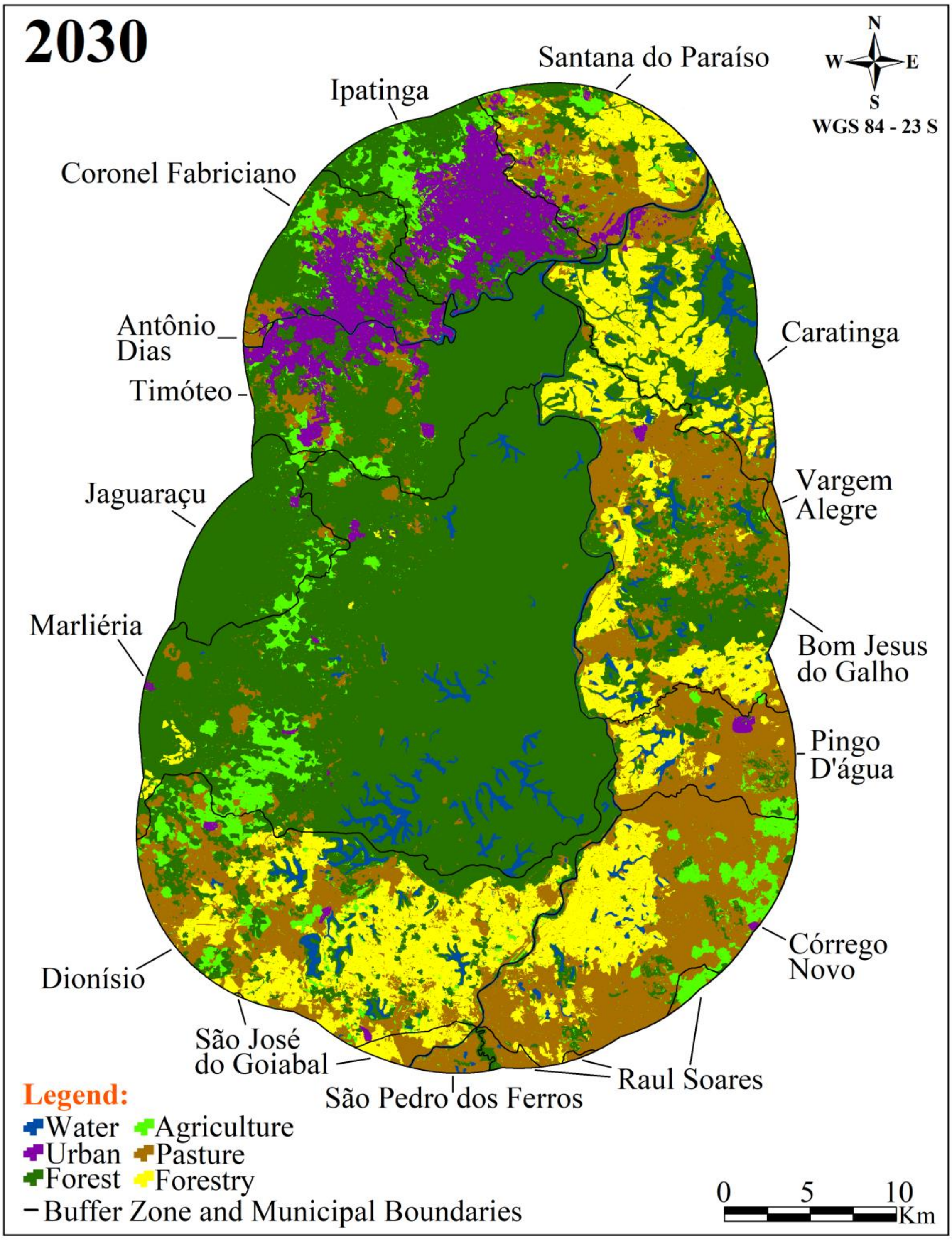

Figure S1. Land uses classes of the PERD buffer zone predicted for the year 2030 by classification of the Dinamica EGO, according to the municipal boundaries.

