Creation of a management plan for the Ibity Massif, Madagascar: diagnosis

En haut: Vue générale du Massif d'Ibity, nouvelle aire protegée ; en bas à gauche ; Mosaique bois de tapia – formation heubeuse ; en bas à droite: Savane à *Loudetia simplex.* (Photos par Swanni T. Alvarado)

I. Chapitre 1

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Abstract

Globally, the number of protected areas has increased exponentially during the last 25 years, particularly in biodiversity rich developing countries. Many recent initiatives have integrated sustainable local socio-economic development into the management of these areas. Because the process of deforestation and species extinction is often accelerated and more acute on islands, substantial efforts have been undertaken in these regions to create and strengthen local environmental organizations, to establish new protected areas, and to improve natural resources management. A new protected area (PA) is currently being established at Ibity Massif, and a community-based conservation and restoration project is being coordinated by the Missouri Botanical Garden (MBG). Ibity Massif is a quartz mountain located on the Malagasy highlands 25 km south of Antsirabe and 200 km south of the capital, Antananarivo. In December 2008, a temporary protection order was issued for Ibity (renewed in December 2010), and definitive establishment of the new PA is pending. This initiative has involved significant outreach and community education programs focusing on raising awareness of Ibity's conservation and economic importance, the threats to its biodiversity, and ongoing efforts to reduce fire frequency and implement ecological restoration projects with significant local community participation. The aim of the present study is to document and synthesize the diagnostic process undertaken at Ibity in order to: 1) facilitate dissemination of the data gathered to inform establishment of the new protected area; 2) summarize the initial state of the environment on the massif prior to the implementation of a management plan and thus establish a baseline that can be used to assess the effectiveness of the new protected area; and 3) encourage those responsible for other projects to adopt similar procedures.

Keywords: Management plan, protected area, fire, conservation.

1. Introduction

The establishment of protected areas is one of the main tools used to prevent habitat loss, a major issue for the conservation of biodiversity as it leads to habitat reduction and fragmentation and causes the decline and loss of wild populations of plants and animals (Pressey *et al.* 1993; Naughton-Treves, Holland, & Brandon 2005; Nagendra 2008). Protected areas have two main roles: 1) they encompass a representative sample of the biodiversity of the regions in which they are located and 2) they buffer biodiversity from processes that threaten its persistence (Margules & Pressey 2000). Threats to habitat integrity can be direct, such as the conversion of natural and semi-natural ecosystems to farmlands or other land-uses, or they can be indirect, such as pollution or the introduction of invasive non-native species (Holdgate 1991).

Margules and Pressey (2000) proposed a six-stage process for the development of conservation projects (Figure I-1) : 1) compile data on the biodiversity of the region where the conservation project is planed ; 2) identify conservation goals for the region; 3) review existing conservation areas 4) select additional conservation areas; 5) implement conservation actions; and 6) maintain the required values of conservation areas. These authors emphasize the fact that when establishing protected areas, conducting a proper diagnosis is a crucial step for success: it provides the baseline data against which both conservation objectives are set and evaluation will be based. The success of a conservation project is not guaranteed by the creation of the protected area (Margules & Pressey 2000). To work and to be sustainable over time, protected areas also have to implement adaptive management that draws from on-going evaluation, itself based on good monitoring protocols and reliable baseline data. During the diagnostic stage, three main parameters must be identified (Holdgate 1991): a) the target environmental system: its components, structure, history, present dynamics and trends; b) the current impacts on the system and the demands that will be placed on it by human societies; and c) the capacity and resilience of the system to satisfy these demands and the management required to deliver them in a sustainable manner. To optimize the long-term success of a conservation project, the process of establishing and managing a new protected areas must be carried in collaboration with the local human population, taking their needs into account within the framework of sustainable socioeconomic development (Korhonen 2007). The diagnosis stage must thus factor in both biodiversity and the current and projected future environmental impacts of human activities, which are often inadequately documented and understood (Robèrt et al., 2002).

