Chapter 2.4
Evaluations of Forest Cover at Regional and Local Levels in the Tolagnaro Region Since 1950

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Abstract

We review the changes in the surface area of the littoral forest in the region of Tolagnaro by using aerial photographs and satellite images from 1950 to 2005. The analysis is supplemented by a classification of forest canopy cover to evaluate the degree of degradation of the remaining forests. The regional forest area declined by 26,563 ha or 40% between 1972 and 2002. The surface area of the littoral forest was reduced by 4,022 ha, corresponding to 56% between 1950 and 2005. In 2005, the largest block of littoral forest measured 252 ha. According to our classification of forest degradation, the percentage of forest classified as being in good condition decreased from 44% in 1998 to 36% in 2005.

Résumé

Evaluation de la couverture forestiére aux niveaux local et régional dans la région de Tolagnaro depuis 1950. Ce chapitre décrit les changements de la superficie de la forêt littorale dans la région de Tolagnaro à partir de photographies aériennes et d'images satellites de 1950 à 2005. L'analyse est complétée par une classification de la couverture de la canopée forestière pour évaluer le degré de dégradation des forêts résiduelles. La superficie forestière de la région a diminué de 26,563 ha, soit 40 %, entre 1972 et 2002. La superficie de la forêt littorale a été réduite de 4,022 ha, ce qui correspondant à 56 %, entre 1950 et 2005. En 2005, le plus grand bloc de forêt littorale mesurait 252 ha. Selon notre classification de la dégradation de la forêt, le pourcentage de la forêt classée dans les catégories de forêts en bon état est passé de 44 % en 1998 à 36 % en 2005.

Introduction

Prior to human occupation, humid and sub-humid littoral forest covered approximately 465 100 ha, or 0.8% of the total land surface of Madagascar, of which only about 47,900 ha remain today (89.7% loss; Consiglio *et al.* 2006). From the original littoral forest, only 10.3% remains in the form of small forest fragments, and only 1.5% of these are included within the existing protected areas network. This chapter presents a review of the changes in the surface area of the littoral forest in the region of Tolagnaro from aerial photography available since 1950 and the satellite images since 1972. Three different levels of interpretation are presented within this analysis: 1) at a regional scale, within 20 km from the littoral zone; 2) within the littoral area to the north and south of Tolagnaro; and 3) at a very local level to evaluate the state of the remnant littoral forest fragments.

The data cover a 55-year period from 1950, which includes the oldest known aerial photographs of this region, to 2005 (MIR Télédétéction 1998, unpubl. data). A semi-quantitative method of classification based on forest structure has been used for evaluating and visualizing the degree of deterioration of the remaining forests.

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Methodology

Changes in the regional forest surface areas

Forest surface area was estimated at a regional scale for a zone within 20 km of the coastline. The information used is based on the digital analysis of spatial data from different images: Landsat MSS 1972, Landsat TM 1984/1992, SPOT Panchromatique 1995, and Landsat TM 2002 (Table 1). All native forest types were used in the analysis, including the littoral forests on the sand of the coastal plain, as well as a part of the classified low altitude humid forest of Tsitongambarika.

The regional native forest covered from the years 1972, 1984, 1992, and 2002 was calculated by an automatic classification of multi-band Landsat MSS and Landsat TM satellite data. The automated method of classification was used instead of the Normalized Difference Vegetative Index (NDVI) method, as the former gives an excellent discrimination of vegetation types, whereas the NDVI system sometimes misclassifies zones of slash-and-burn agriculture with forest regeneration (MIR Télédétection 1998).

A sub-sample area, including dense humid forest, littoral forest, and shaded forest, was first extracted from each satellite image in order to produce a single generalized "forest class." The spectral signature of this new forest class, representing total forest cover, was calculated for each channel of the different images. The final classification of the complete image was made using the newly created spectral signatures and the "maximum likelihood" algorithm of classification (Bonn and Rochon 1992). The 1972 image is notably masked with cloud cover, particularly in the southwest region of the study area, and the dataset had to be edited in order to add these missing zones. The 1995 regional forest cover has been defined by thresholding the panchromatic SPOT data. The threshold values consist of extracting from the panchromatic channel the pixels whose values of gray are located in the interval corresponding to forest cover. Given that the spectral values of the wet, dense, humid, and littoral forests are different, their thresholding was carried out separately to obtain the best possible discrimination between the total forest and the other elements of the landscape.

