Vegetation cover and land use of a protected coastal area and its surroundings, southeast Brazil

Cobertura vegetal e uso da terra de uma área costeira protegida e seu entorno no sudeste do Brasil

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Abstract

We applied remote sensing techniques on a TM Landsat 5 image (1:50,000) to map land use and vegetation cover of the Restinga de Jurubatiba National Park and surroundings. The thematic map generated from the digital classification of the image allowed us to spatially characterize and quantify the different land uses and soil covers of the area. Thirteen classes were identified. The most representative classes in the park were the *Clusia* (31.99%) and Ericaceae formations (29.14%). More than 90% of the park is occupied by native vegetation and coastal lagoons. The surroundings are very much altered by human activities (e.g. 70.64% is used for agriculture and/or cattle raising). Two hundred and three forest fragments (0.3 to 235 ha) were identified, of which 45.3% are less than 5 ha. Most fragments (56.7%) have a very elongated shape, and are thus submitted to an intense edge effect. The intense fragmentation of the surroundings and the isolation of this protected area can imply, in the long run, the loss of genetic diversity.

Key words: Atlantic forest complex, landscape ecology, protected areas, remote sensing, restinga.

Resumo

Foram aplicadas técnicas de sensoriamento remoto em uma imagem TM Landsat 5 (1:50.000) para mapear uso e cobertura vegetal do Parque Nacional da Restinga de Jurubatiba e seu entorno. O mapa temático gerado a partir da classificação digital da imagem permitiu caracterizar espacialmente e quantificar os diferentes usos e coberturas do solo da área. Treze classes foram identificadas. As classes mais representativas no parque foram as formações de *Clusia* (31,99%) e Ericaceae (29,14%). Mais de 90% do parque é ocupado por vegetação nativa e lagoas costeiras. O entorno está muito mais alterado por atividades humanas (e.g. 70,64% são utilizados para agricultura e/ou pastagem). Duzentos e três fragmentos florestais (0,3 a 235 ha) foram identificados, dos quais 45,3% menores que 5 ha. A maioria dos fragmentos (56,7%) tem a forma muito alongada, estando assim submetidos a um forte efeito de borda. A intensa fragmentação do entorno e o isolamento desta área protegida podem implicar, em longo prazo, em perda da diversidade genética.

Palavras-chave: Complexo da Floresta Atlântica, ecologia da paisagem, áreas protegidas, sensoriamento remoto, restinga.

Introduction

The concept of national parks, as it first appeared in nineteenth century United States, was based on romantic visions of the beauty of nature and wilderness preservation. This was soon redefined as the preservation of complex ecosystems and maintenance of biodiversity (Hironaka 2003) in different types of reserves collectively called protected areas - of which national parks are only one of them. Although the practice of creating protected areas fastly spread worldwide, these sites often present problems

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such as isolation and poor connection to other wild areas (e.g. Ayres *et al.* 2005). Thus, the focus on wilderness islands has been gradually shifting towards a landscape mosaic view, where networks of different types of protected areas (Metzger 2006) are fostered. Ecological corridors, for instance, are now an obvious way to perform environmental protection across size scales (Fonseca *et al.* 2004; Hilty *et al.* 2006).

This upscale movement towards a landscape approach, when dealing with protected areas, often requires application of remote sensing techniques on satellite images (e.g. Richter *et al.* 2004). Selection of viable and priority habitats for conservation (Anacleto *et al.* 2005; Ayres *et al.* 2005) and analysis of land use patterns and changes in time (Martins *et al.* 2006) are common procedures to which such tools are applied.

