Chapter 19
Spatio-Temporal Evolution of the Fragmentation Classes of the Mikea Dry Deciduous Forest (Southwestern Madagascar)

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Abstract In southwestern Madagascar, the Mikea forest is a highly diverse ecosystem of great biodiversity, which mixes dry deciduous forest in the eastern part and xerophytic thicket in the western coastal area. However, dry forests and shrubs are rapidly destroyed due to slash-and-burn cultivation (*hatsaky*) and exploitation of forest resources by riparian communities and external operators. The aim of this paper is to evaluate forest fragmentation in the Mikea national park, by comparing past and recent forest maps. The analysis of forest fragmentation is based on landscape indices. The changes in forest cover have been detected from time-series SPOT satellite images registered over 15 years (1999, 2005, and 2014). Between 1999 and 2014, forest area is reduced by 39.8% which is equivalent to an annual forest loss rate of 4.6%. The forest fragmentation is associated with a significant decrease in forest patch size. The mean patch size decreases from 37,228 to 18,731 ha from 1999 to 2014. The primary direct causes are economic driven due to intense anthropogenic activities such as wood charcoal production, logging, accompanied by frequent wild land fires. The indirect cause is the absence of a sustainable environmental management and conservation strategy.

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Introduction

Phillipson et al. (2006) consider Madagascar as a major hotspot of global biodiversity. In the southwestern region of Madagascar, the Mikea forest is a dense dry forest where the forest degradation rate is considered as higher than in any other region in Madagascar (Ravonjimalala et al. 2015). The area of Mikea forest is 184,630 ha in 2011. It is bounded in the North by the Mangoky River and in the South by the Manombo River. A little known human group called Mikea including about 1000–2000 people lives inside this forest. Mikea people still have a traditional way of life (Stiles 1998). Region biodiversity includes among others two (02) endemic birds species, *Uratelornis chimaera* and *Monias benschi* (Rakotonomenjanahary and Hawkins 2000) as well as two (02) mammals species, *Microgale jenkinsae* and *Macrotarsomys* (Goodman and Soarimalala 2005; Lourenço et al. 2004).

The forest cover change and its consequences have been recognized as a threat to the environment (Laurance 1999). It affects forest fragmentation and loss of biodiversity through connectivity decrease (Liu et al. 2014; Martínez et al. 2015). Forest fragmentation is a transformation of the landscape in which a massive intact natural forest is divided into several small forest plots, more or less isolated (Bogaert et al. 2004; Collins et al. 2009; Fahrig 2003). It is one of the leading agents of species extinction at local and global scales (Bregman et al. 2014). Unfortunately, the process of forest fragmentation is not yet sufficiently widely studied, less than deforestation, notably within tropical dry forests (Worku et al. 2014) although this type of forest is known for its vulnerability related to a weak potential for regeneration and restoration (Vieira and Scariot 2006).

The main objectives of this study are to quantify forest fragmentation mechanisms from deforestation.

Material and Method

Study Area

The region under study is situated at about 100 km north of the city of Toliara, (22° 31′ 39.47″ S; 43° 32′ 2.57″ E, 120 m a.s.l.) surrounding the village of Analamisampy (Fig. 19.1). The climate is semi-arid with an annual rainfall ranging from 600 to 1000 mm. 90% of the rainfall occurs during the rainy season (November–March) while the rainfall during the dry season (April–October) is below 50 mm (Blanc-Pamard et al. 2005). The average annual temperature is about 24.1 °C.