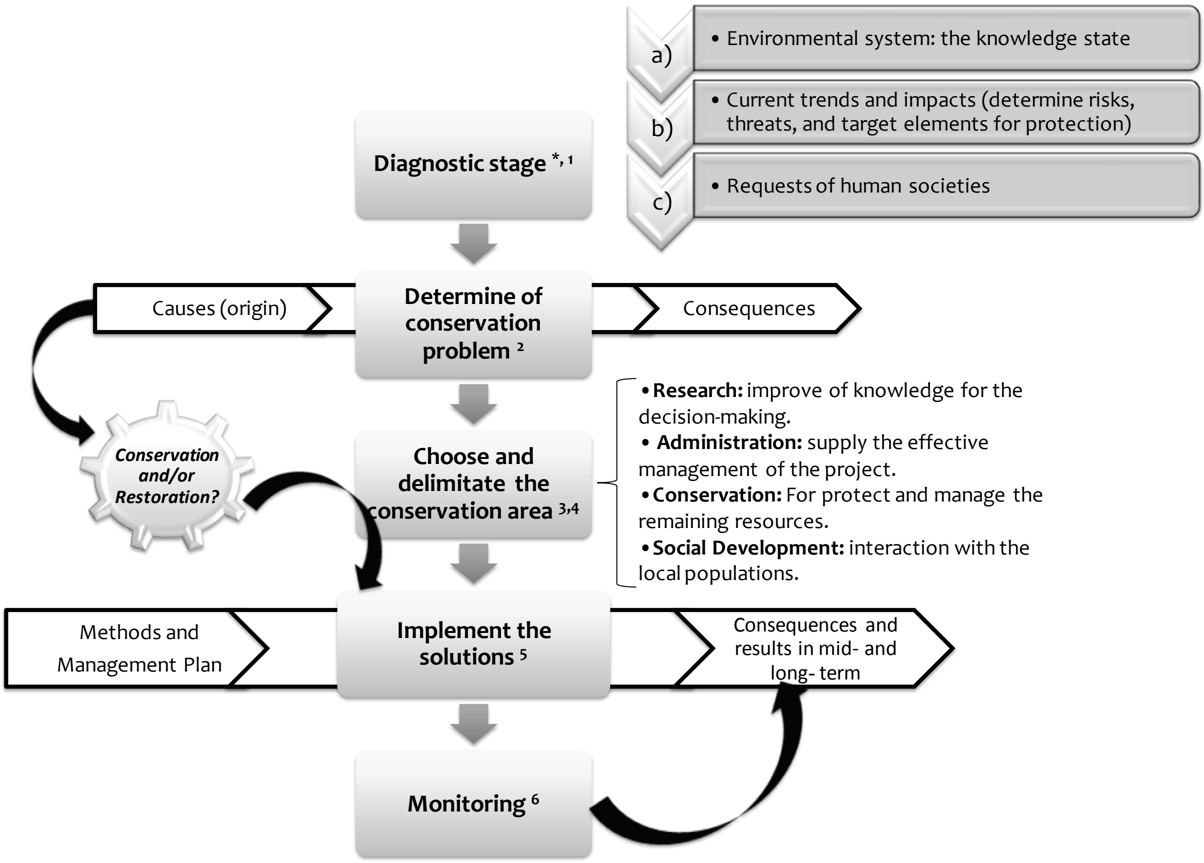

Figure I-1: Stages in the establishment of a new protected area and the development of its management plan. *Diagnostic stage follows Holdgate's (Holdgate 1991) parameters (a, b, c). [1, 2, 3, 4, 5, 6] Stages for planning proposed by Margules et Pressey (2000).

Starting in 2003, Madagascar's environment ministry began implementing a new Protected Areas System (Système d'Aires Protégées à Madagascar - SAPM) designed to triple the area managed for conservation from 1.8 million ha to a total of 6 million ha (Borrini-Feyerabend & Dudley 2005). This has been accomplished in large part by establishing partnerships with national and international non-governmental organizations (NGOs), such as Conservation International, the Wildlife Conservation Society, the Worldwide Fund for Nature, the Missouri Botanical Garden, and others, which have taken on the responsibility of establishing and managing new protected areas in collaboration with local communities. The total coverage of Madagascar's protected areas has increased over the last decade by more than 4.3 million ha (Atlas numerique SAPM 2011), 40.7% of which is at sites that are still in the process of obtaining government approval, and the remainder (59.3%, or nearly 2.6 million ha) have formally been granted temporary or permanent protection (Ministère de l'Environement et des Forêts, 2010).

The natural vegetation of the Malagasy highlands is highly fragmented (Ganzhorn *et al.* 2001; Vågen 2006), with a history of human occupation dating back more than 1500 years (Burney *et al.* 2004). The highlands lie in the center of the island, and cover about 70% of its total area. The natural grasslands, sclerophyllous woodlands and forests that once dominated have been replaced by vast expanses of anthropogenic grasslands as well as agricultural areas, such as rice paddies and to a lesser extent farmland, through the extensive use of human-set bush fires as an agro-pastoral tool (Kull 2000). Because of the apparent homogeneity of the vegetation that occurs in the highlands today and the extensive area now used for agriculture, the network of protected areas was limited in this part of the island.