In this study we applied remote sensing techniques to provide a descriptive account of vegetation cover and land use of a national park protecting a coastal sandy plain ecosystem in southeast Brazil, locally named *restinga*, and its surroundings, here defined as a 10 km wide buffer. Our interest in this vegetation type derives from the fact that literature indicates a strong biogeographic and ecological influence of the neighboring Atlantic rain forest (Scarano 2002, 2009). For instance, it has been reported that *restinga* vegetation is composed by at least 80% of plant species originated from such rain forest (Araujo 2000). This descriptive effort allowed us to address two issues that are relevant to the conservation of this national park: (1) what is the land-use pattern of the national park's surroundings? And (2) how this landscape-level analysis relates to the prevalent classification of local plant communities proposed by Araujo *et al.* (1998)?

Material and Methods
Study Area
The Restinga de Jurubatiba National Park (22º08'–22º19'S; 41º17'–41º43'W) is located in the north coast of the state of Rio de Janeiro, southeast Brazil (Fig. 1). It was created on April 29th, 1998, to protect an area of 14,838 ha of sandplains and coastal lagoons, representing one of the largest *restinga* ecosystems protected by federal law (Rocha *et al.* 2004). Jurubatiba appeared suitable for this type of study both because the results can contribute to its management and also for the fact that it has a long tradition of biodiversity research, since it houses a site of the Brazilian Long-Term Ecological Research Programs (Barbosa *et al.* 2004).

Unlike most sandy coastal plains in Rio de Janeiro, which date from the Holocene, the Jurubatiba plains consist of a series of parallel pleistocenic beach ridges (120,000 yr BP) formed by the silting of marine sediments (Martin *et al.* 1993). These beach ridges reach a maximum 10 km wide. The region is formed by three geomorphologic provinces: mountain region (area of occurrence of Precambrian crystal rocks), Tertiary tablelands (*tabuleiros*) and Quaternary sandy plains (see Martin *et al.* 1993). The park protects the Quaternary sandy plains, which display ten different plant communities according to Araujo *et al.* (1998): three forest formations, three open scrub areas, one closed scrub area, two grassland formations and one aquatic formation. The surroundings are composed mainly of Tertiary ground. Climate is Köppen's Aw tropical rainy type, with hot and rainy summer and dry winter (Henriques *et al.* 1986).

Image processing
A Landsat 5 TM image (July 4th, 2005, referenced for the path/row 216/75) was used to generate the image map and the thematic map.

Geometric image correction was made using the Spring Software (version 4.1), based on an image of the same scene existent at the Laboratory of Remote Sensing and Environmental Studies ESPAÇO (Institute of Geosciences, Federal University of Rio de Janeiro). Control points distributed through the image, in places of easy recognition as highways, river mouths etc., were chosen. The root mean square error of the test points was of 56.04 m that is in accordance with the specification for cartographic accuracy standard for the scale proposed in category C (Cruz & Barros 2012), for elaboration of the image and thematic map. The projection used was UTM and datum WGS 84.

The limits of the national park were obtained in "shape" format (www.ibama.gov.br) with the North American 1927 datum. Datum transformation and the surrounding buffer (Fig. 1) were made in ArcMap module from ArcGis software (version 9.1).