Considerações Finais

Com o desenvolvimento da pesquisa pôde-se observar que o Parque Estadual do Rio Doce e sua zona de amortecimento recebem um forte impacto dos usos antrópicos, onde nos últimos 15 anos, principalmente as culturas exóticas (eucalipto), seguem uma tendência de crescimento, em consenso com o crescimento populacional com a presença das três grandes cidades próximas, do avanço da cana-de açúcar e das grandes terras usadas como pastagens. Como reflexo deste avanço, o meio natural apresenta cada vez menos regiões conservadas e tende-se a aumentar a cada ano sua fragmentação florestal, o que vai de encontro à presença da Unidade de Conservação, que necessita de uma área de entorno para servir como proteção, para auxiliar no fluxo gênico e no deslocamento seguro para a biodiversidade local.

Apesar do importante trabalho de conservação desenvolvido pelo PERD, o seu entorno possui cenários futuros preocupantes, o que torna necessária uma grande atenção contra essas previsões negativas. Apesar de existirem agricultores familiares e terras conservadas com matas primárias, tende-se a sofrer uma grande pressão dos latifundiários regionais, dada a sua forte presença na economia, sejam elas advindas das pressões da silvicultura ou da pastagem. Torna-se necessário então reverter essa situação aumentando as áreas florestais da região, em contrapartida evitando o aumento da sua fragmentação, além de buscar ampliar e proteger as APPs que ali se encontram, através da maior rigidez das leis ambientais e do fortalecimento da educação ambiental.

Todos os dados serão disponibilizados em formatos de artigos científicos, folhetos de divulgação para o PERD, UFMG, instituições que fazem parte da zona de amortecimento do parque e que participaram dos workshops do estudo (gestores ambientais, administradores dos municípios: prefeitos e secretarias), empresas atuantes na região e claro, a população como um todo. Esperamos que sejam muito bem aproveitados em pesquisas do Parque e seu entorno e que sejam de grande valia principalmente para os seus gestores, servindo também para a atualização do seu plano de manejo que data de 2002, demandando um conhecimento das atualidades que o cerca para uma melhor tomada de decisões.

Apêndices – 1) ***Folheto do estudo***: disponibilizado ao meio acadêmico, população da ZA, empresas e gestores ambientais.

2) ***Artigo 3 sugerido pela banca - em elaboração:*** *Comunidades do entorno, interações e workshop* - etapa retirada do artigo 2 (atualidades e cenários futuros 2030 da zona de amortecimento do PERD) para integrar dados de outros estudos que também foram realizados nas comunidades do entorno e assim a publicação de um artigo mais completo.