There are, however, some highland grasslands and grassland/shrubland/woodland mosaics that constitute centers of high floristic diversity and endemism (Gade 1996), and it is the conservation of these areas that is most important to ensure that representative stands of remaining highland vegetation will be able to persist. One such area is the Ibity Massif, a quatzitic massif located 25km southwest from Antsirabe, that was formally recognized as a new protected area in December 2008. Ibity's geomorphology, soil characteristics, elevation, climate, and natural fire regime generate local conditions that have resulted in the establishment of unique plant communities that are home to many herbaceous and woody species endemic to Madagascar and in some cases to this massif itself (Birkinshaw *et al.* 2006).

The initiative to establish a new protected area on Ibity began in 2003, and was promoted by the Missouri Botanical Garden (MBG) in partnership with Conservation International (CI) (Alvarado *et al.* 2012). The flora and the fauna were inventoried and mapped, and the effects of human pressures were assessed in order to inform the process of delimiting the new protected area setting precise conservation objectives (Randriatsivery 2005; Rasoafaranaivo

2005; Birkinshaw *et al.* 2006). Within the framework of establishing new protected areas, adequate baseline data are often not collected, or they are fragmentary and/or not readily available (Bruner *et al.* 2001; Hockings 2003; Nagendra 2008). Moreover, those projects that do attempt to collect data often target values that are of limited or no use for evaluating conservation priorities and ensuring effective protection (DeFries *et al.* 2005; Nepstad *et al.* 2006). In this context, the aim of the present study is to document and synthesize the diagnostic process undertaken at Ibity in order to: 1) facilitate dissemination of the data gathered to inform establishment of the new protected area; 2) summarize the initial state of the environment on the massif prior to the implementation of a management plan and thus establish a baseline that can be used to assess the effectiveness of the new protected area; and 3) encourage those responsible for other projects to adopt similar procedures.

2. Diagnostic of the Ibity New Protected Area

2.1. Protected areas in Madagascar

The IUCN defines protected areas as “a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (IUCN 1994). In 1980, the "World Conservation Strategy" emphasized the need to protect the functioning of ecological processes and to maintain protected areas by emphasizing development needs (IUCN/UNEP/WWF 1980). Conservation efforts often try to take into account these considerations as well as general principles of ecology (including human ecology) along with both social and ethical factors (Holdgate 1991). Currently, the conservation of natural ecosystems can only be achieved by reaching a sustainable balance with local human populations and their demands on natural resources. Conservation objectives therefore require strategies that allow for managing an entire landscape, including areas dedicated to production and others to protection (Margules & Pressey 2000). The Code of Protected Areas in Madagascar (Code des Aires Protégées de Madagascar, COAP) (ANGAP 2001) follows as closely as possible this inclusive model in order to protect biodiversity and ecological habitats, conduct research, promote ecotourism, and contribute to the sustainable development of the populations living in the around protected areas, as well as contributing to regional and national economic development (Randrianandianina *et al.* 2003). In practice, however, this inclusive model remains very difficult to implement because of the complexities of each local situation, and as a consequence some targets are not fully achieved.

2.2. Physical setting of the Ibity New Protected Area

This New Protected Area (NPA) is located in Madagascar's central highlands, 200 km southwest of the capital, Antananarivo, and 25km south of the city of Antsirabe (47°01'E 20°07'S (Figure I-2). The land belongs to the Malagasy state (and thus comprises «Terrain Domanial»), and there are no private holdings within the NAP itself. Ibity's elevation ranges between 1400 to 2254m, which makes it the highest quartzitic massif in Madagascar. The climate is characteristic of tropical highlands, classified as Cwb (C : warm weather; w : dry winters; b : warm summers) using the Köppen classification system (Peel, Finlayson, & McMahon 2007), with cool and dry winters (June to October) and rainy summers (November to May). Average annual rainfall is 1583mm (based on data from 1961 to 1990; Meteorology Service of Ampandrianomby).

