Accepted refereed manuscript of:
Pierri Daunt AB & Silva TSF (2019) Beyond the park and city dichotomy: Land use and land cover change in the northern coast of São Paulo (Brazil).
Landscape and Urban Planning, 189, pp. 352-361.
DOI: https://doi.org/10.1016/j.landurbplan.2019.05.003

Beyond the park and city dichotomy: Land use and land cover change in the northern coast of São Paulo (Brazil)

Ana BeatrizPierri Daunt[1], ThiagoSanna Freire Silva[1,2]

[1] São Paulo State University (Unesp), Institute of Natural Sciences and Technology, Geography Department, Rio Claro, Brazil

[2] Biological and Environmental Sciences, Faculty of Natural Sciences, University of Stirling, Stirling FK9 4LA, UK

Abstract The natural and cultural landscapes of the Northern Coast of São Paulo State (Brazil) are threatened by increasing urban growth, as a result of inefficient land use management and fast population growth. Our work analysed land use/cover changes (LULCC) between 1985 and 2015 at 5 year intervals, to describe and understand the main processes and drivers of landscape change. LULCC were mapped using Landsat images and geographic object-based image analysis (GEOBIA), based on the Random Forests supervised algorithm. Over 30 years, we show a dichotomic trend for the two main land change trajectories: forest persistence and fast urban growth. We found only 8% of forest disturbance within the State Parks, while dense urban settlements grew 163% outside the park, mainly replacing rural uses. We estimate that all available land for human settlement may be occupied by 2030 as a result of this fast urban growth. Our study exemplifies a likely pattern of land use change for coastal regions, with fast urban growth driven by economic interests in transforming these regions into urban and touristic hubs, clashing with environmental policies for forest conservation and afforestation. The history of LULCC in the Northern Coast of São Paulo State has resulted in several land use conflicts in the present, especially when considering fast urban growth versus a very large proportion of areas where no human settlement is permitted. This complex combination of drivers has led to rural depopulation and decrease in small-scale agricultural uses, reducing the diversity and functionality of the studied landscape.

1. Introduction

Mankind has been shaping ecosystems and landscapes since the establishment of the first human settlements, but the speed, frequency and magnitude of landscape changes has increased mainly since the second half of the 20th century; presently, more than 75% of Earth's ice-free land shows evidence of alteration as a result of human land use (Antrop, 2000; Ellis & Ramankutty, 2008). Land use and land cover changes (LULCC) are difficult to predict and manage, and can result in severe consequences for climate, biodiversity, and ecosystem integrity and services, especially in the case of land build-up, which is usually irreversible (Elmqvist et al., 2013, Verburg et al., 2015). Also, modern landscape changes are characterized by the loss of landscape diversity and changes in multifunctionality, mostly as a result of fast urbanization and urban population growth (Antrop, 2005), as well as by increased *per capita* land consumption (Inostroza, Baur & Csaplovics, 2010). Land conversion from rural to urban uses can lead to several critical impacts on the quantity, quality and cost of food supply, and changes the complex relationship between people and the landscape though cultural heritage, feelings and values (Antrop, 2005; Bürgi, Verburg, Kuemmerle, & Plieninger, 2017; De Groot, 2006; McNeely & Scherr, 2009; Nassauer, 1995; Tuan, 1983).

In South America, almost 84% of the total population lives in cities, and predictions estimate that both urban population and urban areas will continue to increase rapidly in the next years (Inostroza et al., 2010; UN 2009). Such fast and intense urbanization in developing countries usually leads to vulnerability to extreme climate events, human settlement on socially and environmentally risky areas, pollution, deforestation, habitat and biodiversity loss, violence, and criminality (Elmqvst et al., 2013; Maricato, 2003).

In Brazilian coastal zones, fast urban growth is of large interest and concern in terms of LULCC and landscape changes. The region known as the “Northern Coast of São Paulo State” (NCSP) has a strong touristic vocation and has shown one of the highest annual rates of population growth in the country (1.6% from 2015 to 2016), twice as large as the state average (FSEADE, 2016) and caused mostly by migration from other regions and from local rural areas to urban centers (Carmo, Marques, & Miranda, 2012; Rosemback et al., 2017). Economical interests in infrastructure development and expanding agricultural frontiers have been discussed as the main drivers of urban sprawl and deforestation in tropical ecosystems (Geist & Lambin, 2002), and the natural and cultural landscapes of the Northern Coast of São Paulo State are presently threatened by inefficient management of the increasing urban growth, leading to forest fragmentation and losses of biodiversity (Ab’Sáber, 1986; Dean, 1996; Ribeiro, Metzger, Camargo Martensen, Ponzoni, & Hirota, 2009)

To control the impact of urban sprawl and to protect the Atlantic Forest, any form of human settlement is strictly forbidden in more than 80% of the NCSP territory, according to several environmental and land use policies and laws. Furthermore, long term LULCC data is not widely available for Brazil and most developing countries, thus independent studies quantifying LULCC are important to understand current occupation patterns and improve future urban planning and governance. Our work thus mapped land use and land cover changes between 1985 to 2015, at five year intervals, to answer the following questions: 1) what are the main processes and trajectories of land use/cover change in the NCSP during the last 30 years? 2) What could be the main drivers of these changes? 3) What are the possible consequences of these changes on natural and cultural landscapes? 4) Have environmental legislation and regulations been effective in preserving forest cover?

2. Methods

2.1 Study area

The Northern Coast of São Paulo State is a recognized state administrative unit, mainly located along the Serra do Mar mountain range, and including four municipalities: Caraguatatuba, Ilhabela, São Sebastião and Ubatuba (Figure 1). The physical landscape of the NCSP is composed by three main physiographic compartments: the upland plateau between 800 and 1300 m of elevation; the escarpments of the Serra do Mar mountain range, placed between the coastal plains and the uplands and characterized by steep slopes; and the coastal plains, with elevations below 20m and slopes of less than five degrees (Almeida & Carneiro, 1998; Rossi &

Queiroz Neto, 2001). Most human settlements occur on the coastal plain, but recent urban growth has pushed new settlements towards the steeper inland transitions. Considering the high annual rainfall volume (between 800 and 1200 mm) and the very steep slopes, this region includes several high-risk areas for human settlement (Ab’Sáber, 2007; Rossi & Queiroz Neto, 2001).

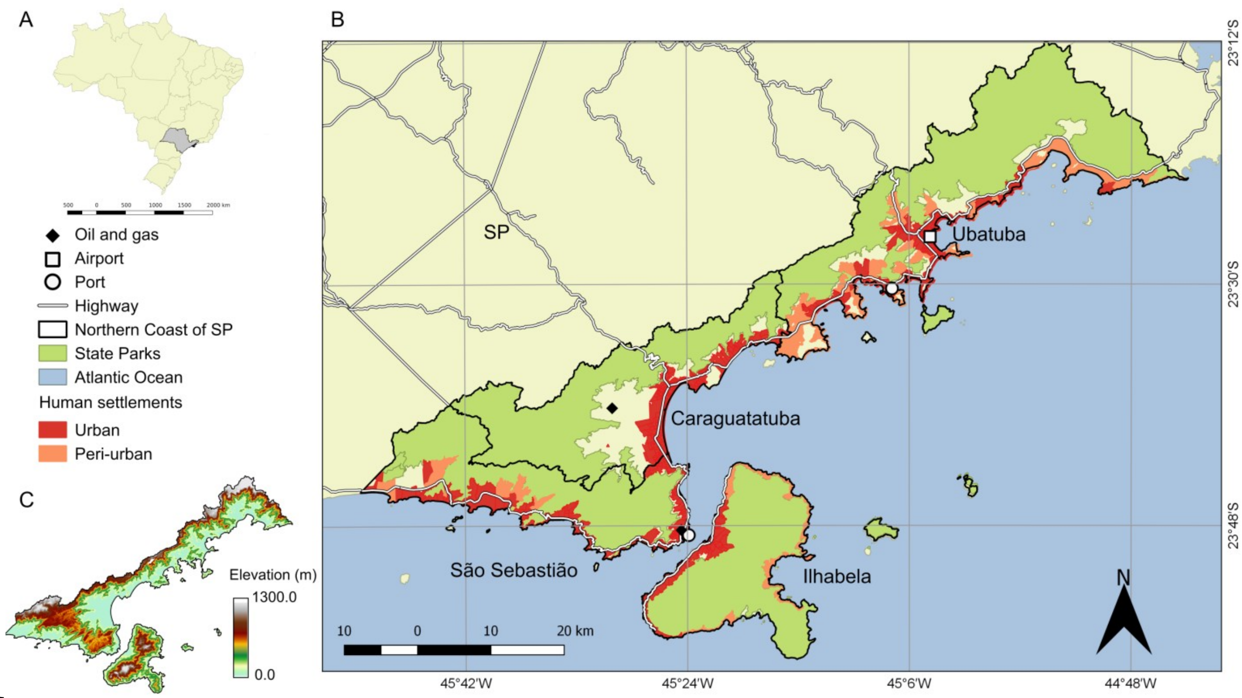

Figure 1. A) Map of Brazil showing the location of São Paulo State (SP). B) Northern Coast of São Paulo State showing the location of state parks, main highways, oil and gas infrastructure, major ports and airports, and urban and peri-urban census sectors (IBGE, 2010). C) Digital Elevation Model (ALOS World3D, https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm).