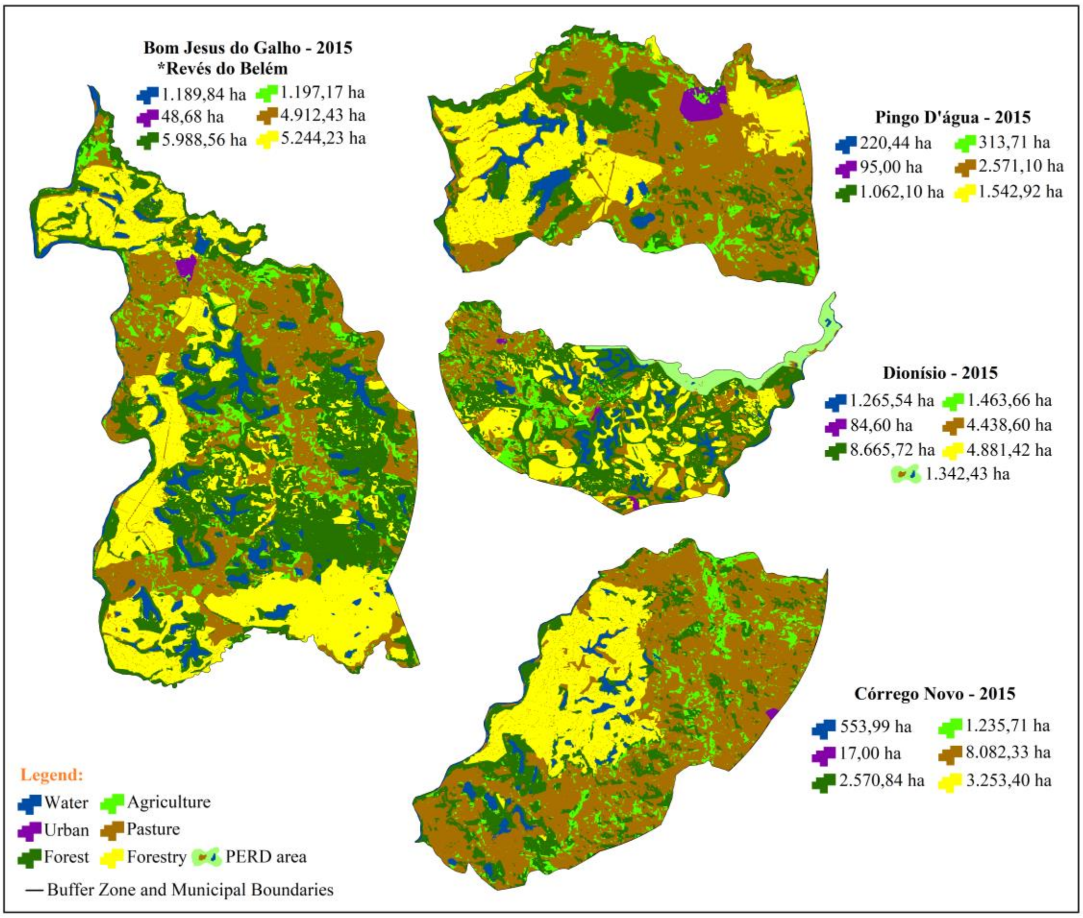

Figure 1. Thematic maps of the year 2015 of the four municipalities involved in the dynamics of the workshops.

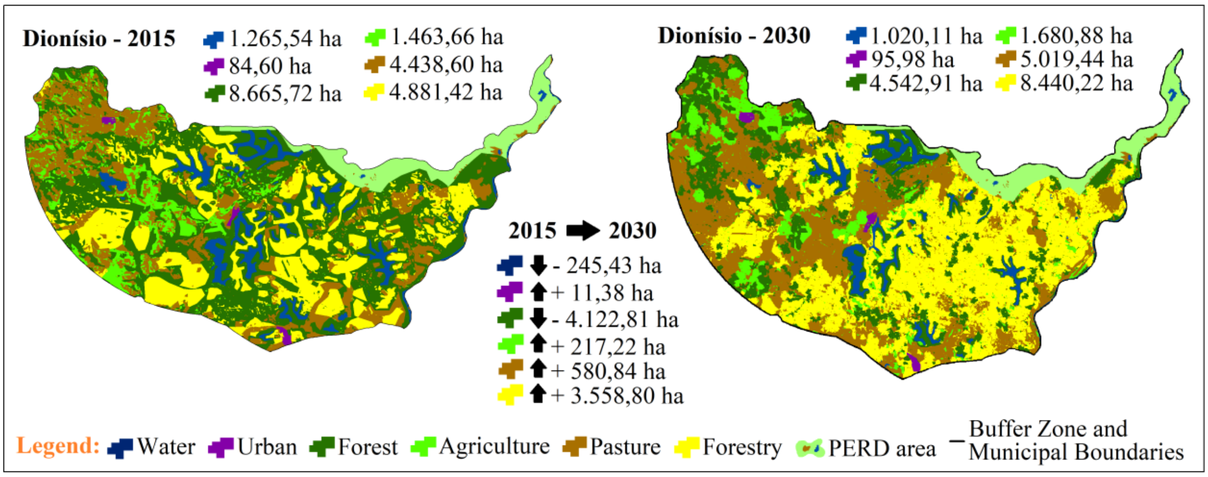

Figure 2. Land use maps of Dionísio for the years 2015 and 2030 (future scenario).