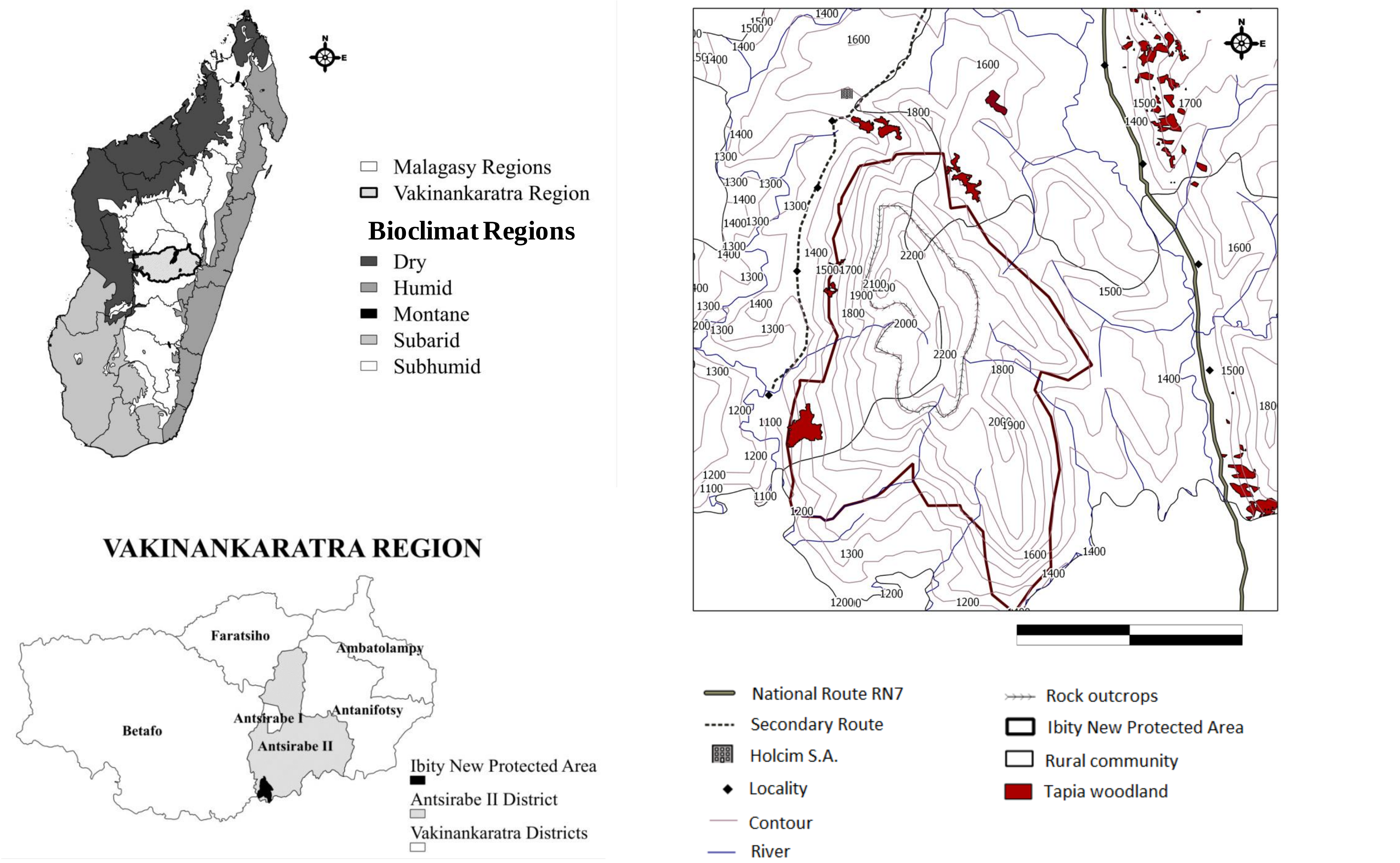

Figure I-2: Location of the Ibity new protected area and its surroundings (Vakinankaratra Region, Antsirabe II District, Rural Communes of Manandona, Sahanisvotry and Ibity)

3. Materiel and methods

3.1. Biological characteristics of Ibity

3.1.1. Vegetation

In order to establish a vegetation map of the Ibity area, photo-interpretation of LANDSAT TM 1999/158-074 satellite images was used to make an initial assessment of the distribution of the various plant formations represented on the massif. The presence of these formations was then confirmed on the ground, and their physiognomy and floristic composition were described. The results of this work are presented in maps prepared using IDRISI 3.2, ARCVIEW 3.2 and MAPINFO software (Birkinshaw *et al.* 2006). An initial draft of the vegetation map was updated using the Atlas of the Vegetation of Madagascar (Moat & Smith 2007).

Forty-six target species, defined as species found on Ibity and with a restricted distribution or endemic from Madagascar, Malagasy highlands, quartzitic massifs or Ibity, were selected from the Tropicos botanical database (www.tropicos.org/). To survey the selected target species, ten sites were chosen on quartzitic substratum from the topographic and geological maps, and from the vegetation map previously obtained in order to cover the main habitats of the massif. The inventory of target species was done in plots established at each site that varied in size from 20m×50m (1000m^2) to 20m×250m (5000m^2), depending on the available area of each vegetation type. The distribution of target species was added to the vegetation map created previously (Birkinshaw *et al.* 2006).