The NCSP is located within the Atlantic Forest biome, which has one of the most diverse tropical biotas in the world (Mittermeier et al., 2004) and is among the biomes most threatened by human land use changes and urbanization process globally (Dean, 1996; Ribeiro et al., 2009). The Atlantic Forest was recognized as a biosphere reserve by UNESCO in 1991, and the Serra do Mar mountain range holds some of the largest and best preserved Atlantic Forest remnants (Fundação SOS Mata Atlântica; Instituto Nacional de Pesquisas Espaciais, 2016; Ribeiro et al., 2009). To protect the Atlantic Forest, several environmental and land use policies and laws have been passed during the late 20th and early 21st centuries, and three state parks were created in the NCSP in 1977 to support biodiversity conservation, environmental education and scientific research: “Serra do Mar”, “Ilhabela” and “Ilha Anchieta”. All state parks are classified as “integral protection” conservation units under the Brazilian Protected Areas legislation (*Sistema Nacional de Unidades de Conservação* - SNUC) (Brasil, 2000; São Paulo, 1977), thus any form of human settlement or land use is strictly forbidden. As an exception, the management plan of Serra do Mar State park has delimited a special restricted zone that allows sustainable use by native populations under park management regulations (São Paulo, 2006). Federal Law n° 11428/2006 protects the Atlantic Forest biome and regulates the practices of deforestation, classifying transgressions as environmental crimes (Silva, Batistella & Moran, 2006).

In addition to being an important biodiversity hotspot, the Northern Coast of São Paulo State also has unique historical and cultural characteristics, currently preserved by indigenous and traditional peoples (Ab’Sáber, 1986; São Paulo, 2006), such as the Tupi-Guarani nation and the Caiçara and Quilombola ethnicities, which have historically contributed to landscape sustainability and multifunctionality (Diegues, 2001; Antrop, 2005).

During the 20th century, coffee producers and the industrial aristocracy “rediscovered” the coast of São Paulo for leisure and nature contemplation, occupying it with large secondary residences, and turning the region into a tourism hotspot (Campos, 2000; São Paulo, 2006). Also during the second half of the 20th century, the tourism and oil industries demanded increased access to the NCSP, bringing the expansion of transportation networks and resulting in high rates of migration and population growth, with a resulting decrease in rural areas and urban expansion (Carmo et al., 2012; Cunha, 2003; Silva, 1975).

2.2 Land use and land cover data

We acquired seven Landsat Collection 1 Higher-Level Surface Reflectance images (formerly known as Landsat Climatic Data Record images) distributed by the U.S. Geological Survey (USGS), covering the entire study area (path 76 row 220, WRS-2 reference system, https://earthexplorer.usgs.gov/). The series included six images acquired by the Landsat 5 Thematic Mapper (TM) sensor, on 1985-07-27, 1990-07-09, 1995-05-04, 2000-01-10, 2005-05-15 and 2010-02-22, and one image from the Landsat 8 Operational Land Imager (OLI) sensor, from 2015-08-15. To avoid variations caused by vegetation phenology and changes in solar geometry, which could be detected as false cover changes (Kennedy, Yang, & Cohen, 2010), we favoured images from the dry season of each year (May – August), with the exception of images from 2000 and 2010, which had extensive cloud cover during this period.

We applied a geographic object-based image analysis (GEOBIA) approach, which has become more popular for LULCC mapping during the last years (Blaschke, 2010). We chose this method as it enables mixed use classification and requires less workload for manual post-classification corrections. We segmented the images into objects with homogeneous spectral responses using the Shepherd segmentation algorithm implemented in the open source library "RSGISlib", accessible through the Python programming language (Bunting & Clewley, 2013). This algorithm requires three parameters: minimum object size in pixels (*minPixls*), maximum number of clusters (*numClusters*), and distance threshold between object pixels (*disThres*). We tested different parameter combinations, and chose the optimal combination based on visual assessment of the spatial coherence and spectral homogeneity of the resulting objects (Blaschke et al., 2014), corresponding to *minPixls* = 50, *numClusters* = 120 and *disThres* = 100 (Appendix A). Mean spectral responses were then computed for each object across all multispectral Landsat bands (1, 2, 3, 4, 5 and 7 for TM; 1, 2, 3, 4, 5, 6 and 7 for OLI) to be used as inputs for the classification algorithm (Blaschke, 2010).

We then classified land use and land cover at each imaged date using the Random Forests supervised algorithm (Breiman, 2001) implemented in the “Sci-Kit learn” Python library (Pedregosa et al., 2012). This algorithm is an ensemble learning method based on classification and regression trees built through randomization of the training data (Breiman, 2001). In our case, training data were the spectral responses of samples with known LULC categories (Table 1). Homogeneous regions were manually selected as training samples, and delineated separately for each combination of LULC class and each imaged date, distributed as best as possible throughout the study area. The total area sampled for training each class depended on the relative proportion of the class within the scene, varying from 0.13 km² for bare soil to 14.10 km² for mature forest (Appendix A). Selection was based on visual interpretation of the images aided by visual comparison with high resolution datasets (see below).

Table 1 - Land use and land cover classes used for mapping land cover changes in the Northern Coast of São Paulo State, Brazil, between 1985 and 2015, using Landsat historical data.

Land use / land cover class	Description
Mature forest	Dense forest characterized by advanced successional stages and comprised mainly by primary forest, or occasional old-growth secondary forest.
Regenerating forest	Less dense forest at early to medium successional stages, mostly comprised by regenerating secondary forest.
Non-forest vegetation	Native or exotic vegetation including pastures, grasslands and agriculture.
Bare soil and rock	Exposed soil or rock surfaces lacking vegetation and buildings and including sandy beaches and rocky shores.
Peri-urban	Mixed areas with lower population density and sparse buildings, including a high diversity of rural uses, agroforestry, and small forest fragments.

Dense urban settlements	Dense built-up areas, mostly urban.
Water	Free water surfaces.

The Sci-Kit learn implementation of Random Forests takes the following main parameters: "*n_estimators*", the number of trees used for decision, "*bootstrap*", which is the randomization method, ''*out-of-bag*'' (OOB), which estimates the classification error, and "*class_weight*", which balances training samples. We optimized this parameter combination based on minimization of the OOB error, leading to "*n_estimators*" = 500 and "*class_weight*" = "balanced". The remaining parameters were kept at the default values (Appendices A) (Pedregosa et al., 2012). The automated classification was followed by careful visual inspection and manual correction of the land cover maps at the 1:25.000 scale, to improve map accuracy for all dates.

To aid image interpretation and support map validation and accuracy assessment, we obtained digital georeferenced colour aerial photographs from 2001 and 2010 at the 1:10.000 scale, freely available at www.datageo.sp.gov. We also used the GoogleEarth™ platform to assess the accuracy of the most recent classification, based on Landsat 8 OLI. To generate the ground truth dataset, we randomly distributed 40 random points per LULC class for each date, which were then visually interpreted and classified based on the available high-resolution imagery. We then used these sets to build confusion matrices and derive global accuracy, per-class accuracy, the kappa index of agreement, and commission and omission errors (Congalton, 1991).

Land use and land cover changes were quantified using map algebra, by comparing LULC maps in successive pairs. The area of each type of change was calculated using the "*raster*" package (Hijmans et al., 2016) of the R programming language (R Core Team, 2012), which we then used to build the LULCC matrix. We then quantified the areal changes of each class in relation to the class area in the previous time step (PTS), both as absolute areas and as percentages. When relevant, we also determined changes in relation to the initial class area at the first time step (FTS), also in absolute and percentage values. We separately quantified absolute and PTS and FTS percent changes inside and outside State Parks, to better understand the different drivers on each type of land. For that, we used the official park limits provided by the Forestry Foundation of São Paulo. As the limits of Serra do Mar State Park were reviewed and expanded in 2010, changes prior to 2010 were quantified considering the original 1977 limits, and changes after 2010 considered the newly expanded limits.