We used a classification based on object (GEOBIA) (Cruz *et al.* 2007) developed in the software e-Cognition 4.0. The definition of the classes and the choice of the samples that would represent each one of these classes were based on the description of the plant communities at the national park (Araujo *et al.* 1998), and on the data acquired in field works performed during the years of
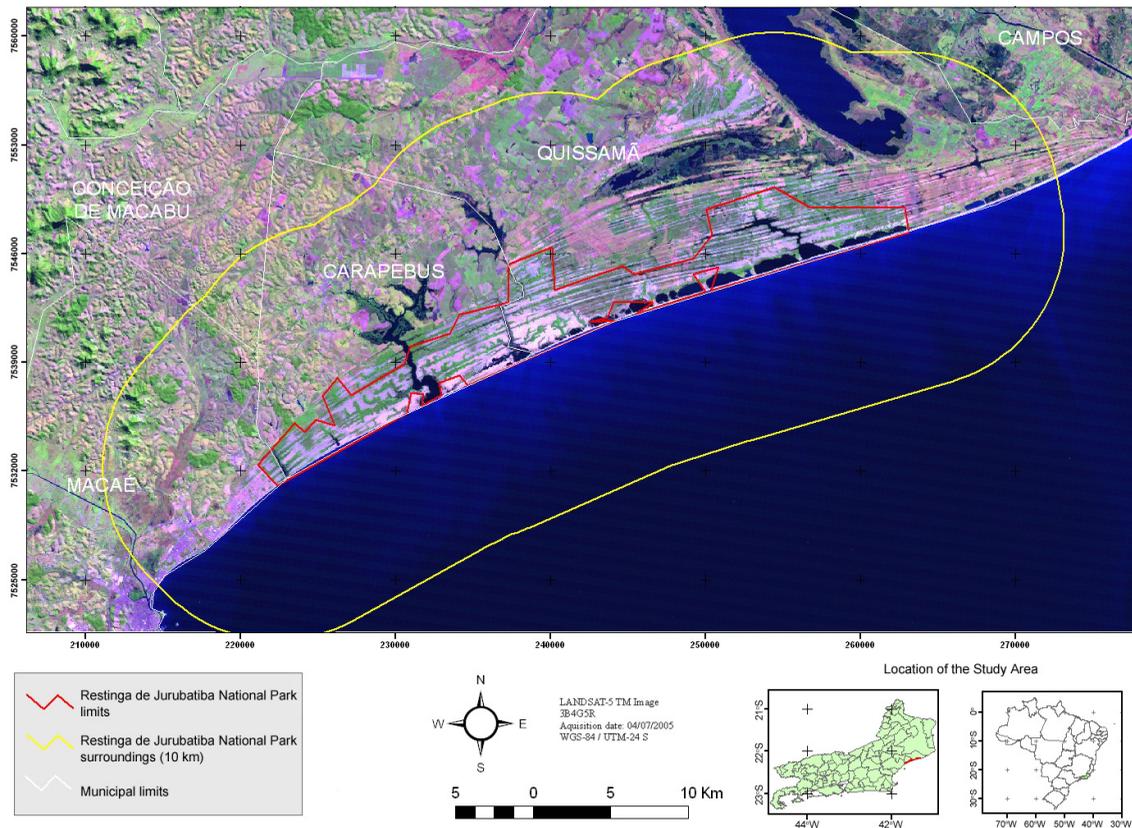
Figure 1 – Landsat 5 TM image showing the Restinga de Jurubatiba National Park and surroundings.

2005 and 2007. In this occasion, the area of the national park and of the surroundings were surveyed by car in almost their entire extensions and GPS landmarks were annotated as sample areas for classification and to minimize uncertainty in the final editing process.

The scale parameter used for segmentation was 10 and the bands used were 1 (blue); 2 (green); 3 (red); 4 (near-infrared); 5 (mid-infrared) and 7 (mid-infrared). A first classification was generated based on the nearest neighbor, and a second one was generated based on modeling the descriptors average, standard deviation and ratio between all bands, and NDVI (normalized difference vegetation index). The GEOBIA classification allows for the association of a wide range of descriptors during the analysis of the best set of rules that would permit a more accurate class discrimination. In this case, this mean NDVI associated to reflectance values of some isolated bands allowed the discrimination of some classes.

The process adopted for classification is not totally automatized. Even with the supervision of

a specialist to establish the rules, there is a need to perform final manual editions. This procedure used the image 5R4G3B and the software ArcGis (9.1).

To calculate the overall accuracy of the mapping, we used the tool "create random points", in ArcGIS software version 9.3. It was decided to generate to each class 10 random points, since one of the classes is nearly 50% of the mapping. These points were projected on images (2005) available on Google Earth. Then, it was generated a confusion matrix, whose diagonal represents the overall accuracy. Later, the classes were quantified for the park and its surroundings.