Because grasslands are dominant on the massif (occupying 98.5% of the land area), a study was specifically carried out to describe their species richness and composition. Five sites for each of four types of herbaceous savannas, defined according to their dominant grass species (see Results below), were studied. At each site, a species inventory was conducted using the minimum area protocol of Bouxin and Gautier (1982): species were recorded on an area of 1m^2, then 2m^2, then 4m^2, 8m^2, 16m^2, etc. until the minimum area was reached, i.e., until no new species were encountered. Species identifications were confirmed in Antananarivo at the reference herbarium of the Tsimbazaza Botanical and Zoological Park and at the offices of the Missouri Botanical Garden (MBG), using the *Flore de Madagascar et des Comores* (Humbert

1936) and the "Flora of the grasses of pasture and the cultures of Madagascar" (Bosser 1969).

3.1.2. Fauna

In order to determinate animal target species, which are keys for conservation plan (e.g. endemics species or endangered), a fauna inventory was carried out on Ibity by various consultants who covered all habitat types (see Birkinshaw et al. 2006 for details).

3.2. Current trends and impacts at Ibity

Before the process of establishing the Ibity NPA initiated, fire was believed to be the main cause of degradation and threat for diversity on the massif, as shown by interviews with members of local communities (villagers, local authorities, etc.) (Birkinshaw et al. 2006). In October 2003, Kiboy, a smaller massif situated to the north of Ibity, was struck by a fire at the end of the dry season. The burn was very aggressive because of the high fuel load and low fuel moisture at that time of year (Knapp *et al.* 2005; Govender, Trollope, & Van Wilgen 2006). This event offered an opportunity to carry out a pair of one-year ecological studies, one on plant community structure and composition (Randriatsivery 2005) and one on plant phenology (Rasoafaranaivo 2005), in order to begin assessing the effects of fire on Ibity's vegetation.

3.2.1. Impacts of fire on Ibity's herbaceous grassland plant community

The ecological effects of fire on grassland vegetation were studied with respect to structure and species composition, richness and biomass. Three sites of *Loudetia simplex* grasslands on quartzitic soil were chosen at altitudes between 1665 and 1755m in the burned zone, and three additional sites were examined in the unburned zone (control). At each site, five 100m transects were established, along which 100 points were read with a pin at 20cm intervals (for a total of 500 points/site, pin-transect methodology). At each point, the species touching the pin were noted, along with the number of contacts and the height at which each species touched the pin. In order to compare primary production (kg/ha/year) in the burned and unburned areas, plant biomass was sampled every month for one year following the fire by cutting the vegetation at 5cm above the ground in two 1m² quadrats at each study site (12 samples); fresh and dry biomass were weighted.

3.2.2. Impacts of fire on plant phenology

To assess the effect of fire on plant phenology, ten Malagasy endemic species were selected for this study, and individuals were monitored every two months for one year starting in December 2003, two months after fire: *Aloe capitata* var. *quartzicola* H. Perrier (Xanthorrhoeaceae), *Dialypetalum compactum* Zahlbr (Campanulaceae), *Distephanus polygalifolius* (Less.) H. Rob. & B. Kahn (Asteraceae), *Dioscorea hexagona* Baker (Dioscoreaceae), *Xerochlamys bojeriana* (Baill.) F. Gérard (Sarcolaenaceae), *Pachypodium brevicaule* Baker (Apocynaceae), *Pentachlaena latifolia* H. Perrier (Sarcolaenaceae), *Philgamia glabrifolia* Arènes (Malpighiaceae), *Abrahamia ibityensis* (H. Perrier) Randrian. & Lowry, ined. (Anacardiaceae), and *Uapaca bojeri* Baill (Phyllanthaceae). These ten species were monitored in the four following vegetation types, depending on the habitat in which they are found: sclerophyllous forest, rocky outcrop vegetation, herbaceous grassland, and woody grassland. Monitoring was carried out in twenty 20m×50m permanent plots, ten each in the burned and unburned areas (one plot/species/area). In each plot, 50 individuals of each species were randomly chosen and marked. The phenological stage [vegetative (Vg), in floral bud (Fb), in flower (Fl) and in fruit (Fr)] was noted for each species. The number of seedlings of each of the ten species was also estimated.

3.2.3. Spatio-temporal evaluation of vegetation dynamics

The spatio-temporal evaluation of vegetation dynamics was studied on Kiboy to assess changes during several years following the 2003 fire. This was done through the comparison of aerial photographs (E=1/50.000, mission91 ING/FTM 99/500, pictures 0856 and 0857; and E=1/10.000, mission N50-FTM-252/100/2000, pictures 08 and 09) and satellite images. Stereoscopic analyses of aerial photos enabled interpretation of the images from the recognition criteria established in the field.