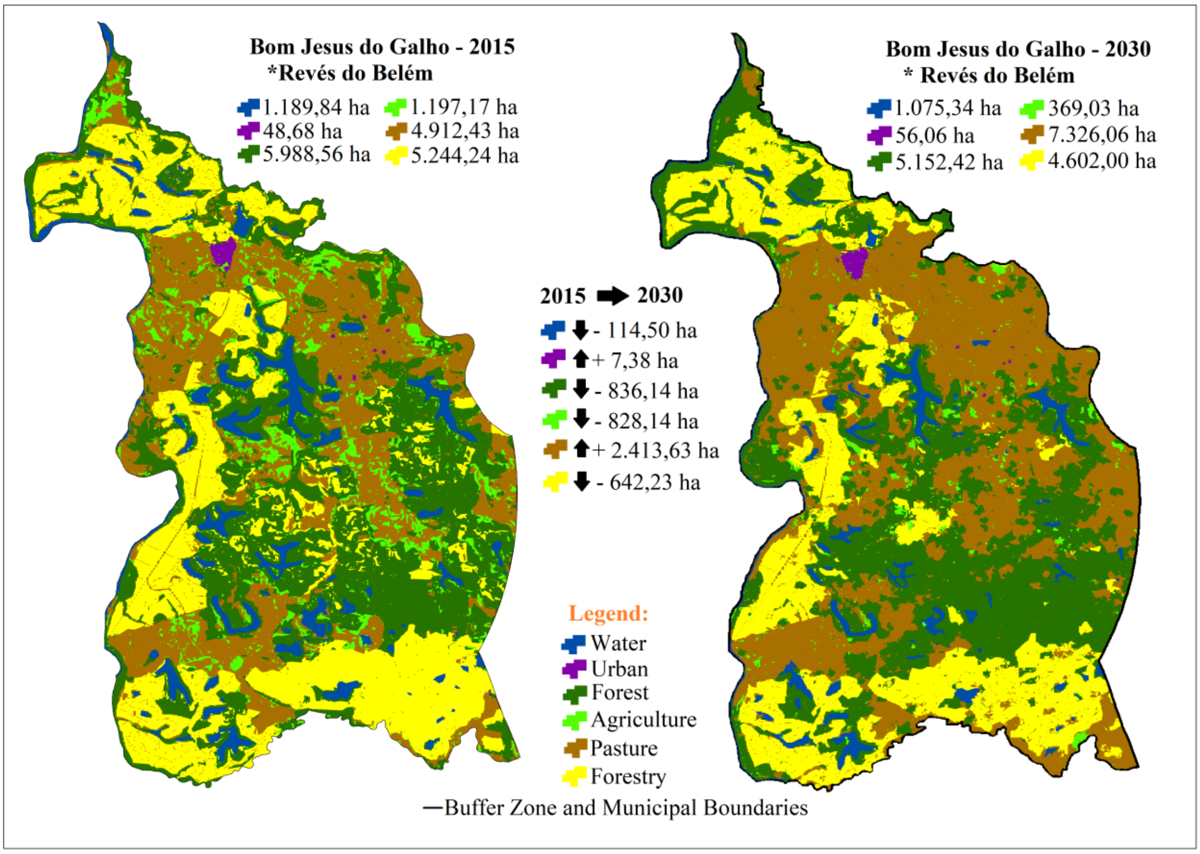

Figure 3. Land use maps of Bom Jesus do Galho (Revés do Belém) for the years 2015 and 2030 (future scenario).