A circularity index (CI) was obtained for each forest fragment presented in the surroundings, following the equation $CI = (2\sqrt{\pi S})/P$, where S = area and P = perimeter of the fragment (Nascimento *et al*. 2006). According to Viana & Pinheiro (1998), CI < 0.6 indicates that the fragments are "too elongated", between 0.6 and 0.8, "elongated", and > 0.8, "rounded" very elongated and elongated fragments are supposedly more subjected to border effects.

Results and Discussion

The legend of Figure 2 is the result of the automatic classification process combined with visual image interpretation and includes 13 classes of land use and soil cover for the national park and its surroundings. The overall accuracy of the mapping was 95%. The areas and percentages of each class are presented in Table 1. Due to the spatial resolution of 30 m, classes of vegetation cover comprised, in certain cases, more than one plant community described by Araujo *et al.* (1998). A description of classes is presented in Table 2.

Differently from some studies using remote sensing techniques already developed in this site (Henriques *et al.* 1986; Oliveira-Galvão 1991; Cruz *et al.* 2003; Jamel 2004), we sought to correlate the classes for use and cover of the soil with the vegetation communities defined by Araujo *et al.* (1998), as well as to quantify these classes.

The most predominant class at the park was the *Clusia* formation (31.99%), where density of vegetation islands varies, thus generating different spectral images. Oliveira-Galvão (1991) recognized a "light" *Clusia* formation (less thicket density and greater level of anthropization) and a "dark" *Clusia* formation, but our study included both in the *Clusia* formation. The open formation of Palmae was included in the *Clusia* class. Second was the Ericaceae formation (29.14%), best represented between the Paulista lagoon and the extreme northeast of the park, where the sandy ridges are narrower. This formation is composed by three physiognomies forming together strips parallel to the sea. Taken jointly, it is easy to distinguish the Ericaceae formation, but when there are wider ridges we can confuse them with the *Clusia* formation, because the spectral response is very similar. Therefore, the distinction between these formations is only possible through confirmation in the field, as done here. The mapping by Henriques *et al.* (1986), which covered the southwest portion of the park, established a representativeness of 41.2% for the *Clusia* formation and 9.1% for the Ericaceae formation. These figures, especially for
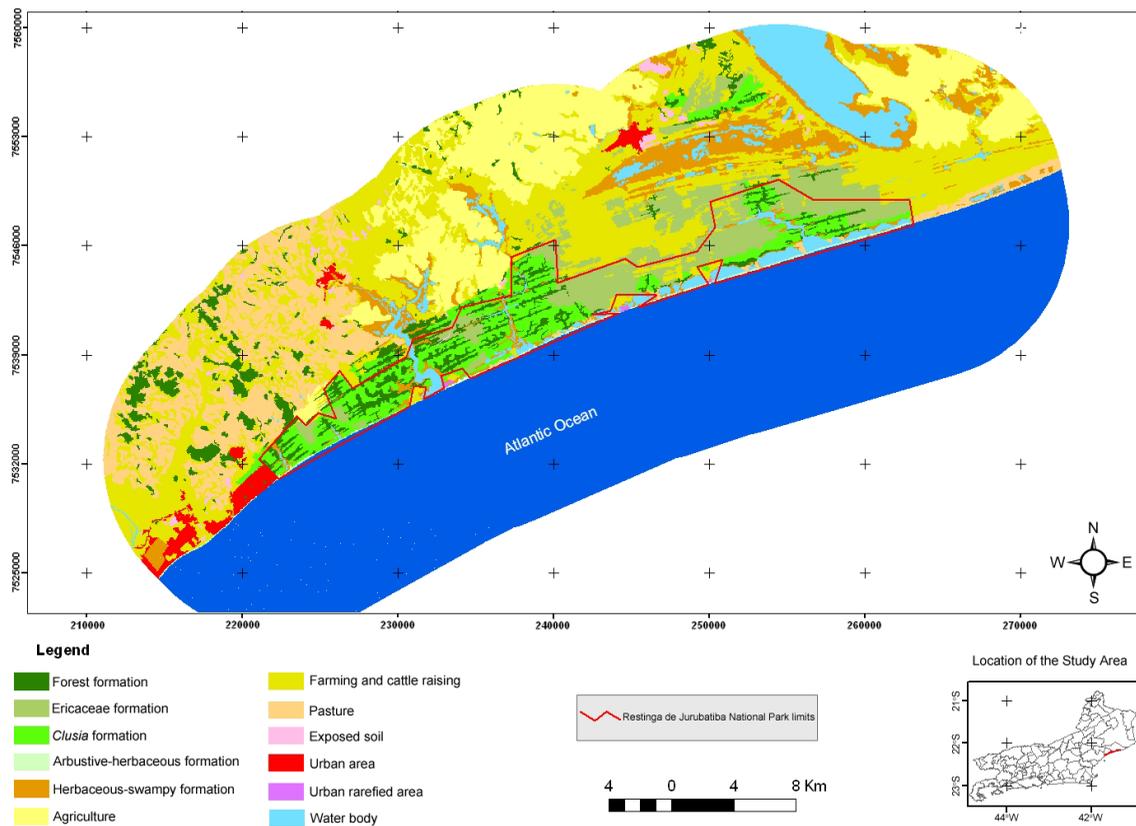