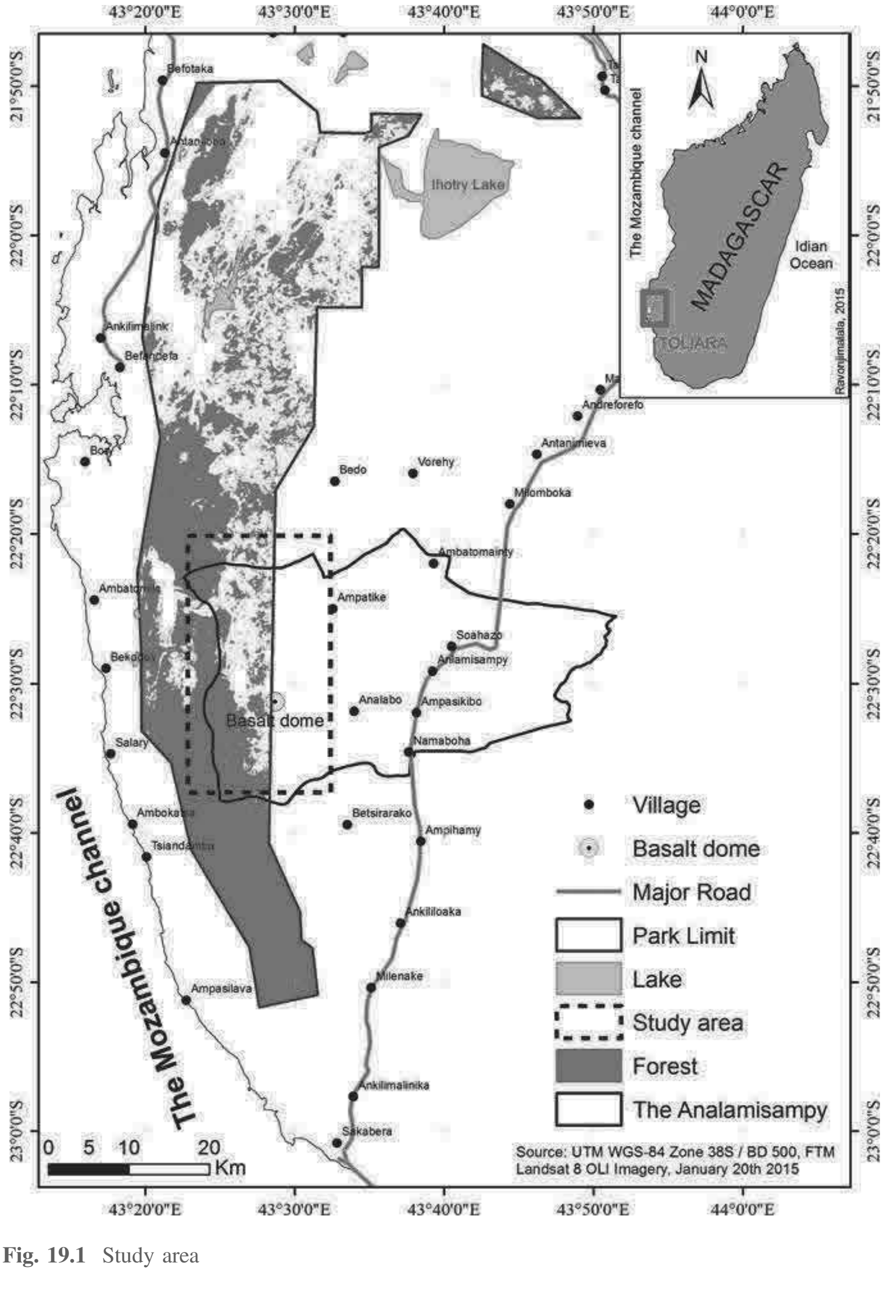


Fig. 19.1 Study area

Table 19.1 Characteristics of the satellite images

Date	Satellite type	Resolution (m)	Resolution (m)	Path/Row
		XS	PAN	
99-04-01	SPOT 4	20	10	162–395
05-05-01	SPOT 4	20	10	162–395
14-11-28	SPOT 5	10	2.5	162–395

Spatial Images

Three (03) SPOT images (KJ 162/395) were employed to map land cover and to identify its evolution through time. Dates of images were 1999, 2005, and 2014. These images have a spatial resolution of 20 m for multispectral channels (XS) and 10 m for the panchromatic channel (PAN). Their characteristics are given in Table 19.1. Atmospheric correction was applied to all images in order to correct the effect of atmosphere on pixel spectral values (Mustak 2013), using the method proposed by Bernstein et al. (2005). An image fusion operation between PAN and XS channels with pan sharpening method (Aiazzi et al. 2007) is applied to the 1999 and 2005 scenes. It enables to obtain synthetic images with 10 m resolution.

Image Classification

We used an object-based classification method which is more adapted to very high resolution images (Blaschke 2010). Object-oriented classification was done in two steps. The first step consisted in the segmentation of the images into meaningful objects, which gathered pixels sharing spectral and textural homogeneity. The implemented segmentation type used contour filters to define the outline between segments (Meinel et al. 2000).

The second phase was the classification of the segments (or objects), using a support vector machine (SVM) algorithm because of its ability to solve complex classification patterns, which are generally the case when working with landscapes (Huang et al. 2013).

Landscape Metrics

The quantitative methods of landscape ecology are based on the application of landscape metrics (Turner and Gardner 1991). These metrics render quantitative information about landscape composition and configuration allowing a more

Table 19.2 Summary table of landscape metrics. All equations are available in McGarial and Marks (1995)

Index name	Acronym	Analysis level	Landscape structure concept
Class area (ha)	CA	Class	Fragmentation
Number of patches	NP	Landscape/Class	Fragmentation
Patch density (#/100 ha)	PD	Landscape/Class	Fragmentation
Largest patch index	LPI	Landscape/Class	Fragmentation
Mean patch area (ha)	AREA_MN	Landscape/Class	Fragmentation
Mean euclidean nearest neighbour distance (m)	ENN_MN	Class	Connectivity/Isolation
Shannon's diversity index	SHDI	Landscape	Heterogeneity

objective comparison of different patterns in space and time. Consequently, landscape metrics have widely been used in literature to study large natural areas, forest evolution, or urban expansion (Başkent and Kadioğullari 2007). Table 19.2 describes the landscape metrics used in this study. We selected landscape metrics suitable to characterize fragmentation classes.