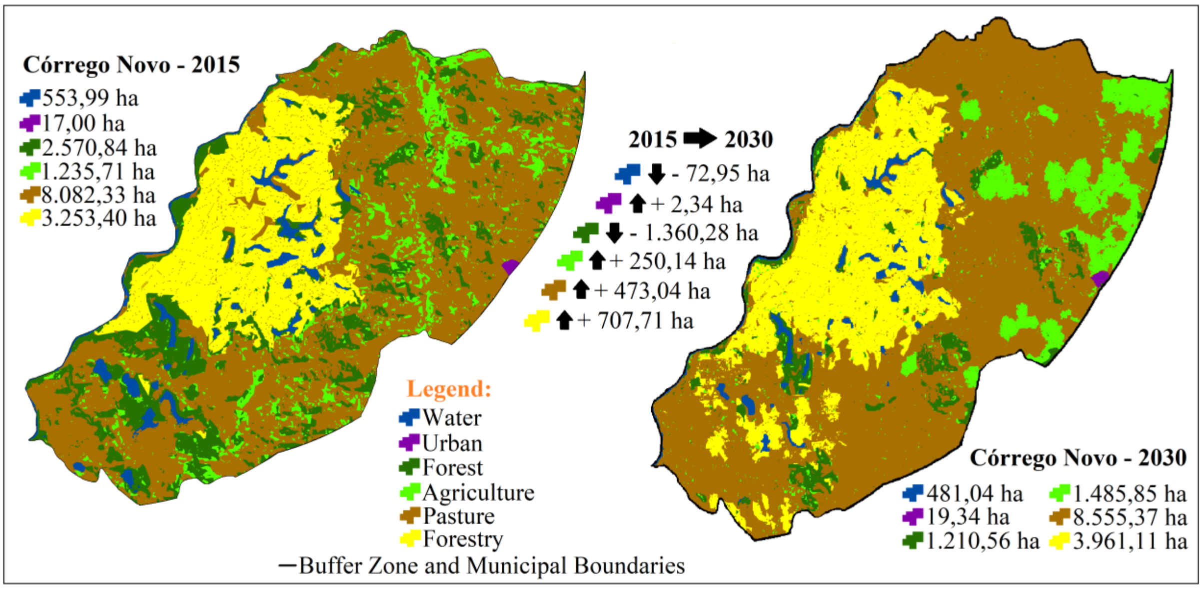

Figure 4. Land use maps of Córrego Novo for the years 2015 and 2030 (future scenario).

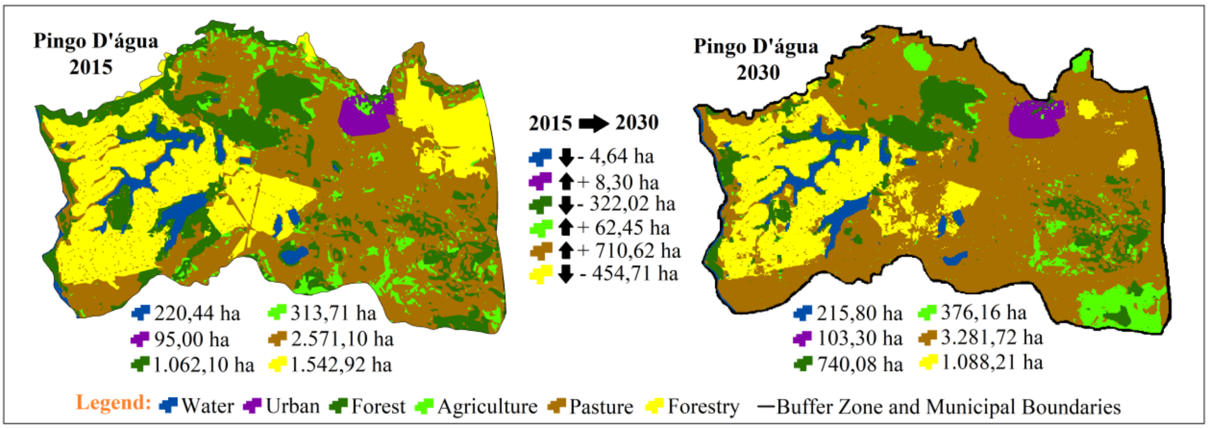

Figure 5. Land use maps of Pingo D'água for the years 2015 and 2030 (future scenario).

Figure 6. 3rd Workshop - stages of the meeting.

Analyzing the work developed with the communities of four municipalities and local stakeholders, we can say that the prospects for improvement of the PERD buffer zone are promising. An action matrix was built and the interaction between the population and the companies operating in the region established. Several proposals aimed at improving the economy and regional development, whether social or environmental, were discussed together. The project is still under development in the region, the next actions will consolidate the decisions taken.