3. Results

Land use and land cover maps for 2015, 2010 and 2000 had overall accuracies of 0.94, 0.88, and 0.88, respectively, after manual revision and correction. Corresponding Kappa agreement indices were 0.92, 0.86, and 0.86. Considering that map classes, imaging sensor and mapping methods were the same for all years between 1985 and 2010, and based on the close similarity between 2010 and 2000 accuracies, we assumed similar expected accuracies (0.88, κ = 0.86) for all remaining TM-based LULCC maps. The “dense urban settlement” class had the best Kappa index and the smallest errors, and the “peri-urban” and “regenerating forest” classes had the lowest Kappa indexes and the highest Omission and Commission errors (Table 2). Both “peri-urban” and “regenerating forest” classes comprised a more heterogeneous mixture of land cover elements than the remaining classes, which may explain the lower accuracies.

Table 2. Kappa index of agreement and omission and commission errors for each LULC class from 2000, 2010 e 2015, after manual correction.

Classes	Kappa Index			Omission Error			Commission Error		
	2000	2010	2015	2000	2010	2015	2000	2010	2015

Non-forest vegetation	0.85	0.91	0.94	0.15	0.07	0.05	0.13	0.07	0.05
Peri-urban	0.79	0.68	0.85	0.13	0.17	0.07	0.18	0.28	0.13
Bare soil/rock	0.83	0.97	0.93	0.00	0.03	0.09	0.15	0.03	0.06
Dense urban settlements	1.00	1.00	0.88	0.05	0.00	0.03	0.00	0.00	0.10
Mature forest	0.85	0.88	1.00	0.10	0.10	0.06	0.13	0.10	0.00
Regenerating forest	0.81	0.72	0.93	0.26	0.31	0.08	0.15	0.23	0.06

3.1 Overall patterns of land use and land cover change

During the historical period investigated, we identified six main land cover change processes for the entire study area: increases in 1) dense urban settlements and 2) peri-urban cover, 3) afforestation, 4) deforestation (change to non-forest cover) and 5) forest disturbance (change from mature forest to regenerating forest); we also identified 6) a large amount of forest persistence. The expansion of dense urban settlements and peri-urban areas occurred mostly in the coastal plains. Forest persistence was the most dominant process along the 30 years studied, and was observed mostly at interior areas and over steep scarp terrain (Figure 2). The land cover and land use maps for each mapped date can be found in Appendix B.i.

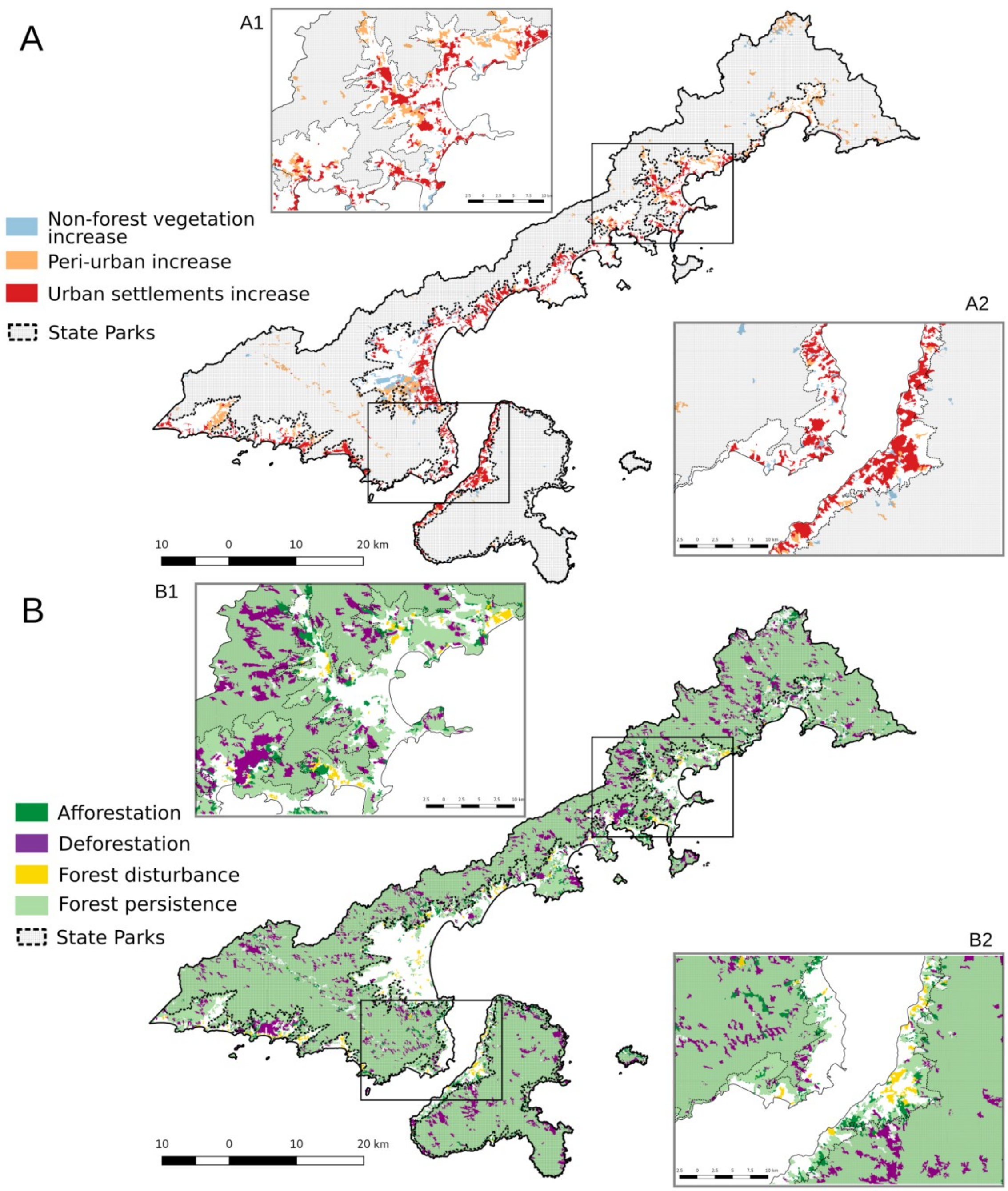

Figure 2 Main land use and land cover change processes observed between 1985 and 2015. A) Non-forest vegetation, peri-urban and dense urban settlement increase; B) Forest dynamics: afforestation, deforestation, forest disturbance (primary to secondary forest), forest persistence.

Dense urban settlements increased from 46.3 km² in 1985 to 123.8 km² in 2015, an increase of 167% over 30 years, and the peri-urban cover increased 14 km² (26.6% of the class area in FTS). From the initial 1985 map, by 2015 dense urban areas replaced 25% of non-forest cover (33.7 km^2 FTS), 28.6% of bare soil cover (5.6 km^2 FTS), 24.4% of peri-urban cover (12.4 km^2 of urban intensification FTS) and 10.9% of mature forest (5.3 km^2 of deforestation FTS) (Appendices B). Regenerating forests in 1985 were replaced by other LULC classes by 2015: 8.1% of non-forest vegetation (17.5 km^2), 10.2% of peri-urban (22 km^2), and 11% of dense urban settlement (23 km^2).

3.2 Land use and land cover changes outside State Parks

From 1985 to 2015, dense urban settlements increased between almost all time steps, replacing mostly peri-urban uses and rural uses characterized by non-forest vegetation (Figure 3), as well as a few natural cover areas, especially regenerating forests. Over the entire period, dense urban areas increased 74.5 km^2 (162.4% FTS) outside park limits, at an average annual rate of increase of 3.6%. The largest expansion of urban settlements occurred between 1995 and 2000 (almost 28 km^2, 43.6% of PTS), followed by 1985 and 1990 (23%, 11 km^2 PTS). Bare soil areas increased 12 km^2 (94.3% PTS) from 1990 to 1995 and then decreased almost 60% between 1995 and 2000, reflecting the frequent practice in the NCSP of clearing large areas to build urban settlements and private condominiums (urban sprawl, Appendix B). We also observed urban intensification in this period, shown by substitution of 9.6 km^2 (23.6% PTS) of peri-urban areas in 1995 by dense urban areas in 2000. The rate of dense urban expansion then started to decrease by the beginning of the 21^{st} century; 2005 to 2010 was the only interval without dense urban growth, and dense urban cover increased only 17.6 km^2 (17% PTS) from 2010 to 2015.