Legend

- Forest formation
- Ericaceae formation
- *Clusia* formation
- Arbustive-herbaceous formation
- Herbaceous-swampy formation
- Agriculture
- Farming and cattle raising
- Pasture
- Exposed soil
- Urban area
- Urban rarefied area
- Water body

Restinga de Jurubatiba National Park limits

4 0 4 8 Km

Location of the Study Area

Figure 2 – Map of vegetation cover and land use at the Restinga de Jurubatiba National Park and surroundings.

Table 1 – Area and percentage of classes of land use and vegetation cover of the Restinga de Jurubatiba National Park and surroundings.

Classes	National Park		Surroundings (10 km)	
	Area (ha)	%	Area (ha)	%*
Forest formation	2343.03	15.73	3204.82	4.41
Clusia formation	4766.05	31.99	1094.28	1.51
Ericaceae formation	4341.68	29.14	3437.27	4.73
Herbaceous-swampy formation	768.64	5.16	6439.42	8.87
Shrubby-herbaceous formation	325.02	2.18	103.67	0.14
Agriculture	10.45	0.07	13924.26	19.17
Pasture	146.74	0.98	10997.76	15.14
Farming and cattle raising	571.83	3.84	26389.85	36.33
Exposed soil	7.74	0.05	589.83	0.81
Urban area	0	0	1470.24	2.02
Urban rarefied area	0.78	0.01	39.91	0.05
Water body	1344.87	9.03	4944.79	6.81
Atlantic Ocean	270.38	1.81	57921.49	-
Total	**14897.21**	**100**	**72662.83**	**100**

* Atlantic Ocean excluded

the Ericaceae formation, are very different from our study and show the non-uniform distribution of these formations along the site.

The herbaceous-swampy formation covers 5.16% and includes aquatic vegetation. It often forms extensive areas in the shallowest zones of the lagoons near their margins, and frequently borders the permanently and periodically flooded woods. The shrubby-herbaceous formation (2.18%) comprises two vegetation communities: the reptant halophila-psammophila and the post-beach dense shrubby form. In many parts of the park, this formation was totally or partially degraded due to the construction of an oil pipeline (recently removed) and placement of coarse clayey-sand for vehicle transit, in addition to transit of 'off-road' vehicles (pers. obs.). Finally, forest formation contributes with 15.73% of the area, encompassing three physiognomies. These results highlight one of the main peculiarities of restinga vegetation in this part of the coast: although plants mostly originate from the Atlantic rain forest, the predominant local formations are open vegetation, often with rain forest tree species that assume shrubby habit (see Scarano 2009).