The 2005 forested areas were interpreted from QuickBird satellite images. Each of the three areas is covered by a panchromatic image (range of gray) and a multi-spectral image made up of four channels (Table 1). The first stage was to convert the 16 bit QuickBird images into 8 bit images (due to software processing limitations). It is important to note that the QuickBird images are only covering 11 bit of the available 16 bit spectrum. For the 16 bit images, the pixels values will range between 0 and 65535, and for the 11 bit images between 0 and 2047. Thus, the used range is only a small portion of the total available range (2047/65535). Hence, the image will appear to be very dark, almost black, because 63488 values (65535-2047) will be at 0 (value corresponding to black).

Changes in the littoral forest surface area

This second analysis was restricted to the littoral area within 50 km to the northeast and 23 km to the southwest of Tolagnaro. The forest surface areas was estimated by the interpretation of the aerial photographs dating from 1950, 1974, and 1989, the 1995 SPOT data, and the 2005 QuickBird satellite images. The extraction of the aerial photo data has been conducted with an Abraham-type stereoscope. The use of this device, rather than a mirror stereoscope, gives an optimal view of the vegetation's canopy and therefore allows a better identification of the forest strata. The forest contours have been drawn directly on the aerial photographs with a bold pencil (line width about 1.5 mm). On the panchromatic aerial photography, the forested areas appear in a range of gray colors that are darker than the area with no vegetation, apart from water. On color photographs, the forest is distinguished in general by its characteristic green color, though some forest fragments display a pale brown color. The 1974 and 1989 aerial photographs are respectively at a scale of 1:15 000 and 1:20 000, and provide sufficient resolution to map details at a scale of 1-2 ha. However, the 1950 photographs with a scale of 1:50 000 do not enable the identification of surfaces below 5 ha; moreover, on these photographs, the presence of cloud and shade as well as some "off-spot" sectors present certain analytical difficulties. The interpreted contours of the aerial photographs have been digitized into a geo-referenced database employing a geo-coded SPOT image as base map. Using a digitizing table, three to five reference positions have been identified on each one of the aerial photographs and on the reference SPOT image in order to position each within a coordinate system. Control points were based on the hydrographic network and the road system. However, these points were more difficult to extract in the Sainte Luce sector, where only three control points per air photograph were generally used. The average positioning error was estimated at 75 m, being lower in flatlands and higher in topographic relief. Following the positioning of each aerial photograph, contours of interpretation were digitized manually.

The 1995 forest area was interpreted from the Panchromatic SPOT image (Table 1), which was carried out on a high-resolution screen with the SPOT image as a reference and this was imported directly into the geo-coded database. On the SPOT image, like on the panchromatic aerial photographs, forested areas appear within a range of gray colors, which are generally darker than the other elements of the landscape, excluding water bodies. However, the lack of distinctness in the definition of the forest contours constituted an obstacle. The interpretation of the forest area of the SPOT image was made in association with the 1989 aerial photograph. The 1950 and 1974 aerial photographs were processed with a lower level of precision than the 1989 aerial photographs and the 1995 Panchromatic SPOT image and pose some challenges. First, the 1950 aerial photographs have varied quality and a smaller scale. Second, the 1974 aerial photographs cover only a section of the study zone and thus cannot be used in the modeling exercise. For these reasons, the forest fragments or openings less than 4 ha were not retained in the 1950 and 1974 images. In contrast, given the large scale and the quality of the data input, the interpretation of the forest area of 1989 and 1995 was made for minimal surfaces ranging 1-2 ha.

After this conversion, it was necessary to reorder some 2047 values into 256 classes (8 bit images, ranging between 0 and 255). Once the multi-spectral images were normalized, it was possible to create composite images by associating three channels to the red, green, and blue references. Depending on the channel sequence, each of the resulting composite images highlights different elements (vegetation, rock exposures, etc.). For vegetation formations, two combinations are often used: 3,4,2 (where channel 3 is associated with red, channel 4 with green, and channel 2 with blue) and 4,3,1 (where channel 4 is associated with red, channel 3 with green, and channel 1 with blue). The latter combination provided easier division of forested areas. The outlined 1995 and 1998 forest cover were then overlaid on this new composite image and the 2005 forest contours were manually digitized.