3) ***Artigo 4 sugerido pela banca - em elaboração:*** *Fragmentação florestal da zona de amortecimento do PERD 2015 e 2030* - Atualidade e cenário futuro.

PERD buffer zone: forest fragmentation

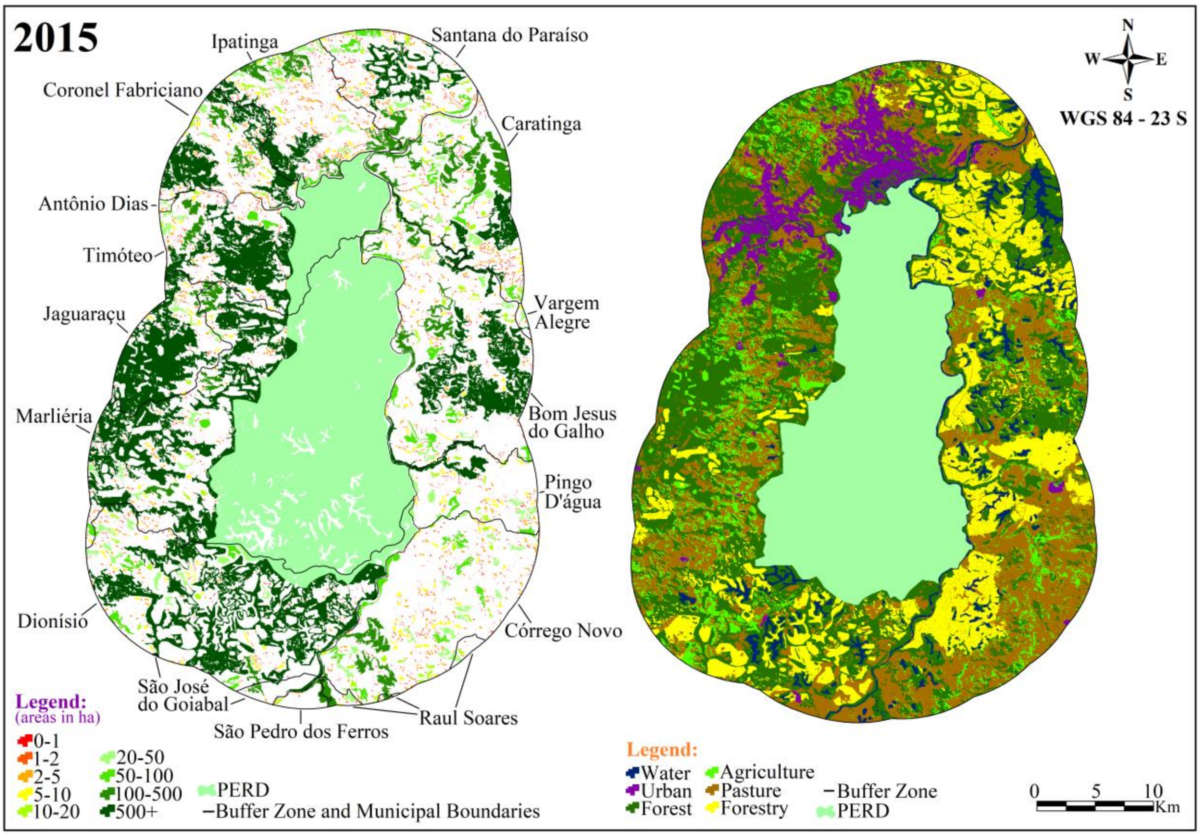

Figure 7. Forest fragmentation of the PERD buffer zone by municipalities and total land uses classes of the PERD buffer zone, both for the year 2015.

Table 1. *Forest* land uses of the PERD and buffer zone identified for the year 2015, with their respective areas in hectares and percentages.

Landscape Type	2015	
	Area (ha)	**%**
Native Florest of PERD	34.512,67	43.03
Forest Fragments of Buffer Zone	45.690,38	56.97
Total Forest Area	**80.203,05**	**100.00**

Table 2. Size and number of *Forest* patches of the PERD buffer zone with their respective areas in hectares and percentages identified for the year 2015.