The water bodies represent 9.03% of the national park area. This includes all 18 coastal lagoons. These lagoons are shallow, with depths not over 3 m, and show considerable salinity variations among them (Enrich-Prast *et al.* 2004). The Atlantic Ocean was included as a class to be quantified, for being part of the official limits of the national park and it represents 1.81% of its area.

Over 90% of the park comprises native vegetation formations and water bodies. However, it would be desirable that degraded areas and/ or areas transformed into pasture and used for agriculture (4.89%) were recovered, which requires land tenure regularization. In this sense, the recent successes in ecological restoration of sandy coastal plains (e.g. Zamith & Scarano 2006) are encouraging.

Since a great part of the hydrological system of the region (lagoons, rivers and areas subject to floods; Martin *et al.* 1993) drains into the park, any impact or contamination (including the water table) by domestic sewage, chemical defensives and fertilizers can compromise its integrity (see Soffiati 1998).

The surroundings of the park encompass the municipalities of Macaé, Carapebus, Quissamã, Conceição de Macabu and Campos dos Goytacazes. The Atlantic Ocean responds for 44% of the surrounding area of the park, followed by cattle raising farms (36.33%), agriculture (19.17%) and pastures (15.14%). Those three terrestrial classes together add up to 70.64% of the land use. Agriculture is represented mainly by sugar cane, although other cultures (e.g. coconut) are also found. In many cases, there are areas used both for agriculture and pasture. In the northern limit of the national park, the pasture areas reach the coastline. The agricultural activities removed the vegetation cover and changed the landscape, often entailing negative impacts in the study site. Typical examples are sugar-cane farming and the risks of associated fires, as well as the extensive grazing of cattle (that is already moving towards the interior of the national park). The lack of settlement of the land situation hinders the effective supervision of the protected area and its surroundings. Furthermore, it is apparent that most properties do not abide to the Brazilian forest code legislation (see Lewinsohn 2010; Metzger 2010). The result is that the forest fragments (N=203; 4.41% of the area) remaining in the surroundings of the park are usually isolated by a matrix composed of agriculture and cattle

Table 2 – Relationship between the classes found in thematic map elaborated from Landsat 5 image, 2005, and the plant communities described by Araujo *et al.* (1998) to the Restinga de Jurubatiba National Park.

Vegetation formations found in thematic map	Plant communities described by Araujo *et al.* (1998)	Description
Shrubby-herbaceous formation	Reptant halophila-psammophila Post-beach dense shrubby form	Comprises two communities: the reptant halophila-psammophila that begins near the beach slope and usually assumes widths between 5 to 10 m (sometimes covering the external ridge entirely in places where the adjacent community was degraded); and the post-beach dense shrubby formation, adjacent to the former, that originally covered the external sandy ridge crest.
Clusia formation	*Clusia* open scrub Palmae open scrub	Comprises two communities: the first one (*Clusia* open scrub), and more representative, is formed by vegetation islands of varied sizes interspersed with sand stretches with sparse vegetation. *Clusia hilariana* Schltdl. (Clusiaceae) is the dominant tree species. The second (Palmae open scrub) occupies in general areas where original tree or shrub formations were devastated or subjected to periodic fires. The dominant species is the dwarf palm *Allagoptera arenaria* (Gomes) Kuntze, which is resistant to fire.
Ericaceae formation	Ericaceae open scrub	This formation is composed by three physiognomies, forming together strips parallel to the sea. The first is an open sandbank with vegetation islands, which are inserted by topographically lower strips, with dense herbaceous or more spaced cover (that flood in the periods of increased rainfall). Between the strips with islands and herbaceous vegetation, there is a thicket of shrub-trees with approximately 4-6 m of height.
Forest formation	Periodically flooded forest Permanently flooded forest Forest on sandy ridge	Comprises three communities: the periodically flooded woods, which occur in the swales between sandy ridges, in ancient lagoon areas, and are subject to surfacing of the water table during the rainy season; the permanently flooded woods, closer to the lagoons, which are subjected to almost constant flooding by the water table, and present an open and lower canopy; and the woods on sandy ridge, without influence of the water table, which are placed on older ridges and present few remnants in the area. In some instances, those three physiognomies can occur side by side, following topographic variations.
Herbaceous-swampy formation	Herbaceous-swampy Aquatic	Comprises two communities: the herbaceous-swampy, which are frequently dominated by *Typha domingensis* Pers.; and the aquatic formation, adjacent to the former, which occurs in some of the local lagoons.