Forest state classification

The analysis of both aerial photographs and satellite images showed that these tools were effective for evaluating rates of deforestation over time, but they are not very effective for determining the level of forest habitat degradation. These images are generally not sufficiently precise for differentiating the types of anthropogenic degradation within forest blocks, often associated with selective tree extraction and charcoal production. The color and the texture of the images do not always reflect well these levels of degradation, which can often be confused with different topographic conditions or varying viewing angles. Based on ground-truthing and the determination of the true condition of a given forest block, it was clear that a system needed to be developed for a simple and easy-to-use classification of anthropogenic pressure.

Table 1. Details and specifications of the satellite images used in the analyses.

	Acquisition date	Altitude	Lateral cover	Spatial resolution	Spectral resolution of the available channels
LANDSAT MSS	11 August 1972	919 km	185 x 185 km	60 x 80 m	MSS4: 0.5 - 0.6 μm MSS5: 0.6 - 0.7 μm MSS6: 0.7 - 0.8 μm MSS7: 0.8 - 1.1 μm
LANDSAT TM	25 November 1984 17 December 1992 19 January 2002	705 km	90 x 90 km	30 x 30 m	TM1: 0.45 - 0.52 μm TM2: 0.52 - 0.60 μm TM3: 0.63 - 0.69 μm TM4: 0.76 - 0.90 μm TM5: 1.55 - 1.75 μm TM7: 2.08 - 2.35 μm
Panchromatic SPOT	2 August 1995	740 km	60 x 60 km	10 x 10 m	XP: 0.51 - 0.73 μm
QUICKBIRD	17 August 2005 30 August 2005	450 km	16.5 x 16.5 km	0.60 x 0.60 m (Panchromatic) 2.4 x 2.4 m (Multispectral)	Pan: 450 – 900 μm Multispectral Blue: 450 – 520 μm Green: 520 – 600 μm Red: 630 - 690 μm Near IR: 760 – 900 μm

A five-state, semi-quantitative method was developed for the classification of the level of deterioration of the littoral forests, based on the percentage of canopy coverage. The five classes were established based on inventories of the littoral forest zones, and provide a more coherent categorization of field observations. It is important to emphasize that this methodology was used only for evaluating forest degradation, specifically selective cutting of canopy trees (Table 2).

Table 2. The five class categorization of forest degradation based on canopy cover.

Class	% of natural canopy represented
1	91 to 100%
2	71 to 90%
3	51 to 70%
4	21 to 50%
5	0 to 20%

Subsequently, the five classes are condensed into three categories, which provide the means to qualify the level of anthropogenic forest perturbation:

Category 1. Classes 1 and 2 – largely intact or slightly damaged littoral forest,

Category 2. Classes 3 and 4 — fairly or severely damaged littoral forest, and

Category 3. Class 5 — heavily damaged littoral forest.

Methods

The method consists of using forest contour maps, based on the interpretation of the most recent aerial photographs or satellite images, and establishing transects to cover each forest block with a 50 x 50 m grid. Sample points are established at the intersection of the grid. If the block is too narrow to include more than one transect, one single line is drawn with sample points at each 50 m. The following data are obtained at each sampling position within the 50 x 50 m grid: general condition of the forest; signs of cutting (stumps); openings; agricultural areas; fires; and observations of the vertical structure of the forest canopy level (upper, intermediary, or lower). Finally, the field observer evaluates, with a schematic way, the % of the canopy cover at the sampling position for the area he can visualize from this point.

Specifically, the observer estimated within a 20 m radius of the sampling site the percentage of the tree canopy coverage. In cases where the canopy was continuous, representing 100% cover, this corresponds to a littoral forest in good condition, where no selective cutting or openings other than natural could be noted. In degraded situations, there were canopy openings. All the sampling positions were then analyzed for a given forest block, and a single class was allocated when there was no variation between positions, or a range of classes were designated for a given block when there was variation in the level of disturbance. To reduce variation between different observers in the evaluation of percent canopy cover, different preliminary tests were conducted to standardize their estimations.

The first field inventories of the Mandena, Petriky, and Sainte Luce forest blocks were carried out in 1998 based on pre-established transects placed on the 1995 MIR maps. These preliminary observations provided important methodological insight into the vertical structure of these forests, as well as various localized anthropogenic pressures. Based on the mapped information gathered at this time, reliable "portraits" were constructed on the degree of deterioration of a given forest block.