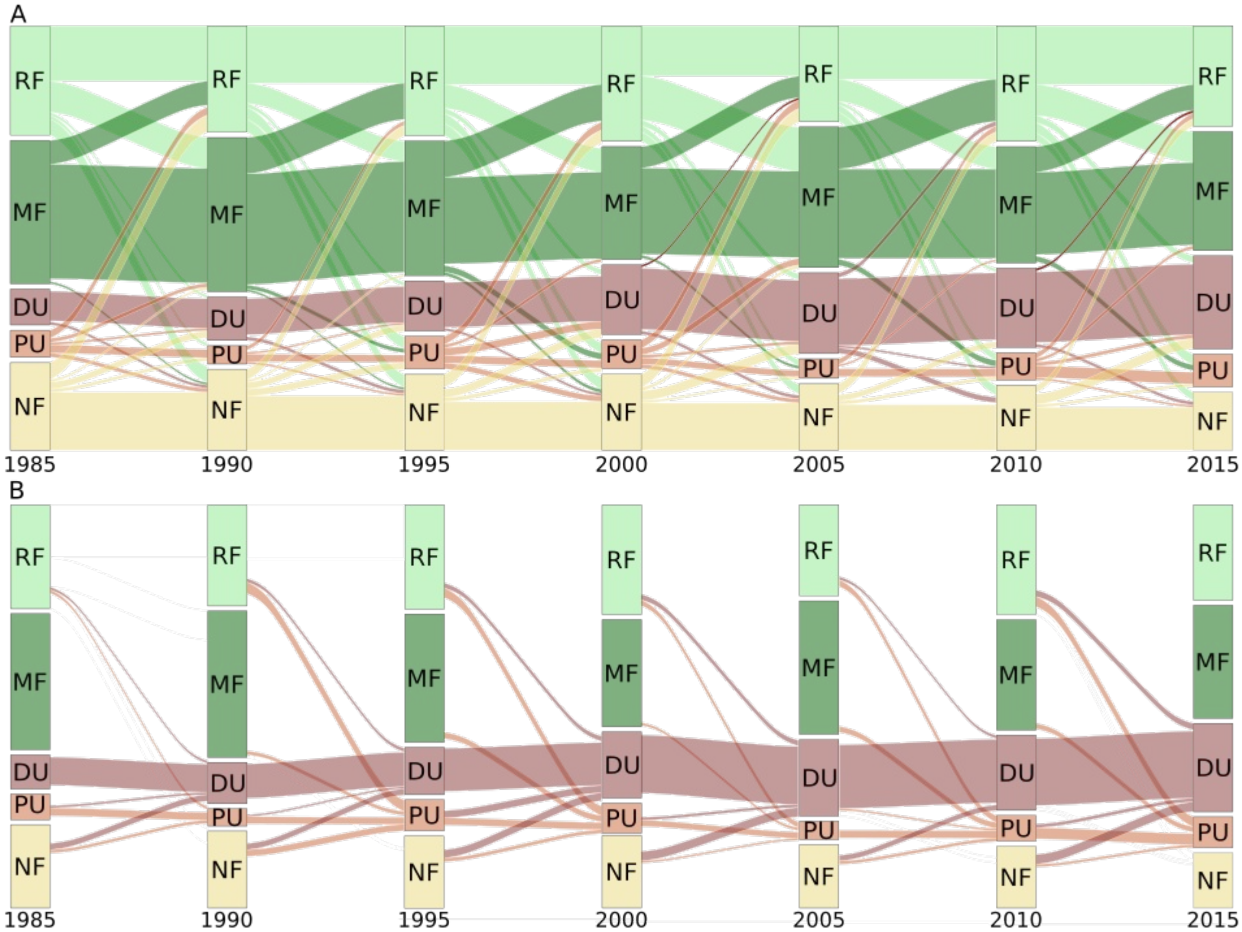

Figure 3. Land use and land cover change trajectories for the areas of the Northern Coast of São Paulo outside park limits: A) All conversion types; B) land use / cover conversion to dense urban settlements and peri-urban areas. RF = Regenerating forest; MF = Mature forest; DU = Dense urban settlement; PU = Peri-urban; NF = Non-forest vegetation.

Peri-urban areas increased 6.7 km² (19.5% PTS) from 1985 to 2015, at an average annual rate of increase of 1.9%. From 1985 to 1990 we quantified a peri-urban decrease of 33% PTS (10 km²) as a result of land abandonment and substitution by recovering forest and non-forest vegetation (land abandonment, Figure 4). We then observed high peri-urban growth between 1990 and 1995 (73.8% PTS, 17 km²), 2005 to 2010 (40% PTS, 10 km²), and 2010-2015 (17% PTS, 17.6 km²) (Figure 3B and Figure 4). This growth can be linked to new settlements (urban sprawl and a few new rural villages). Between 1995 and 2000, a peri-urban decrease of 4 km² (10% PTS) happened mostly due to urban intensification (Figure 4). Since dense urban settlement and urban intensification occurred mostly within the flat coastal areas, our data suggests that the peri-urban areas have been shifted towards interior and steeper areas (Figure 2 and 4).

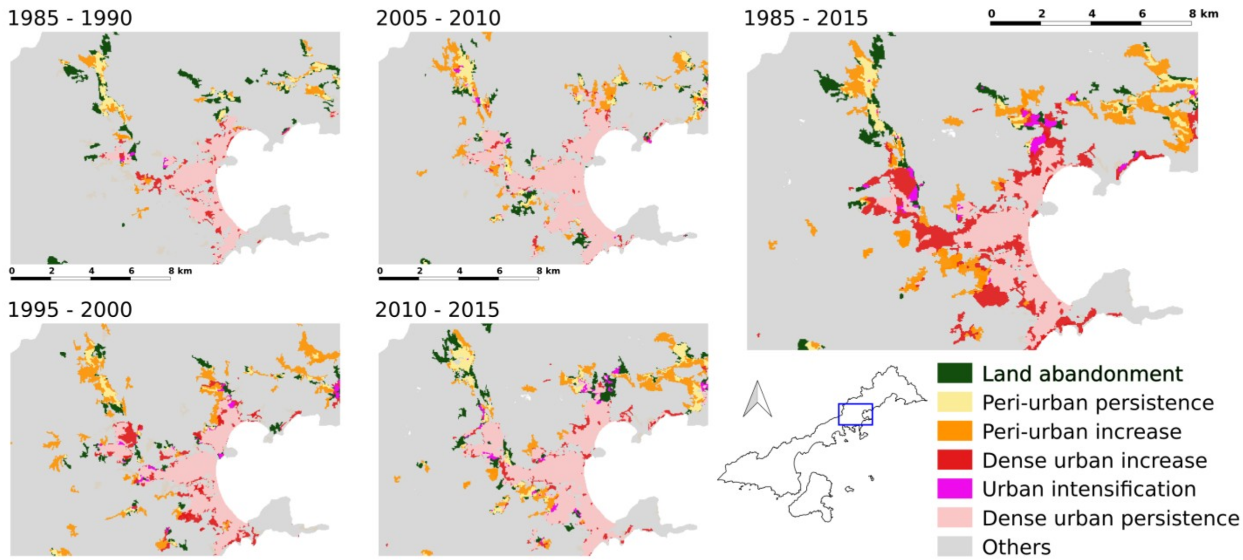

Figure 4. Peri-urban and dense urban settlement dynamics: example from the central region of Ubatuba municipality. Land abandonment = peri-urban conversion to non-forest vegetation and regenerating forest; Peri-urban persistence = peri-urban maintenance during the time step; Peri-urban increase = conversion from any cover class to peri-urban; Dense urban increase = conversion from any cover class to dense urban; Urban intensification = conversion from peri-urban to dense urban, Urban persistence = dense urban maintenance during the time step.

During the entire studied period, mature forest cover outside park limits decreased 16% and regenerating forest decreased 8% FTS due to deforestation. Mature forests present in 1985 were converted into peri-urban areas (5.1% FTS), dense urban settlements (3% FTS) and regenerating forests (24% FTS, i.e. forest disturbance) (Figure 3A). The 1995 to 2000 period had the largest loss of mature forest, 24 km^2 (15% PTS), while regenerating forests increased 11 km^2 (7.9% PTS) (Figure 3A). Forest cover outside park limits represented c.a. 50% of the NCSP territory in 2015, considering both mature and regenerating forests (Figure 2 and Figure 3A). Even outside park limits, we could quantify high percentages of forest cover persistence, with 64% of the forested area in 1985 remaining forested in 2015. We also observed afforestation, resulting mostly from land abandonment, with a substitution of 20% of peri-urban and 15% of non-forest vegetation by regenerating forests from 1985 to 2015 (Appendices B).