Results and Discussion

Forest Cover Classification and Change

The forest cover maps in Fig. 19.2 show the evolution of forest cover during 15 years. A basalt dome and the limit of the Mikea National Park, fixed in 2007, are given as benchmarks. The area of forest lost in 15 years is 37,227 ha, which represents 80% of the total forest area. The maps show the different forms of the forest fragments in the study area.

Quantitative Metric Analysis of Dry Deciduous Forest Pattern Change

We calculated landscape metrics using FRAGSTATS software (McGarigal et al. 2012). Comparison of landscape metrics outcomes between years provides valuable information about landscape heterogeneity, fragmentation, and connectivity. This study particularly investigated the forest fragmentation process using a set of classic and accurate landscape metrics. Table 19.3 shows the mean values of the landscape metrics for forest/non-forest land uses.

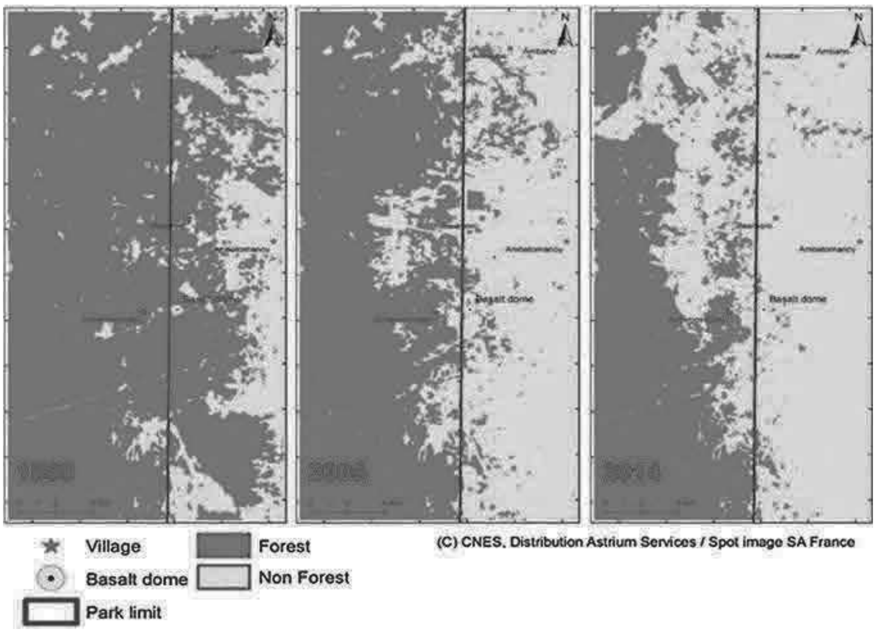


Fig. 19.2 Forest cover in the 3 analyzed years

Table 19.3 Landscape metrics for 1999, 2005, and 2014

	Type	CA	NP	PD	LPI	AREA_MN	ENN_MN	SHDI
1999	Forest	37,228	304	0.7	78	122	95	0.5
	Non-forest	9,149	436	0.9	10	21	138	
2005	Forest	26,625	421	0.9	53	63	142	0.7
	Non-forest	19,752	277	0.6	39	71	145	
2014	Forest	18,647	438	0.9	30	43	131	0.7
	Non-forest	34,205	144	0.3	58	192	145	

The number of patches (NP) per class gives an idea about the evolution of the fragmentation of a class between periods. Comparisons of NP values for forest between 1999 and 2014 show an increase of the index value from 304 to 438.

The forest class area (CA) gives the overall forest size over the area. The former decreases from 37,228 ha (80%) in 1999 to 18,647 ha (40%) in 2014.

The increased number of small patches in an area is considered as one of the basics of forest fragmentation assessment. While the total number of forest fragments increases from 304 to 421 during the first period (1999–2005), the increase is less important (421–438) during the second period (2005–2014). In 1999, the forest area is found in patches between 10,000 and 40,000 ha; the remaining forest fragments can be observed in isolated patches with an area lower than 100 ha. In

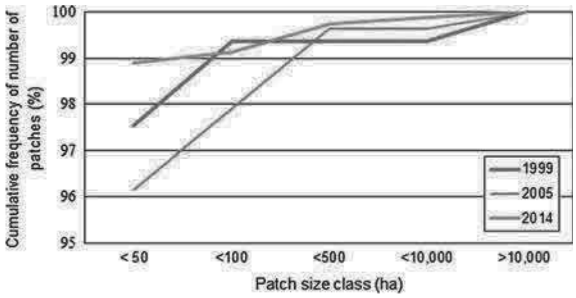


Fig. 19.3 Evolution of cumulative frequency of NP distribution over forest patch size classes in the Mikea dry deciduous forest

2005, the majority of forest plots have a size less than 100 ha, only three fragments have a size between 100 and 500 ha and only one lies between 500 and 2000 ha.