The changes in the forest surface cover and the method developed for the evaluation of the forest degradation level were verified by Missouri Botanical Garden (MBG), Royal Botanic Gardens (RBG-Kew), and FOFIFA, as part of a 2001 study (Lowry *et al.* 2001). It was concluded that the five-category, semi-quantitative classification based on canopy cover was particularly useful to examine human pressure and evaluate changes over time. The methodology was further evaluated and corrected by adding data on the level of deterioration of a given block, dendrometric criteria, and floristic composition (Henderson 1999, Ingram and Dawson 2005, 2006, Ingram *et al.* 2005a, 2005b). Given that the Tolagnaro littoral forests are extremely fragmented, each forest block was assigned a unique number. Further, given differences within a forest associated with human degradation, there can be several different class categorizations within the same block.

In 2005, QuickBird satellite images covering the region were used to revise the forest limits and levels of deterioration. These reassessed "portraits" were important to follow the changes of regional forest cover and to provide insight into the effectiveness of local conservation measures.

Results

Regional forest area

Regional forest area was in constant decline between 1972 and 2002. In total, 26,563 ha (40%) of forest were removed during these 30 years, corresponding to an average annual surface of 885 ha (Figs. 1 and 2).

The data show a clear acceleration of deforestation between 1992 and 2002. In 10 years, nearly 14,000 ha of forest disappeared, and lowland formations have been severely damaged. Slash-and-burn culture is the main cause of this deforestation.

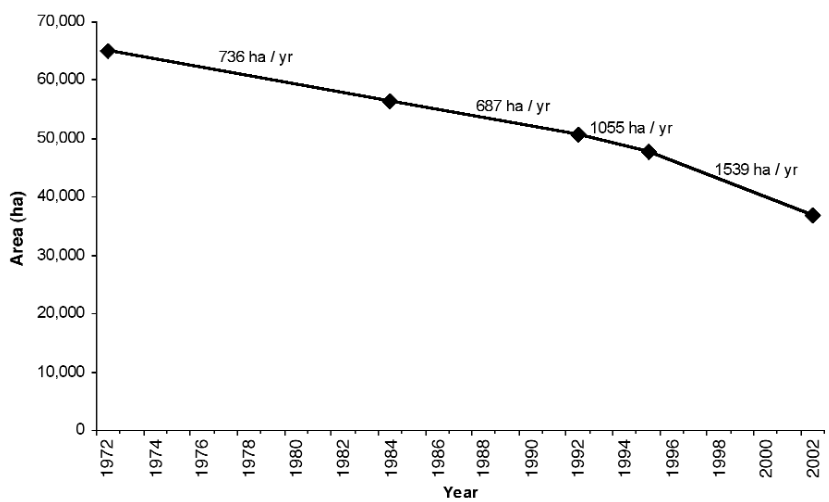

Figure 1. Trends in regional natural forest cover area between 1972 and 2002.

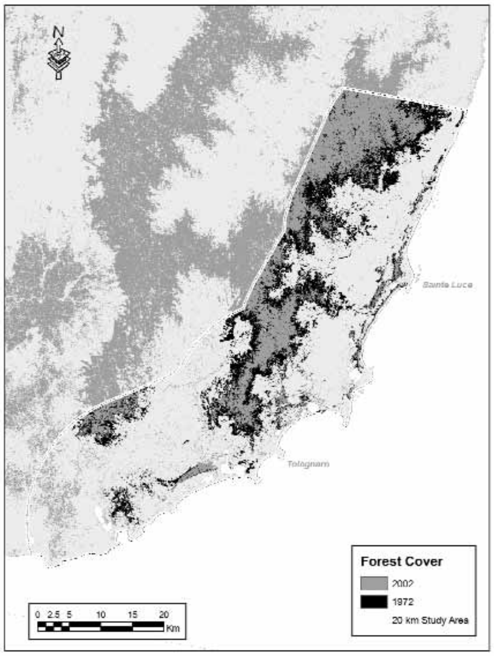

Figure 2. Change of the regional natural forest cover in the Tolagnaro region between 1972 and 2002. Study included approximate 20 km from coast. The darker color in the map indicates forest lost since 1972.