3.2.4. Human demands on resources and environmental capacity to satisfy them

To assess demands placed on the resources of the Ibity massif as a result of human use and to evaluate potential anthropogenic pressures, the socio-economic context and natural resource use were studied. Interviews were carried out with members of the local communities, focusing on several key issues: grazing (place, mode, etc.), agriculture, and fire (period, use, place). In order to establish a map of land-uses around Ibity, land-uses were mapped from LANDSAT TM 1999/158-074 satellite images and confirmed on the ground (Birkinshaw *et al.* 2006).

4. Results

4.1. Biological characteristics of Ibity

4.1.1. Vegetation

Five vegetation types were identified on Ibity, using the classification system of White (1983): dense forest, open forest, woody grasslands, grasslands and freshwater aquatic and marsh vegetation (Table I-1). The current vegetation mosaic found on Ibity is dominated by grasslands, interspersed with fragments of tapia woodland, composed of *Uapaca bojeri*, in association the other woody species of Sarcolaenaceae (Madagascar's largest endemic family) (Figure I-3). A total of 423 species belonging to 89 families and 251 genera were recorded, among which 46 species were defined as conservation targets (species with restricted distribution or endemic of Madagascar, Malagasy highlands, quartzitic massifs or Ibity) (MBG 2012). Sixty-two percents of the species are endemic to Madagascar, including those belonging to two endemic families, Asteropeiaceae (one species) and Sarcolaenaceae (six species). Among these, 25 species are endemic to the Ibity massif itself. Several plant families are particularly species-rich on Ibity, such as Asteraceae (especially the genera *Helichrysum* and *Senecio*), Lamiaceae, and Fabaceae. Ibity is also a hotspot of diversity for *Aloe*, with 12 species (4 species endemic to the massif) (MBG 2012).

Table I-1: Vegetation types on Ibity Massif. Names used in the various unpublished reports are in French and indicated within brackets in the first column (Birkinshaw *et al.* 2006). For family names of species see Appendix 4 (Annexe 4) of the thesis.

Vegetation Type (White 1983)	Alternative name	Structural definition	Characteristic Taxa	Observations
Dense forest (Forêt dense)	Wet dense forest of average height	Vegetation comprising a continuous stand of trees at least 10m tall with interlocking crowns	*Tina* sp., *Ilex aquifolium*, *Polyscias ornifolia*, *Rhus taratana*, *Weinmannia stenostachya*	This vegetation type is rare and restricted at present to degraded fragments (e.g. Vohipisaka; < 1 % of the land area)
Woodland (Forêt Claire)	Tapia woodland, Sclerophyllous forest	Open stands of trees at least 8 m tall, with a canopy cover of 40% or more, and with a ground layer usually dominated by grasses and other herbs	*Uapaca bojeri*, *Agarista salicifolia*, *Sarcolaena oblongifolia*, *Schizolaena microphylla*, *Schefflera bojerii*	This vegetation type covers approximately 2% of the massif. The largest and the most intact fragments are in the southwestern part of Kiboy (outside the protected area) and in the east and south of Ibity (within the protected area)
Woody grasslands (Formation herbacée boisée)	Woody savanna	Land covered with grasses and other herbs, with woody plants covering included between 10 and 40% of the ground.	*Pentachlaena latifolia, Leptolaena pauciflora, Xerochlamys bojeriana, Aloe* spp., *Asteropeia densifolia*, *Abrahamia ibityensis*, *Vernonia* spp.	This vegetation type is found on rocky outcrops, protected from bushfires, but can also be found in the mid-slopes (covering ca. 50% of the massif)
Grasslands (Formation herbacée)	Savanna	Land covered with grasses and other herbs, with woody plants covering no more than 10% of the ground.	*Crotalaria ibityensis, Pachypodium brevicole*, species of Poaceae, Cyperaceae, Lamiaceae	This vegetation type covers approximately 40% of the Massif.
Freshwater aquatic and marsh vegetation (Végétation herbacée aquatique et marécageuse d'eau douce)	Bog/marsh	Herbaceous freshwater bog/marsh and aquatic vegetation	Species of Poaceae, Cyperaceae, Eriocaulaceae, Orchidaceae, *Utricularia livida, Drosera natelensis*	Some zones covered with marshes/bogs are found in the higher slopes (< 1% of the massif)