At the municipal scale, all municipalities had LULCC patterns similar to the entire study area. During the 30 studied years, dense urban settlement increases were higher in percentage at Ilhabela (758.9% FTS, followed by São Sebastião (174.4% FTS), Ubatuba (146.5% FTS) and Caraguatatuba (126.2% FTS). Caraguatatuba lost 14.9%, São Sebastião lost 24%, and Ubatuba lost 15% of mature forest, while Ilhabela gained 2.5% from FTS. LULCC data by municipality can be found in the supplementary online material (Appendix B).

3.3 Land use and land cover changes within State Parks limits

The three state parks combined lost 100 km² of mature forest (8% FTS) from 1985 to 2015, replaced mostly by regenerating forest and peri-urban cover. About 85% of total park area has persisted as mature forest (Figure 2). At the municipality scale, from 1985 to 2015, Caraguatatuba lost 7% FTS, of mature forest, Ilhabela lost 8.5% FTS, São Sebastião lost 3% FTS, and Ubatuba lost 10.4% FTS. The dense urban settlement areas increased from 1 km² to 2.7 km² from 1985 to 2015. Between 1985 and 1990, mature forest cover remained the same, and regenerating forest area increased almost 8 km², replacing non-forest vegetation (afforestation). The peri-urban area increased 3 km² and bare soil increased 2.6 km², substituting both forest stages within park limits during 1990 and 1995. From 1995 to 2000, mature forest cover had a decrease of 40 km² (5% PTS), mostly substituted by regenerating forest, which increased 45 km² (44.9% PTS). Ilhabela State Park was the only park that did not lose mature forest cover between 1995 and 2000. We quantified an increase of 2 km² (12.6% PTS) in new peri-urban settlements inside the parks between 2000 and 2005, and observed afforestation caused by changes from regenerating to mature forest; mature forest increased 15 km^2 while regenerating forest decreased 60 km^2. Regenerating forests replaced 107.6 km^2 of mature forests between 2005 and 2010. There were no notable changes within park areas between 2010 and 2015 (Appendix B).

4. Discussion

4.1. Peri-urban and urban increases, land abandonment and rural decreases: why have people moved to cities?

The fast observed urban expansion in NCSP (167% of dense urban and 26.6% of peri-urban from 1985 to 2015) can be linked to urban population growth, which went from 87,777 inhabitants in 1980 to 223,914 in 2000 and 281,800 in 2010, as a result of migration to urban centers (Instituto Brasileiro de Geografia e Estatística, 1980, 2000, 2010). In 1970, 81% of the censused population was classified as urban, increasing to 95% in 1980 and more than 98% in 1991, 2000 and 2010 (Carmo et al., 2012; IBGE, 1970, 1980, 2000, 2010; Rosemback et al., 2017). Inostroza et al (2010) have investigated different cities in South America and shown that population growth was a very important driver for urban expansion during the second half of the 20th century, led mostly by emigration from rural areas to the cities. Over time, population increase has been losing its importance as a driving force for urbanization in Latin America, but cities have continued to grow fast, mostly as a result of changes in demographic structure and increases in the amount of per capita land consumption, influenced by economic changes (Geist & Lambin, 2002; Inostroza et al., 2010).

Both urban growth and population increase by the end of the 20^{th} century may have been strongly influenced by the construction of new highways, especially the BR-101 highway, which provided better and faster access to NCSP (Carmo et al., 2012; Cunha, 2003; Comitê de Bacias

Hidrográficas do Litoral Norte, 2016). In coastal zones, the presence of seaports has been a historically important driver of city development, influencing land use change both directly and indirectly, especially by increasing urban and industrial uses (Cunha, 2003; Felsenstein, Lichter, & Ashbel, 2014). On the NCSP, the São Sebastião and Ubatuba Ports were likely a key driver for development, since their emergence as villages during the first half of 17th century. The presence of the São Sebastião Port has in turn brought oil and gas companies to the same municipality (Cunha, 2003; Teixeira, 2013), and during the early 21st century, the discovery of a new offshore oil and gas deposit in 2003 (*pre-salt*) and the construction of the Natural Gas Treatment Station of Caraguatatuba in 2007 increased investments in infrastructure and transportation projects linked with the energy industrial sector. Based on this timing, we can suggest accessibility improvements and the development of the oil and gas sector as two of the main drivers of the fast urban expansion and intensification observed from 1985 and 2015, especially in São Sebastião and Caraguatatuba municipalities. Landscape accessibility, considering terrestrial and marine transportation of people and goods, is known to be an important driver of landscape change influencing migration, rural depopulation, and the labor market, frequently resulting in rural abandonment and urban expansion (Antrop, 2005; Bürgi et al., 2017). Technological drivers of land use change in coastal zones have been confirmed for other countries; port construction and expansion in Israel (Felsenstein et al., 2014), accessibility improvements in coastal cities in Japan, Turkey, China and Brazil (Elmqvist et al., 2013), and the development of the energy sector and the presence of industries in Italy (Montanari, Londei, & Staniscia, 2014), all leading to rural abandonment and urban expansion.

Tourism linked to coastal and marine activities is the most important component of the economy in the region, also demanding investments in infrastructure development, accessibility, and the construction sector (CBHLN, 2016; IBGE, 2010). NCSP hosts more than 2,000 touristic establishments (i.e. hotels and restaurants), and the population frequently triples in number during the high season (CBHLN, 2016; FSEAD, 2016). Secondary residences within private condominiums are a frequent tourist accommodation in the NCSP, and the annual rate of increase in built-up areas was higher than the annual rate of population growth (1.6%, FSEAD, 2016), for both dense urban (3.6%) and peri-urban (1.9%) increases, which may be explained by the expansion of tourism infrastructure and vacation homes. It is thus reasonable to assume that the tourism sector and the housing market are also strong drivers of the urban expansion quantified by us in the NCSP, especially in the Ilhabela municipality, which has had the highest percent growth in dense urban settlements, and that these activities are likely to continue influencing land use changes and land governance. The role of tourism on land cover change has also been shown for other coastal and touristic regions (Corona, Galicia, Palacio-Prieto, Bürgi, & Hersperger, 2016; Elmqvist et al., 2013),

The complex interaction between economic and political drivers has been discussed before as the main reason behind land use change in coastal and touristic zones, especially regarding changes from agricultural use and forest cover to urban and industrial areas. The presence of ports and industries, as well as other urban and touristic services, provides several job opportunities and make coastal cities an attractive place for living, resulting in fast urban expansion and intensification from migration (Elmqvist et al., 2013; Montanari et al., 2014). In the NCSP, these processes are particularly well illustrated by the land abandonment quantified by us from 1985 to 1990, followed by urban sprawl and urban intensification due to peri-urban-expansion between 1990-1995 and 2005-2015, with dense urban increase during the entire period. Regarding land abandonment in the NCSP, studies suggest that the conversion from rural to urban happened mostly prior to our studied period, between 1960 and 1980 (Campos, 2000; Carmo et al., 2012; Silva, 1975). However, our results shown a continuing trend of conversion from rural to urban uses between 1985 and 2015, which is also reported by the Brazilian Rural Census data (LUPA 1995, 2007), where agricultural areas decreased in almost all NC municipalities, from 20.5% (1995) to 13.9% (2007) of the NCSP territory.

Conversely, part of the observed peri-urban growth between 1985 and 2015 (26.6% of FTS) can be also related to both transitions to mixed land uses and an increase in rural villages. We could not discriminate between these two sources of peri-urban increases due to the spatial resolution of our source images, and their relative contribution to LULCC in the region should be better studied in the future. An increase in rural villages can be a consequence of land use planning policies aiming to improve landscape sustainability provided by traditional populations and small farmers. Protected areas such as Indigenous Territories and Natural Heritage Areas were created during the late 1980’s and early 1990’s aiming to protect these population’s territories. The Serra do Mar State Park management plan has delimited the Historical-Cultural and Archaeological Zone (São Paulo, 2006), allowing native people settlements to persist inside park areas, and Federal Decree n° 6040 (National Policy for Sustainable Development of the Traditional Communities and Populations) has defined and protected traditional populations as a Brazilian Heritage, such as the *Caiçara*, Indigenous and *Quilombola* populations (Brasil 2007). The presence of local stakeholders, non-profit organizations and non-governmental organizations has been shown to be essential for developing sustainable cities, especially in regions with land use conflicts such as coastal and touristic regions (Elmqvist et al., 2013; Morgado, Gomes & Costa, 2014).