Tolagnaro littoral forest area

The surface area of littoral forest declined by 4022 ha (56%) between 1950 and 2005, which corresponds to an average annual loss of 73 ha. By 2005, the Tolagnaro region littoral forests were heavily fragmented and covered only 3128 ha, distributed in 289 blocks varying in size from 0.06 ha to 252.4 ha (Table 3, Fig. 3).

Levels of deforestation are more pronounced in the Mandena and Petriky zones, than that of Sainte Luce. These differences are associated with significant pressure exerted by the local population for slash-and-burn agriculture and charcoal production. Between 1995 and 1998, there was an intensification of charcoal production at Mandena (Fig. 4). This rapid degradation led to the establishment of a 230 ha conservation zone at Mandena in 1999, along with a program for a robust, community-based management of approximately 2000 ha of the Mandena forests (Rarivoson Chapter 6.1). These conservation measures led to a notable reduction in deforestation between 1998 and 2005 (Fig. 4). Figure 5 shows the regression of the littoral forests from 1950 to 2005.

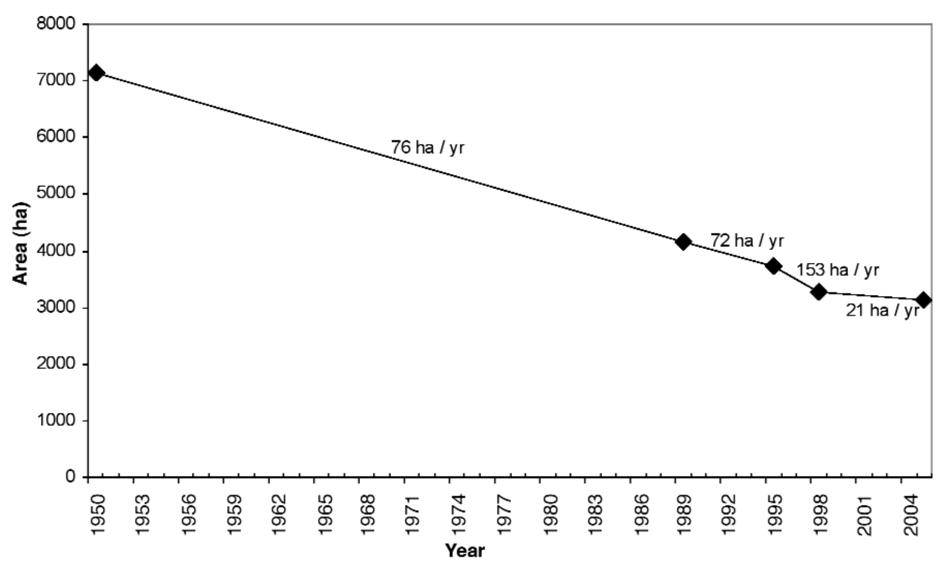

Figure 4. Trends in littoral forest cover in the Tolagnaro region between 1950 and 2005. Note the much reduced deforestation rate from 1998 to 2005, due mainly to the establishment of a community-based forest management at Mandena.