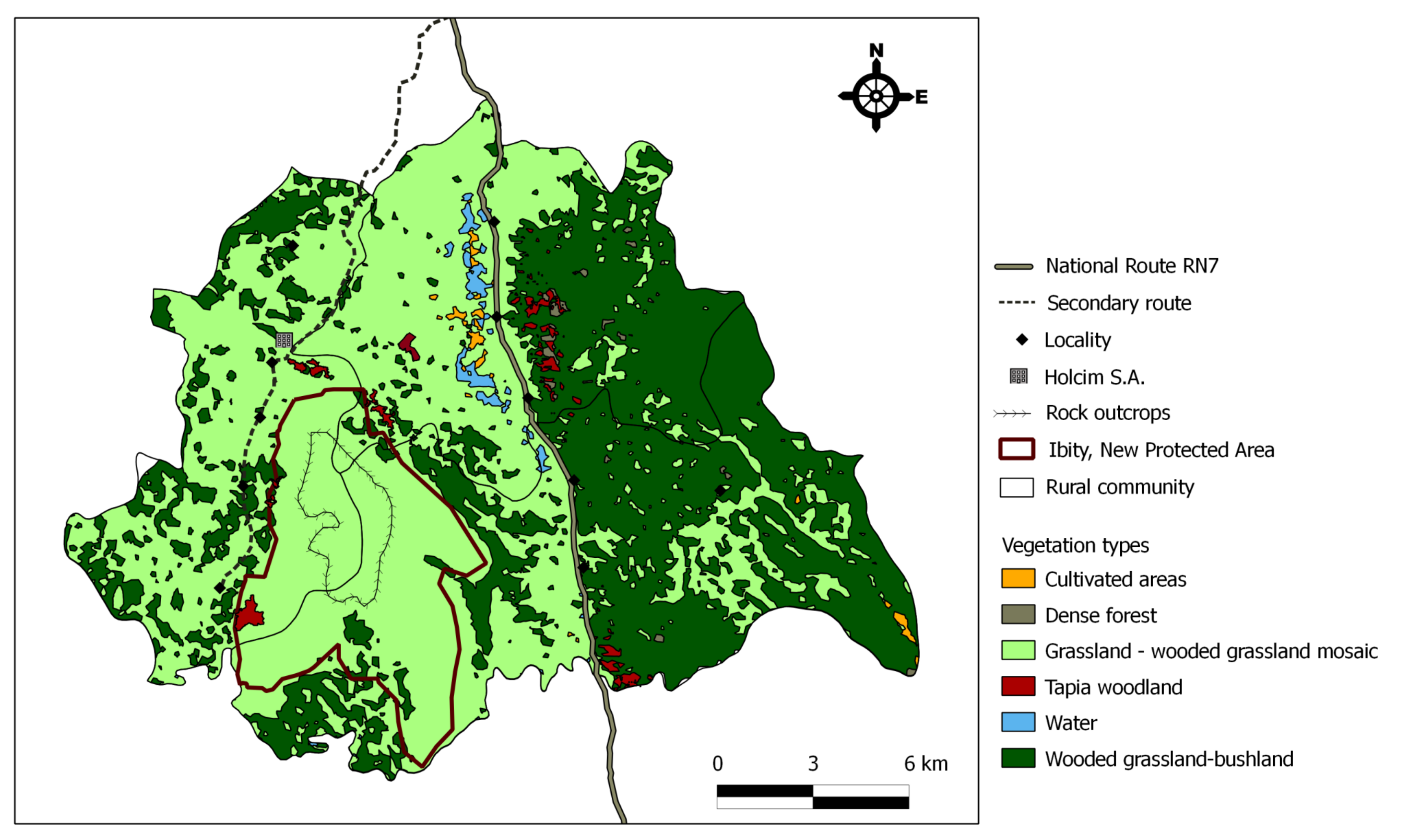

Figure I-3: Vegetation map of the Ibity Massif. Adapted from Moat & Smith (2007). The vegetation type wooded grassland-bushland, not mentioned in Table I-1, are areas planted with exotic species.

Herbaceous grasslands on Ibity are mainly dominated by *Loudetia simplex* subsp. *stipoides*. However, four distinct types of grassland can be distinguished (Table I-2).