4.2. The effect of policies on forest persistence, afforestation, deforestation and disturbance

Mature forest loss and disturbance within park limits (100 km²) were a consequence of settlement intensification and sprawl outside and at the edge of the parks, likely because the footprint of urban expansion usually overcomes political borders (Antrop, 2005; Elmqvist et al., 2013). On the other hand, more than 95% of the state parks are still covered by mature forest (84.3%). As strictly protected areas, we suggest that the legislation instituting the three state parks has been an effective instrument for ensuring forest persistence and afforestation, even if a few deforested areas have been observed. The current policies for parks and other Brazilian protected areas are defined by the 2000 Brazilian Protected Areas federal legislation. This legislation forbids any human settlement inside Brazilian parks, and establishes that parks are created mainly for nature conservation, research and tourism. The federal legislation is usually complemented by the management plan of each protected area; the management plan of Serra do Mar State park (2006) establishes the strategic spatial plan for park management, defining different zones (including protective buffer zones around park limits), and its allowed uses. Considering this, we suggest that both instruments have been equally important for the observed forest persistence and afforestation process, and we recommend more effort by park managers in elaborating and implementing the required management plans. Several protected areas are created without having a management plan in place, or with plans that not integrated with other local land use plans, making it difficult to promote nature conservation strategies that are aligned with the economic and social life of neighbouring communities (Brasil, 2000; Freitas Lima; Ranieri, 2018).

Although urban expansion has mainly removed natural forest areas in the NCSP, regenerating forest have remained as a dominant land cover class outside parks limits, covering more than 40% of these areas and concentrating mostly in the foothills behind the coastal plains. In agreement with our data, a joint report by the S.O.S Mata Atlântica Foundation and the National Institute for Space Research (F.S.O.S & I.N.P.E, 2016) has also quantified a decline in deforestation rates and increase in regenerating areas for the entirety of the Atlantic Forest in São Paulo, between 2000 and 2016. For the NCSP, we suggest that the legal instruments for land use planning and forest conservation published during the late 1990's and early 2000's are likely to be the main drivers of forest persistence and afforestation outside park boundaries quantified between 2000 and 2010. Internationally, the recognition of the Atlantic Forest as a Biosphere Reserve (UNESCO, 1991) strongly influenced Brazilian authorities to improve protection efforts for the Atlantic Forest; the Federal Law of Environmental Crimes (Law n° 9605 of 1998) and the 2006 Federal Law for Protection of the Atlantic Forest Biome criminalizes deforestation and other environmental transgressions in this biome, even outside parks. This law was also the first to protect secondary stage (regenerating) forests against any harvesting or exploring activities, and we suggest that it may have influenced the afforestation process and the persistence of regenerating forest we observed in the NCSP. Also, in terms of strategic spatial planning, the Ecological-Economic Zoning (State Decree 49.215/2004), led by the São Paulo State Government, has probably been an import driver of forest persistence and afforestation quantified after 2005, as this legislation determined standards and policies for land use in the NCSP, and delimited zones where forest cover maintenance is enforced, especially at foothills and riparian forests, in agreement with the Brazilian Forestry Code (1965, 2012).

The topography itself also certainly plays a role in forest conservation on the NCSP. Most forested areas mapped by us were located in steep slope areas, and the parks mostly protect scarps and high elevation areas, while dense urban settlements mostly cover the flat lowlands near the coastline. Topography has been broadly discussed as a driver of forest persistence and afforestation in different landscapes and countries, as a result of human preferences of settling in flat areas (Ab’Sáber, 2007; Pazúr & Bolliger, 2017; Schneeberger, Bürgi, Hersperger, & Ewald, 2007; Silva et al., 2016).

4.3. Consequences of the dichotomy between fast urban growth and forest persistence

Presently, the NCSP shows high rates of human settlement expansion and a continuous decrease in rural areas, while still maintaining more than 80% of its territory protected by the three state parks and by general environmental laws. This trajectory of land use and land cover change between 1985 and 2015 has resulted in loss of landscape heterogeneity and multifunctionality, resulting on a strong dichotomy between urban use and forest cover. Population growth rates have declined since 2000, but are still among the highest in the state (FSEADE, 2016; Instituto Brasileiro de Geografia e Estatística, 2010). Rosemback et al. (2017) predicts that the number of primary residences (i.e. main homes of local residents, excluding tourism-oriented secondary residences) in the in NCSP will increase by 48% by 2030, due to changes in demographic structure. The authors also conjecture that this growth will be mostly located in peri-urban areas, since the dense urban areas are already mainly occupied by tourism infrastructure, and the urban land available for new development is very expensive.

Outside park limits, dense urban and peri-urban areas occupy 160 km^2 (30%), forests occupy c.a. 50% and all other land cover types occupy less than 15% (80 km^2). If our observed average annual rate of urban and peri-urban expansion remains unchanged (business-as usual scenario), we can expect that urban areas will increase by 65.7 km^2 and peri-urban areas will increase by 11.9 km^2, for a total of 77.6 km^2 of built-up areas by 2030. Therefore, for this growth to be accommodated almost all remaining non-protected lands will need to be converted to urban and peri-urban uses by 2030. This assumption is not unreasonable, as several authors have predicted that rates of urban growth will continue to increase rapidly in many parts of the world, considering both sprawl and intensification, especially the peri-urban areas of developing countries and coastal zones surrounded by biodiversity hotspots (Ellis & Ramankutty, 2008; Elmqvist et al., 2013; Verburg et al., 2015). The UN (2009) has also predicted that urban population in South American cities will increase by 34% until 2050, and Inostroza et al. (2010) have predicted that the urban core area of major cities in South America will double by 2035, assuming that rates of change continue at their current levels.

These expected land cover changes are likely to result in negative effects that go beyond a land use planning crisis. The increase in peri-urban use quantified by us between 1990-1995 and 2005-2015 is likely associated to informal settlement leading to disadvantaged neighbourhoods (e. g. “slums”), which suffer from a combination of economic, health, and environmental issues resulting from unplanned urban sprawl and expansion of urban limits. This suburbanization phenomena has been described as a frequent consequence of the fast urban sprawl in several Latin America cities and developing countries in general, usually led by economic drivers (Elmqvst 2013, Inostroza et al., 2010). In Latin America, per capita land consumption has increased for the richer economic classes in urban areas, increasing land prices and driving the poorest segments of the population away from urban centres and facilities (Inostroza et al., 2010).

Furthermore, the loss of traditional rural landscapes will negatively impact quality of life in the region. Traditional uses promote sustainable landscapes (Antrop 2005), and the replacement of rural areas can result in loss of landscape functionality and diversity and critically impact food security, also changing the complex relationship between people and the landscape (Antrop, 2005; Bürgi, Verburg, et al., 2017; De Groot, 2006; McNeely & Scherr, 2009; Nassauer, 1995; Tuan, 1983). Traditional peoples and small farmers still present in the NCSP are currently the main drivers of landscape multifunctionality maintenance. However, most of the territories occupied by these communities are not properly delimited by legal instruments,and if the observed rates of urbanization persist, traditional peoples and landscape multifunctionality will be both under severe threat.

5. Conclusions

Our work provides a detailed characterization of urban expansion and sprawl, and advances our understanding of the main drivers of land use and cover change in the Northern Coast of São Paulo state. These results are an important subsidy for future land use planning and landscape management, as we show that available land for human settlement has been decreasing steadily in the studied region, especially since c.a. 80% of the entire region is still comprised by park areas under very strict land use regulation.

Our observed results and the supporting literature show that economic policies, including the expansion and improvement of road accessibility and the presence of large industrial enterprises were important drivers of population growth until now, resulting in dense urban and peril-urban expansion. Another important driver is the continued expansion of the tourism and housing markets, which also influence migration and increases the demand for both primary and secondary residences, further driving the expansion of built-up areas paired with rural use decline. Current economic and demographic observations suggest that the same rates and trajectories of past land changes can be expected to continue in the future, as there has been no significant changes in land use planning policies and/or efforts to create a more diverse and multifunctional landscape for the NCSP region. If this expectation is proven true, urban and peri-urban expansion will replace all other land uses and cover types outside park areas by 2030, including unprotected forest areas, native and traditional people’s territories and the remaining rural uses. Considering that the Northern Coast of São Paulo state still shows high rates of population growth that demand the construction of new primary residences, and that there are large scale logistic enterprises such as road and port expansion and increases in oil exploration planned for the near future, the region may be fast approaching a land use planning and management crisis.

To authorities and planners, we thus suggest more effort in establishing long-term and sustainable housing and development programs, instead of focusing solely on business and industry growth. For instance, we suggest the development of a tiered municipal urban service tax regime that taxes more highly properties corresponding to industrial uses, high value accommodations, hotels and other enterprises that more heavily consume landscape space and ecosystem services, while providing tax incentives for primary residence uses and for the implementation of sustainable uses and landscape diversification practices in private land.