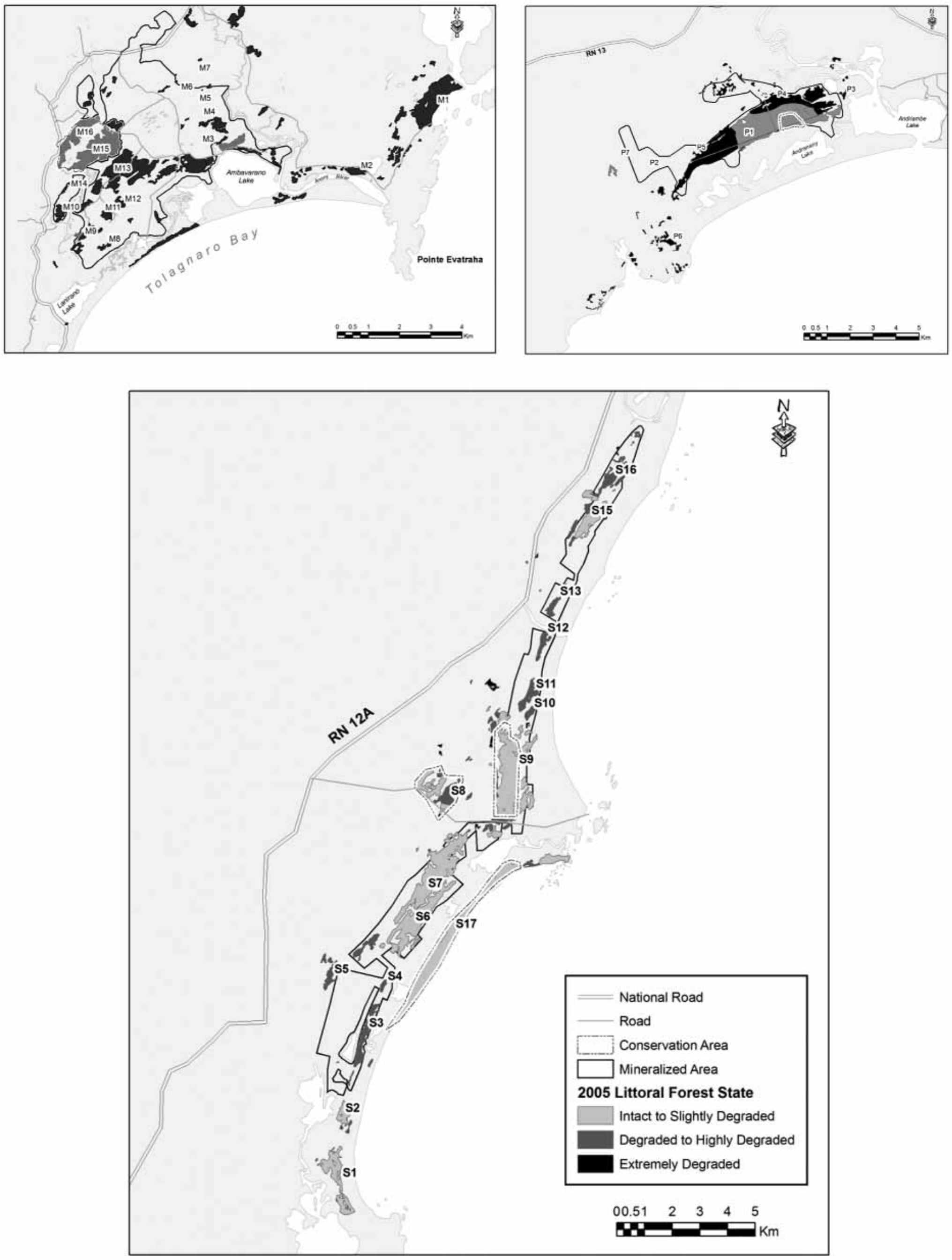

Figure 3. State of the littoral forest blocks at Mandena (upper left), Petriky (lower left), and Sainte Luce (right) in 2005.

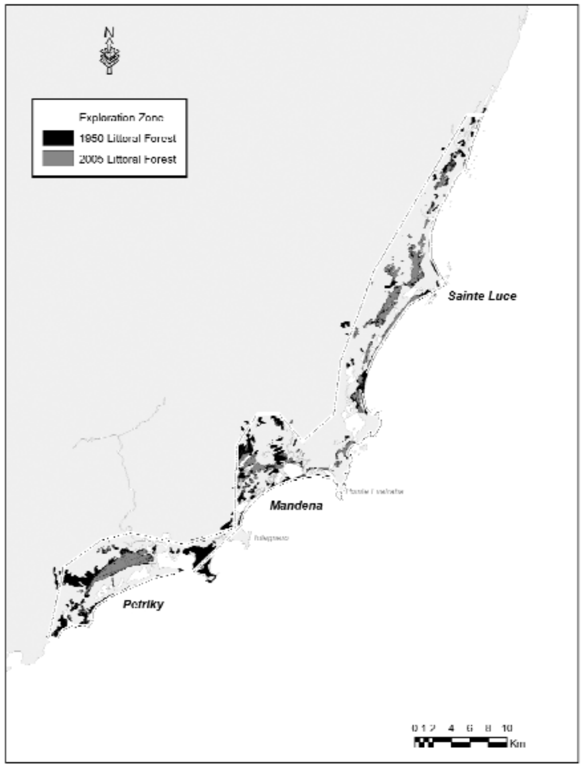

Figure 5. Regression of the littoral forest in the Tolagnaro region from 1950 to 2005. The darker color in the map indicates forest lost since 1950.

In 2005, the littoral forest of the Tolagnaro region represented about 6.5% of the country's remaining littoral forests, which represents less than 1% of all the remaining surface area of Malagasy forests (Consiglio *et al.* 2006).