raising activities. This adds to the difficulty for preservation of those fragments and puts their sustainability at risk (see Viana & Pinheiro 1998). The smallest fragment is 0.3 ha while the largest is 235 ha. The latter is located on a slope, which may have favored its preservation. Fragments < 5 ha are the most frequent (45.3%), which is a common pattern elsewhere in the Atlantic forest domain (e.g. Ribeiro *et al*. 2009). These studies highlight the biological relevance of preserving such small fragments.

More than half (56.7%) of the forest fragments presented a "very elongated" shape (Tab. 3) and would, therefore, be subject to greater border effect (Viana & Pinheiro 1998). Considering that restinga species were mostly originated in the Atlantic forest, preservation and restoration of fragments in the surroundings of the national park should be essential to maintain gene flow and local biodiversity. Moreover, there are no available floristic surveys of such fragments.

Additional classes in the national park surroundings include water bodies (6.81%); herbaceous-swampy (8.87%); remnants of *Clusia* (1.51%) and Ericaceae (4.73%) formations inside private properties and used for pasture; small remnants of the shrubby-herbaceous formation (0.14%) along the coastline, not yet destroyed by the construction of houses, pasture or transit of vehicles; and urban areas (2.02%) that do not have intense vertical constructions or large populations, except for an initially illegal housing development that borders the southwest limit of the park. Finally, beach houses at Carapebus (municipality of Carapebus), João Francisco and Visgueiro (municipality of Quissamã) correspond to the urban rarefied area (0.05%) and its impact on the national park is felt especially during weekends, holidays and vacation periods. The bare soil class (0.81%) is found along the entire park surrounding, without specific concentration.

Our study showed that the surroundings of this protected area are highly fragmented (see also Cruz *et al*. 2003). This results in a virtual isolation of the national park from the regional remnants of Atlantic Forest, which are located mainly on slopes of the Serra do Mar in a range that here varies from 10 to 30 km on a straight line. In this scenario, the reduction of gene flow may be critical to maintaining the diversity and functioning of the local restinga. Furthermore, resilience to climate change also diminishes (Scarano & Garbin 2013).

Table 3 – Form of forest fragments in the surroundings of the Restinga de Jurubatiba National Park, calculated by the circularity index.

Form of fragments	Number of fragments	%
Circular	18	8.9
Elongated	70	34.5
Very elongated	115	56.7

Restoration efforts, especially aimed at the creation of corridors, should also target the continent-sea axis, rather than focusing only the continent-continent axis.

The thematic map produced based on the digital classification of the Landsat 5 image allowed for a spatial characterization of the different uses and soil cover of the national park and its surroundings. The difficulty in determining all plant communities described for the park by Araujo *et al*. (1998) led to a simplification of the legend. This was due to the spatial resolution of 30 m of the sensor. Since the limits between plant formations is very thin, the use of high resolution images would have favored a better class discrimination, as shown elsewhere (Kurihara & Encinas 2003; Dlugosz *et al* 2005; Caris *et al* 2009). However, given the high costs of acquisition of such images and the time needed to digitally process the data, images of medium resolution, as the one used in this study, offer a better cost-benefit ratio. For this reason these images and their products have been frequently used as important tools in the management of protected areas (e.g. Richter et al. 2004).

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