Other forest changes have been found by comparing the distribution of forest patch sizes between the three years (Fig. 19.3). Forest fragment sizes less than 100 ha can be considered as isolated patches. The cumulative frequency of the number of patches indicates a slight similar trend between patch class size intervals in 1999 and 2005. The forest area loss almost affected the entire class area. Weakers values observed for forest class areas less than 100 ha in 2005 may be associated to the disappearance of these small patches by intensive slash and burn during the 1999–2005 period.

The fragmentation process mostly affected the largest forest fragments aside the forest boundary leading to an increase of patch density (PD) and a decrease of LPI and AREA_MN (Table 19.3). An increase of patch density (PD) is also observed in the area. As a result, these metrics indicate that the landscape has become more fragmented between 1999 and 2014. The last landscape level metric calculated shows that there was no important change in SHDI between 1999 and 2014, which indicates that heterogeneity has not affected.

The Fig. 19.2 and the Table 19.3 differentiate two landscape classes, forest vs. non forest. Significant changes of fragmentation index values have been observed for both classes. Non-forest classes expanded and spread all over the region area. The decrease in the ENN_MN of forest patches and the stability of ENN_MN for non forest patches between 2005 and 2014 could suggest an improvement of the structural connectivity between the forest patches.

Causes of Deforestation and Metrics Change from Survey

Comparisons of the classification results over the three different years allowed to detect forest dynamics in the study area. The deforestation rate is quantified using the formula proposed by Puyravaud (2003), generally used to quantify the deforestation trend at a global scale:

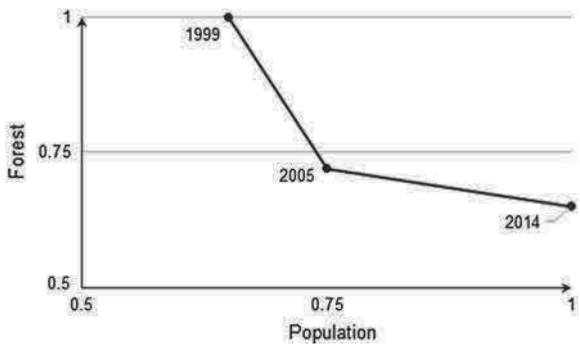
$$t = \frac{100}{t_2 - t_1} \ln \frac{A_2}{A_1}$$

where t represents the deforestation rate, A_1 is the forest landscape state in the initial year t_1 and A_2 is its state for the subsequent year t_2 (Puyravaud 2003). It shows a slight increase which means an obvious decrease of the forest area, about 4.58% per year (Table 19.3).

Landscape metric computation also evidenced the trends of forest fragment loss in the study area. The analysis reveals that the fragment loss affects all the size classes, which means a randomness of forest area reaffectation for agricultural purposes in the study area. The decrease of class areas less than 500 ha between 1999 and 2005 may be associated to the elimination of the isolated forest patches, the increase recorded between 2005 and 2014 could be a consequence of the creation of new small fragments (Fig. 19.3). The large fragments (>500 ha) seem to be stable but in fact they are shrinking and shifting into the lower size classes if they do not disappear entirely, and new large fragments are created (Fig. 19.3). This patch structure evolution reflects human logging strategy. A gradual fragmentation process leads to large fragments at the forest border which are fragmented further in smaller and more isolated forest patches, which are finally converted into non-forest land use.

In addition, biological and ecological characteristics of dry forest emphasize this trend. In fact, such forest types have a relative slow regeneration due to the high increase of population density in the region (Fig. 19.4). Furthermore, slashed and dead fallen trees are also used to provide timber and woody charcoal. These causes related to human activities seem to be the main direct drivers of forest cover changes and transitions in the region.

Fig. 19.4 Comparison of deforestation and population trend



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Conclusion

This work mainly links forest cover loss in the dry deciduous forest of Mikea localized in the southwest of Madagascar to the underlying fragmentation process during 15 years. The combination of spatial observation approaches and landscape metrics acquired from FRAGSTATS helped to highlight the spatial dynamics of dry deciduous forest.

Forest cover loss and the forest fragmentation seem to follow the same trajectory: the use of forest as a resource for people to survive (mainly firewood and woody charcoal for domestic use). This could be evidenced through the evolution of forest fragmentation patterns.

The dynamic pattern of the dry forest in the study area follows the general trend of landscape fragmentation by human activities and settlement sprawl. The incorporation of biological and ecological factors in the analys of the different fragmentation classes could help to understand the impact of this fragmentation phenomenonon biodiversity.

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