Remnant forest fragments

The cartographic analyses of the remaining littoral forests of the Tolagnaro region in 1998 indicate that 44% of the littoral forests were still in good condition. However, by 2005, only 36% of the regional littoral forests remained in good condition (category 1) and 64% were degraded (categories 2 and 3, see Table 3, 4 and 5 and Fig. 3). These rapid rates of degradation are associated with charcoal production (Mandena and Petriky) and selective tree cutting (Sainte Luce). Table 5 shows the regional situation of the remaining forests, as of 2005, inside and outside the mining area and associated protected areas.

Discussion

Changes in the regional natural forest surface area, particularly in the littoral forests, show a clear reduction since 1950, when the first known images of the area were taken. The reduction of the forest surface area resulted in significant loss of habitat and the fragmentation of the littoral forests. This later habitat, before anthropogenic perturbation, is presumed to have covered most of the 1600 km eastern coastal area of the island (Lowry and Faber-Langendoen 1991, Consiglio *et al*. 2006). Despite these alarming figures, the region of Tolagnaro still holds some vestiges of this ecosystem, comprising a total of 3128 ha. The general deforestation trend at the regional level showed a rapid acceleration since 1995, whereas the rates in the littoral forests have slowed down over the past decade.

The semi-quantitative method presented here for classifying natural habitat quality is an important tool for evaluating the degree of anthropogenic forest degradation on Madagascar. According to Armitage (1998), forests can, theoretically, tolerate a certain level of selective cutting if it is carried out according to a precise management plan that utilizes a realistic rotation according to forest growth patterns. However, this type of sustainable management is not currently practiced on Madagascar due to socio-economic conditions, and the forest degrades accordingly. The forest class categorizations 1 and 2 are not irreversible (Table 2) if good management is implemented and tree extraction levels remain minimal, allowing regeneration. However, forest class categorizations 3 and 4 indicate that the forest has been under constant pressure for a considerable period, and that the upper canopy is, as a result, in poor condition. Class 5 is the result of long-term pressure, indicating the removal of the majority of the canopy and the extensive degradation of the forest. In this case, the changes are presumed to have had irreparable effects on the local vegetation and animal communities. This classification method, developed in 1998, remains an excellent technique to understand levels of degradation in littoral forests.

Conclusion

This study presents data on the evolution of forest cover in the Tolagnaro area over a 55 year period at both the regional and local levels. Until about a decade ago, there had been a drastic reduction in forest cover, however, certain areas have seen a stabilization of anthropogenic pressures in recent years. New tools of remote sensing, such as QuickBird satellite images, provide increasingly better resolution and serve as important management tools. Measures of forest cover should be updated at least every five years in order to follow the evolution of regional and littoral forests. These data have enabled the conservation of the remaining forests by informing management and mon-

Table 3. Changes in the Tolagnaro littoral forest surface area between 1950 and 2005.

Year	Littoral forest surfaces (ha)
1950	7150
1995	3737
1998	3278
2005	3128
Category 1 in 2005	1122
Category 2 in 2005	914
Category 3 in 2005	1092
Total in 2005	3128

Table 4. Remaining surface areas in 2005 of the Mandena, Petriky, and Sainte Luce littoral forests separated by classes of habitat quality (see Table 2).

Zone	Classes	Area (ha)
Mandena	3	148
	4	19
	5	571
Total Mandena		**738**
Petriky	3	84
	4	312
	5	494
Total Petriky		**890**
Sainte Luce	1	615
	2	507
	3	155
	4	197
	5	26
Total Sainte Luce		**1500**
Total in 2005		**3128**

Table 5. Extent of littoral forests within the mining zone of the Tolagnaro region in July 2005.

Mining sites	Littoral forests inside the mining perimeter (ha)	Littoral forests outside the mining perimeter (ha)	Total (ha)
Mandena	477.7	644.3	738.1
Sainte Luce	855.7	260.4	1500.0
Petriky	751.5	138.1	889.6
TOTAL	**2084.9**	**1042.8**	**3127.7**
	(66.6%)	**(33.4%)**	**(100%)**
Protected areas*	**504.0**	**473.0**	**977.0**
% protected forests	**24.2%**	**45.3%**	**31.2%**

* Petriky protected area yet to be established.

itoring decisions, the creation of protected areas and plantations, and other mitigation measures.

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