The role of local actors and institutions has been essential for maintaining landscape multifunctionality and protecting traditional rural landscapes, promoting sustainable interactions between forest cover conservation and diverse agricultural uses, but more concrete actions are needed to protect traditional rural landscapes and promote landscape multifunctionality. We urge government agencies and decision-makers involved in the planning and administration of the

NCSP to review current policies and regulations for land use both within and outside parks to make them more inclusive, with strong participation from all stakeholders, otherwise these alternative uses will be lost within a few decades and the progressive urban encroachment will start to strongly threaten the effectiveness of existing protected areas. The developing of more participatory management instruments and regulations that effectively engage public administrators, traditional communities, small farmers, representatives of the tourism sector and other important stakeholders in the land use planning process may improve the success of strategic spatial planning and governance, developing more sustainable and multifunctional landscapes in the region. We also hope our results may help guide landscape management and conservation policies in similar coastal regions throughout the world.

6. References

1. Ab'Sáber, A. (1986). O tombamento da Serra do Mar no Estado de São Paulo. *Revista Do Patrimônio Histórico E Artístico Nacional*, *21*, 7–20. Retrieved from http://portal.iphan.gov.br/uploads/publicacao/RevPat21_m.pdf
2. Ab'Sáber, A. (2007). *Os domínios da natureza no Brasil: Potencialidades Paisagísticas* (4°). São Paulo: Ateliê Editorial.
3. Almeida, F. F. . de;, & Carneiro, C. dal R. (1998). Origem e evolução da Serra do Mar. *Evista Brasileira de Geociências*, *28*(2), 135–150.
4. Antrop, M. (2000). Background concept for integrated landscape analysis. *Agriculture, Ecosystems and Environment*, *77*(July 1999), 17–28.
5. Antrop, M. (2005). Why landscapes of the past are important for the future. *Landscape and Urban Planning*, *70*(1–2), 21–34. https://doi.org/10.1016/j.landurbplan.2003.10.002
6. Blaschke, T. (2010). Object based image analysis for remote sensing. ISPRS Journal of Photogrammetry and Remote Sensing. *Journal of Photogrammetry and Remote Sensing*, *65*(1), 2–16. Retrieved from https://doi.org/10.1016/j.isprsjprs.2009.06.004
7. Blaschke, T., Hay, G.J., Kelly, M., Lang, S., Hofmann, P., Addink, E., Feitosa, R.Q., Meer, F.V.D., Werff, H.V.D., Coillie, F.V. (2014). Geographic object-based image analysis – towards a new paradigm. ISPRS J. *Photogramm. Remote Sensing*. 87, 180–191.
8. Brasil. (2000). Lei n° 9.985, de 18 de julho de 2000, institui o Sistema Nacional de Unidades de Concervação da Natureza. Brasil. Retrieved from http://www.planalto.gov.br/ccivil_03/LEIS/L9985.htm
9. Breiman, L. (2001). Randomforest2001. *Machine Learning*, *45*(1), 5–32. https://doi.org/10.1017/CBO9781107415324.004
10. Bunting, P., & Clewley, D. (2013). The Remote Sensing and GIS Software Library . *Computers and Geosciences*, *60*, 216–226.
11. Bürgi, M., Bieling, C., von Hackwitz, K., Kizos, T., Lieskovský, J., Martín, M. G., … Printsmann, A. (2017). Processes and driving forces in changing cultural landscapes across Europe. *Landscape Ecology*, *32*(11), 2097–2112. https://doi.org/10.1007/s10980-017-0513-z
12. Bürgi, M., Hersperger, A. M., & Schneeberger, N. (2004). Driving forces of landscape change – current and new directions. *Landscape Ecology*, *19*(8), 857–868. https://doi.org/10.1007/s10980-004-0245-8
13. Bürgi, M., Verburg, P. H., Kuemmerle, T., & Plieninger, T. (2017). Analyzing dynamics and values of cultural landscapes. *Landscape Ecology*, *32*(11), 2077–2081. https://doi.org/10.1007/s10980-017-0573-0
14. Campos, J. F. de. (2000). *Santo Antônio de Caraguatatuba: memórias e tradição de um povo*. Caraguatatuba: FUNDACC.
15. Carmo, R. L. do, Marques, C., & Miranda, Z. A. I. de. (2012). Dinâmica Demográfica Economia e Ambiente na Zona Costeira de São Paulo. *Textos Nepo 63*, *63*, 1–111. Retrieved from http://www.nepo.unicamp.br/textos/publicacoes/textos_nepo/textos_nepo_63.pdf
16. Comitê de Bacias Hidrográficas do Litoral Norte (CBHLN). (2014). Relatório de Situação dos Recursos Hídricos do Litoral Norte Ano 2014 – Dados 2013, 42.
17. Comitê de Bacias Hidrográficas do Litoral Norte (CBHLN). (2016). Plano de Bacias

Hidrográficas do Litoral Norte, (Watershed Manage Plan - Northern Coast of São Paulo) 2016

18. Congalton, R. G. (1991). A Review of Assessing the Accuracy of Classification of Remotely Sensed Data A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *Remote Sensing of Environment*, *4257*(September), 34–46. https://doi.org/10.1016/0034-4257(91)90048-B
19. Corona, R. ., Galicia, L. ., Palacio-Prieto, J. L. ., Bürgi, M. ., & Hersperger, A. . (2016). Local deforestation patterns and driving forces in a tropical dry forest in two municipalities of southern Oaxaca, Mexico (1985-2006)) [Patrones y conductores de la deforestación a escala local de la selva baja caducifolia en dos municipios a sur de Oaxac. *Investigaciones Geograficas*, *2016*(91), 86–104. https://doi.org/10.14350/rig.50918
20. Cunha, Í. (2003). Conflito ambiental em águas costeiras: relação porto - cidade no Canal de São Sebastião. *Ambiente & Sociedade*, *6*(2), 83–98. https://doi.org/10.1590/S1414-753X2003000300006
21. De Groot, R. (2006). Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. *Landscape and Urban Planning*, *75*(3–4), 175–186. https://doi.org/10.1016/j.landurbplan.2005.02.016
22. Dean, W. (1996). *A ferro e fogo: a história e a devastação da Mata Atlântica brasileira* (1st ed.). São Paulo: Cia das Letras.
23. Ellis, E. C., & Ramankutty, N. (2008). Putting people in the map: Anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, *6*(8), 439–447. https://doi.org/10.1890/070062
24. Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., … Tidball, K. (2013). *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*. (Springer, Ed.), *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment*. Dordrecht. https://doi.org/10.1007/978-94-007-7088-1_33
25. Freitas Lima, E. A. C.; Ranieri, V. E. L. (2018). Land use planning around protected areas: case studies in four state parks in the Atlantic Forest region of southeastern Brazil. *Land Use Policy*, 71.
26. Felsenstein, D., Lichter, M., & Ashbel, E. (2014). Coastal congestion: Simulating port expansion and land use change under zero-sum conditions. *Ocean and Coastal Management*, *101*(PB), 89–101. https://doi.org/10.1016/j.ocecoaman.2014.08.001
27. FSEADE. (2016). Informações dos Municípios Paulistas. Retrieved from http://www.imp.seade.gov.br/frontend/#/tabelas
28. Fundação SOS Mata Atlântica; Instituto Nacional de Pesquisas Espaciais (F.S.O.S & I.N.P.E). (2016). *ATLAS DOS REMANESCENTES FLORESTAIS DA MATA ATLÂNTICA PERÍODO 2014-2015*. *Fundação SOS Mata Atlântica e Instituto de Pesquisas Espaciais*.
29. Geist, H. J., & Lambin, E. F. (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *BioScience*, *52*(2), 143. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2
30. Hijmans, R. J., van Etten, J., Cheng, J., Mattiuzzi, M., Sumner, M., Greenberg, J. A., … Shortridge, A. (2016). Package “raster”:geographic data analysis and modeling. In: R Package Version 2.5-2. Retrieved from https://cran.r-project.org/package=raster
31. Inostroza, L., Baur, R., Csaplovics, E., (2010). *Urban Sprawl and Fragmentation in*

Latin America: A Comparison with European Cities. The Myth of the Diffuse Latin American City. Lincoln Institute of Land Policy Working Paper. http://www.urbansprawlproject.com/planos/Inostroza_et_al_2010.pdf