Sizes of Forest Patches (ha)	Number of Forest Patches	2015	
		Total Area (ha)	**%**
900m²-1	5.817	1.184,18	2.59
1-2	410	573,36	1.25
2-5	368	1.138,15	2.49

5-10	151	1.081,41	2.36
10-20	81	1.131,87	2.47
20-50	73	2.313,97	5.07
50-100	33	2.182,07	4.78
100-500	25	5.780,86	12.66
500+	11	30.304,51	66.33
Total Forest Area	**6.969**	**45.690,38**	**100.00**

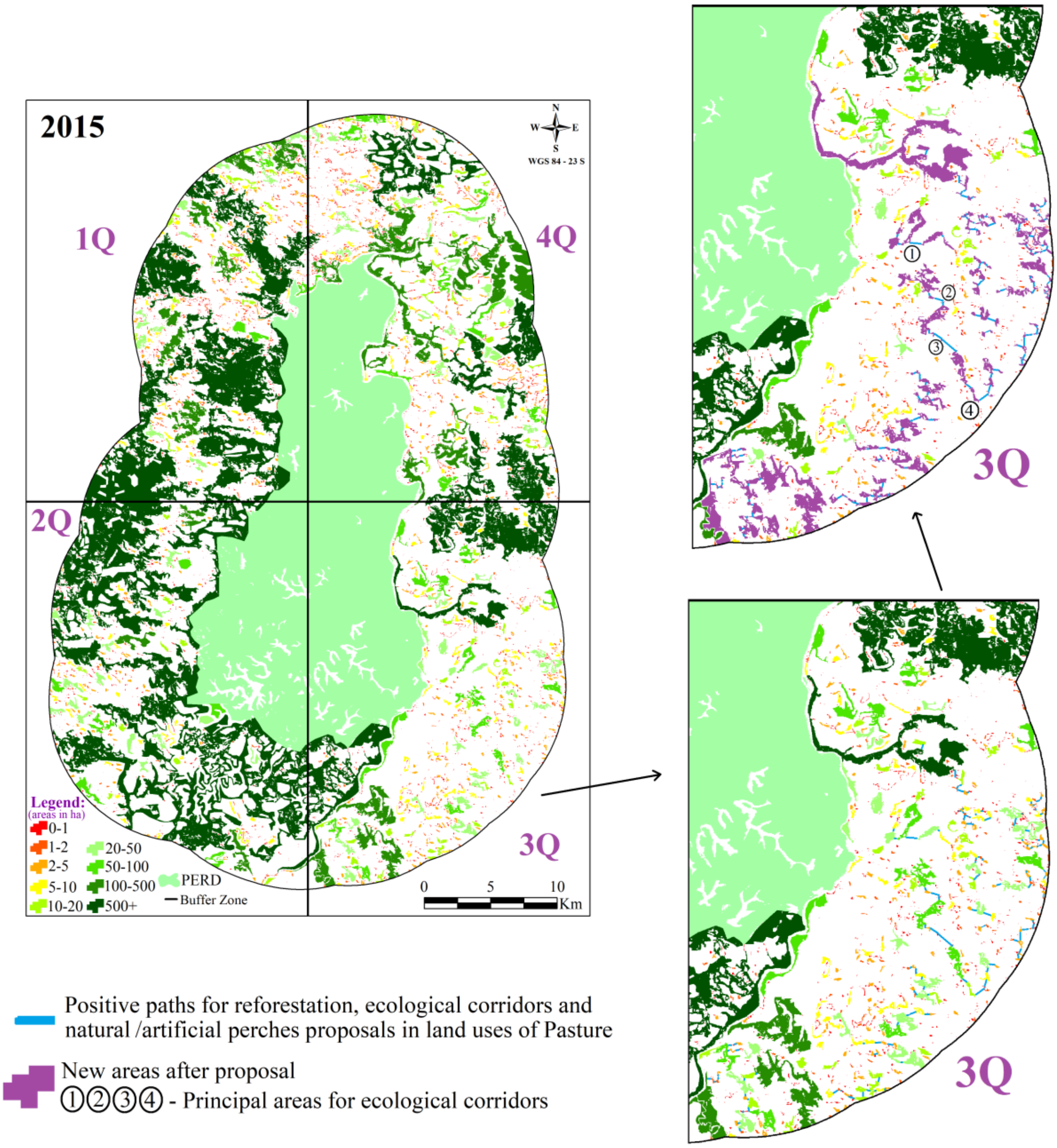

Figure 8. Representation of the four quadrants of the study area for the year 2015, Proposals of environmental techniques, reforestation and ecological corridors in the *3Q* quadrant and Thematic map featuring the final areas of the proposal.