32. Instituto Brasileiro de Geografia e Estatística (IBGE). (1970,1980, 1991, 2000, 2010). Censo 1970,1980, 1991, 2000, 2010. Retrieved March 7, 2016, from http://censo2010.ibge.gov.br/resultados.html
33. Kennedy, R. E., Yang, Z., & Cohen, W. B. (2010). Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr — Temporal segmentation algorithms. *Remote Sensing of Environment*, *114*(12), 2897–2910. https://doi.org/10.1016/j.rse.2010.07.008
34. Maricato E (2003) Metrópole, legislação e desigualdade. *Estudos Avançados* (São Paulo, IEA-USP) 17: 151–166
35. McNeely, J. A., & Scherr, S. J. (2009). *Ecoagricultura : alimentação do mundo e biodiversidade*. São Paulo: Editora Senac.
36. Mittermeier, R. A., Robles-Gil, P., Hoffmann, M., Pilgrim, J. D., Brooks, T. B., Mittermeier, C. G., … Fonseca, G. A. z. (2004). *Hotspots Revisited: Earths Biologically Richest and Most Endangered Ecoregions*. Mexico City: CEMEX.
37. Montanari, A., Londei, A., & Staniscia, B. (2014). Can we interpret the evolution of coastal land use conflicts? Using Artificial Neural Networks to model the effects of alternative development policies. *Ocean and Coastal Management*, *101*(PB), 114–122. https://doi.org/10.1016/j.ocecoaman.2014.09.021
38. Morgado, P., Gomes, E., & Costa, N. (2014). Competing visions? Simulating alternative coastal futures using a GIS-ANN web application. *Ocean and Coastal Management*, *101*(PB), 79–88. https://doi.org/10.1016/j.ocecoaman.2014.09.022
39. Nassauer, J. I. Culture and changing landscape structure. *Landscape Ecology*, v. 10, n. 4, p. 229–237, 1995
40. Pazúr, R., & Bolliger, J. (2017). Land changes in Slovakia: Past processes and future directions. *Applied Geography*, *85*, 163–175. https://doi.org/10.1016/j.apgeog.2017.05.009
41. Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., … Duchesnay, É. (2012). Scikit-learn: Machine Learning in Python. *Journal of Machine Learning Research*, *12*, 2825–2830. https://doi.org/10.1007/s13398-014-0173-7.2
42. . https://doi.org/10.1016/j.landusepol.2016.04.040
43. Ribeiro, M. C., Metzger, J. P., Camargo Martensen, A., Ponzoni, F. J., & Hirota, M. M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation*, *142*, 1141–1153. https://doi.org/10.1016/j.biocon.2009.02.021
44. Rosemback, R. G., Rangel Rigotti, J. I., Da Fonseca Feitosa, F., Vieira Monteiro, A. M., Rosemback, R. G., Rigotti, J. I. R., … Monteiro, A. M. V. (2017). Demografia, planejamento territorial e a questão habitacional: prognóstico da situação habitacional do Litoral Norte Paulista. *Revista Brasileira de Estudos de População*, *34*(2), 1. https://doi.org/10.20947/S0102-3098a0005
45. Rossi, M., & Queiroz Neto, J. P. (2001). Os solos como indicadores das relações entre sedimentos continentais e marinhos na planície costeira: Rio Guaratuba (SP). *Revista Brasileira de Ciência Do Solo*, *25*(1), 113–120. https://doi.org/10.1590/S0100-06832001000100012

46. São Paulo. (1977). Decreto Estadual n° 10.251 de 30 de agosto de 1977. Cria o Parque Estadual da Serra do Mar e dá providências correlatas. Retrieved from http://www.al.sp.gov.br/repositorio/legislacao/decreto/1977/decreto-10251-30.08.1977.html
47. São Paulo. (1995). Levantamento Censitário das Unidades de Produção Agropecuária (*LUPA*) - Brazilian Rural Census data
48. São Paulo. (2006). *Parque Estadual da Serra do Mar - Plano de Manejo.* São Paulo: Secretaria do Meio Ambiente /Instituto Florestal.
49. São Paulo. (2007). Levantamento Censitário das Unidades de Produção Agropecuária (*LUPA)* Brazilian Rural Census data
50. São Paulo. (2015). Plano de Manejo do Parque Estadual Ilhabela. Ilhabela.
51. Schneeberger, N., Bürgi, M., Hersperger, A. M., & Ewald, K. C. (2007). Driving forces and rates of landscape change as a promising combination for landscape change research —An application on the northern fringe of the Swiss Alps. *Land Use Policy*, *24*(2), 349–361. https://doi.org/10.1016/j.landusepol.2006.04.003
52. Silva. (1975). *O litoral norte do estado de São Paulo: formação de uma região periférica /*. São Paulo : Instituto de Geografia, Universidade de São Paulo,.
53. Silva, R. F. B. da., Batistella, M., & Moran, E. F. (2016). Drivers of land change: Human-environment interactions and the Atlantic forest transition in the Paraíba Valley, Brazil. *Land Use Policy*, *58*, 133–144. https://doi.org/10.1016/j.landusepol.2016.07.021
54. Teixeira, L. (2013). *Megaprojetos no litoral norte paulista: o papel dos grandes empreendimentos de infraestrutura na transformação regional. 2013*. Universidade Estadual de Campinas.
55. Tuan, Y. F. (1983). *Espaço e lugar: a perspectiva da experiência.* São Paulo: DIFE.
56. Verburg, P. H., Crossman, N., Ellis, E. C., Heinimann, A., Hostert, P., Mertz, O., … Zhen, L. (2015). Land system science and sustainable development of the earth system: A global land project perspective. *Anthropocene*, *12*, 29–41. https://doi.org/10.1016/j.ancene.2015.09.004

List of tables

Table 1 - Land use and land cover classes used for mapping land cover changes in the Northern Coast of São Paulo State, Brazil, between 1985 and 2015, using Landsat historical data.

Land use / land cover class	Description
Mature forest	Dense forest characterized by an advanced successional stage comprised mainly by primary forest, or occasional old-growth secondary forest.
Regenerating forest	Less dense forest, early to medium successional stages, mostly comprised by regenerating secondary forest.
Non-forest vegetation	Native or exotic vegetation including pastures, grasslands and agriculture.
Bare soil and rock	Exposed soil or rock surfaces lacking vegetation and buildings and including sandy beaches and rocky shores.
Peri-urban	Mixed areas with lower population density and sparse buildings, including a high diversity of rural uses, agroforestry, and small forest fragments.
Dense urban settlements	Dense built-up areas, mostly urban.
Water	Free water surfaces.

Table 2. Kappa index of agreement and omission and commission errors for each LULC class from 2000, 2010 e 2015, after manual correction.

Classes	Kappa Index			Omission Error			Commission Error		
	2000	2010	2015	2000	2010	2015	2000	2010	2015
Non-forest vegetation	0.85	0.91	0.94	0.15	0.07	0.05	0.13	0.07	0.05
Peri-urban	0.79	0.68	0.85	0.13	0.17	0.07	0.18	0.28	0.13
Bare soil/rock	0.83	0.97	0.93	0.00	0.03	0.09	0.15	0.03	0.06
Dense urban settlements	1.00	1.00	0.88	0.05	0.00	0.03	0.00	0.00	0.10
Mature forest	0.85	0.88	1.00	0.10	0.10	0.06	0.13	0.10	0.00
Regenerating forest	0.81	0.72	0.93	0.26	0.31	0.08	0.15	0.23	0.06

List of figures

Figure 1. A) Map of Brazil showing the location of São Paulo State (SP). B) Northern Coast of São Paulo State showing the location of state parks, main highways, oil and gas infrastructure, major ports and airports, and urban and peri-urban census sectors.

Figure 2. Main land use and land cover change processes observed between 1985 and 2015. A) non-forest vegetation, peri-urban and dense urban settlement increase; B) Forest dynamics: afforestation, deforestation, forest disturbance (primary to secondary forest), forest persistence. C) Digital Elevation Model (ALOS World3D).

Figure 3. Land use and land cover change trajectories for the areas of the Northern Coast of São Paulo outside park limits: A) All conversion types; B) land use / cover conversion to dense urban settlements and peri-urban areas. RF = Regenerating forest; MF = Mature forest; DU = Dense urban settlement; PU = Peri-urban; NF = Non-forest vegetation

Figure 4. Peri-urban and dense urban settlement dynamics: example from the central region of Ubatuba municipality. Land abandonment = peri-urban conversion to non-forest vegetation and regenerating forest; Peri-urban persistence = peri-urban maintenance during the time step; Peri-urban increase = conversion from any cover class to peri-urban; Dense urban increase = conversion from any cover class to dense urban; Urban intensification = conversion from peri-urban to dense urban, Urban persistence = dense urban maintenance during the time step.

List of appendices

A) Methods: Scripts for processing on “RSGISlib” free algorithms library, in Python language:

- A.i) Segmentation
- A.ii) Random Forest Classification
- Aiii) Training samples area (km²) for the implementation of Random Forests algorithm

B) Results

- B.i) Land use and land cover maps
- B.ii) Land use and cover characterization inside and outside state parks
- B.iii) Transitional matrix of land use and land cover change Northern Coast of São Paulo State