4) ***Artigo 5 sugerido pela banca - em elaboração:*** *referencial bibliográfico* - Comparação da mesma área de estudo em diferentes escalas de pixels disponíveis.

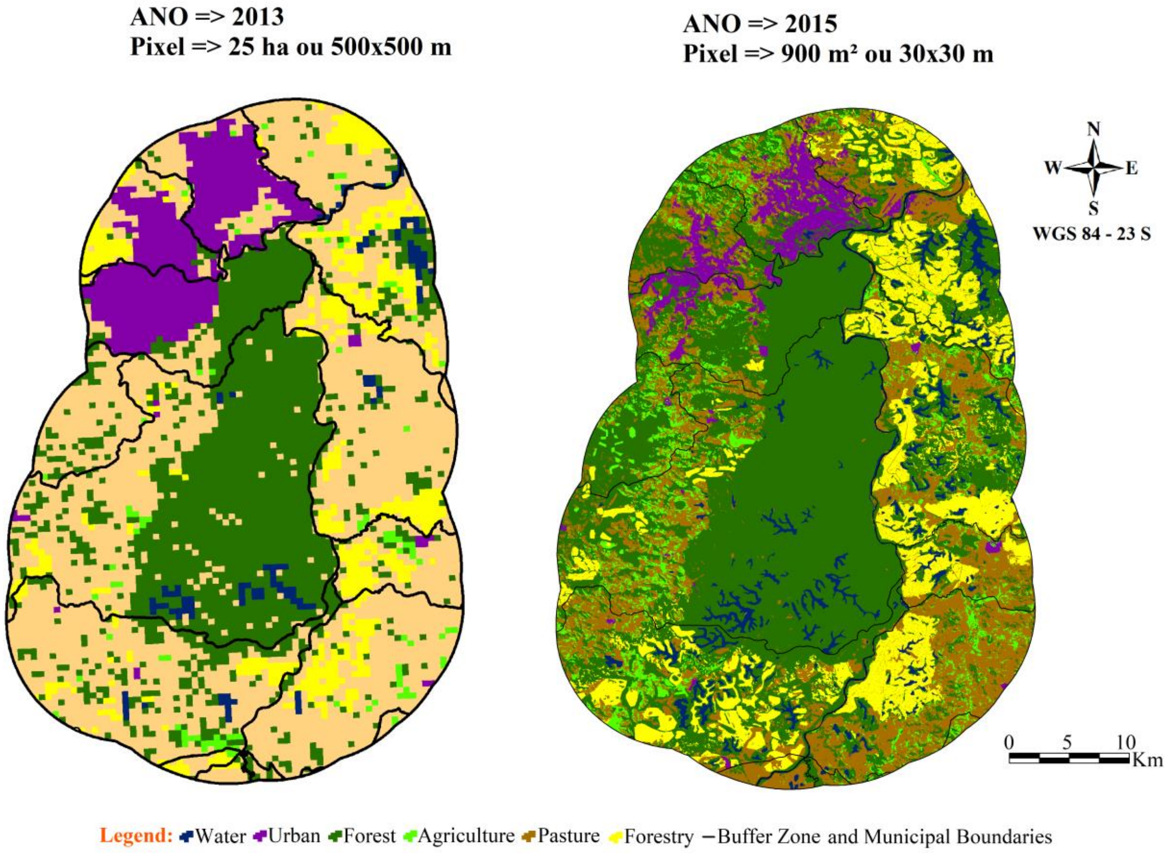

Figura 9. Comparação da mesma área de estudo em diferentes escalas de pixels.