Table I-2: Structure and composition of four herbaceous grassland types on Ibity Massif. For family names of species seeAppendix 4 (Annexe 4) of the thesis

	Loudetia simplex subsp. *stipoides* grassland	**Loudetia madagascariensis grassland on sandy soil**	**Aristida similis grassland**	**Urelytrum humbertianum grassland**
Location	Common throughout the massif	Principally in the summit area	Generally on lower slopes	On the crest
Altitude	1550-1900m	since 1916m	1200-1600m	2014m
Vegetation cover	> 90%	70%	80%	25-30%
Upper herbaceous stratum	80-120cm	80-130cm	60-150cm	> 80cm
	Loudetia simplex subsp. *stipoides*, *Loudetia madagascariensis, Pteridium aquilinum, Urelytrum humbertianum* and *Sporobolus centrifuges*	*Loudetia madagascariensis* only	*Aristida similis* and *Hyparrhenia rufa* only	*Urelytrum humbertianum*, *Erica* sp., *Loudetia madagascariensis* and *Cyperus obtusiflorus*
Middle herbaceous stratum	50-80cm	40-80cm	40-60cm	
	Schizachyrium sanguineum, Ctenium concinium and *Sporobolus centrifugus*	*Sporobolus centrifugus, Vaccinium emernensis, Brachiaria antsirabensis* and *Cyperus obtusiflorus*	*Cyperus obtusiflorus* and *Cynonkis* sp.	
Lower herbaceous stratum	10-30cm	< 30cm	< 30cm	< 20cm
	Cyperaceae	Dominated by *Fimbristylis* sp.	Dominated by *Fimbristylis* sp.	*Dominated by Fimbristylis sp.*
Woody species	Low density of: *Pinus* sp. (exotic), *Xerochlamys bojeriana, Agauria* sp., *Aphloia theiformis* and *Schefflera bojeri*	Low density of: *Vaccinium emirnensis*		

The minimum area (the area after which using a larger quadrat results in finding no new species), established with a species-area curve (Bouxin & Gautier 1982), was reached at 16m² in each of the four grasslands types ((Birkinshaw *et al.* 2006). The upper stratum has a species composition specific to each type, and is either dominated by only one species or by an association of species. Three types (Loudetia madagascariensis grassland, Aristida similis grassland and Urelytrum humbertianum grassland) have the same dominant species in their lower stratum (Fimbristylis sp.). Woody species are present only in Loudetia simplex and Loudetia madagascariensis grasslands.

4.1.2. Fauna

In total, nine insectivorous mammal species and three bat species were recorded at Ibity; 42 species of birds, 20 of reptiles and 10 of amphibians were also found (Annexe 3). Some remarkable species appear to be absent, including *Pteropus rufus* and *Eidolon dupreanum*, both classified as "Vulnerable" in the IUCN Red List (2012), and *Boophis williamsi*, classified as "Criticaly Endangered".

4.2. Current trends and human impacts at Ibity

4.2.1. Impacts of fire on the herbaceous grassland plant community

In the unburned area, 30 species belonging to 10 families and 26 genera were recorded; *Loudetia simplex* was the most abundant species. In the burned area, 32 species belonging to 13 families and 28 genera were inventoried, including one species of Liliaceae and one of Melastomataceae, neither of which were observed in the unburned area. Estimates of vegetation cover varied significantly ($F= 7.77$ $p\text{-value} < 0.05$) according to area and time of year. In the burned areas, the cover increased from February to June, showing that the plant biomass is able to recover quickly, reflecting the fact that it mainly consists of grasses and species of Cyperaceae that reproduce vegetatively by resprouting. After June, during the dry season, a decrease in vegetation cover was observed in both areas. Mean biomass production one year after fire was similar between unburned and burned areas (2725kg/ha/year and 2667kg/ha/year, respectively).

4.2.2. Fire impacts on plant phenology: preliminary studies

For both the burned and unburned areas, we distinguished four phenological groups based on flowering period. Group A (*Abrahamia ibityensis, Dioscorea hexagona, Pentachlaena latifolia, Philgamia glabrifolia* and *Xerochlamys bojeriana*) showed a flowering peak in December (Figure I-4a), which coincides with the peak in rainfall; Group B (*Aloe capitata* var.

quartzicola and *Pachypodium brevicaule*) for which the flowering occurred in the dry season (Figure I-4b); Group C (*Uapaca bojeri*), in which flowering began two months before that for Group A, coinciding with the end of the dry season (Figure I-4c), and Group D (*Dialypetalum compactum* and *Distephanus polygalifolius*), for which the flowering peak occurred between the rainy and dry season (Figure I-4d). Fruit production was not observed for all the species. Peak fruiting for two species of Group A (*A. ibityensis and P. latifolia*) and for *U. bojeri* of Group C was in December and it lasted for one month. Fruit production of *Xerochlamys bojeriana* (Group A) was observed from February to August; fruiting for other species of Group B and C was observed in August. Species of Group D and *Abrahamia ibityensis* (Group A) did not produce fruits in the burned area.

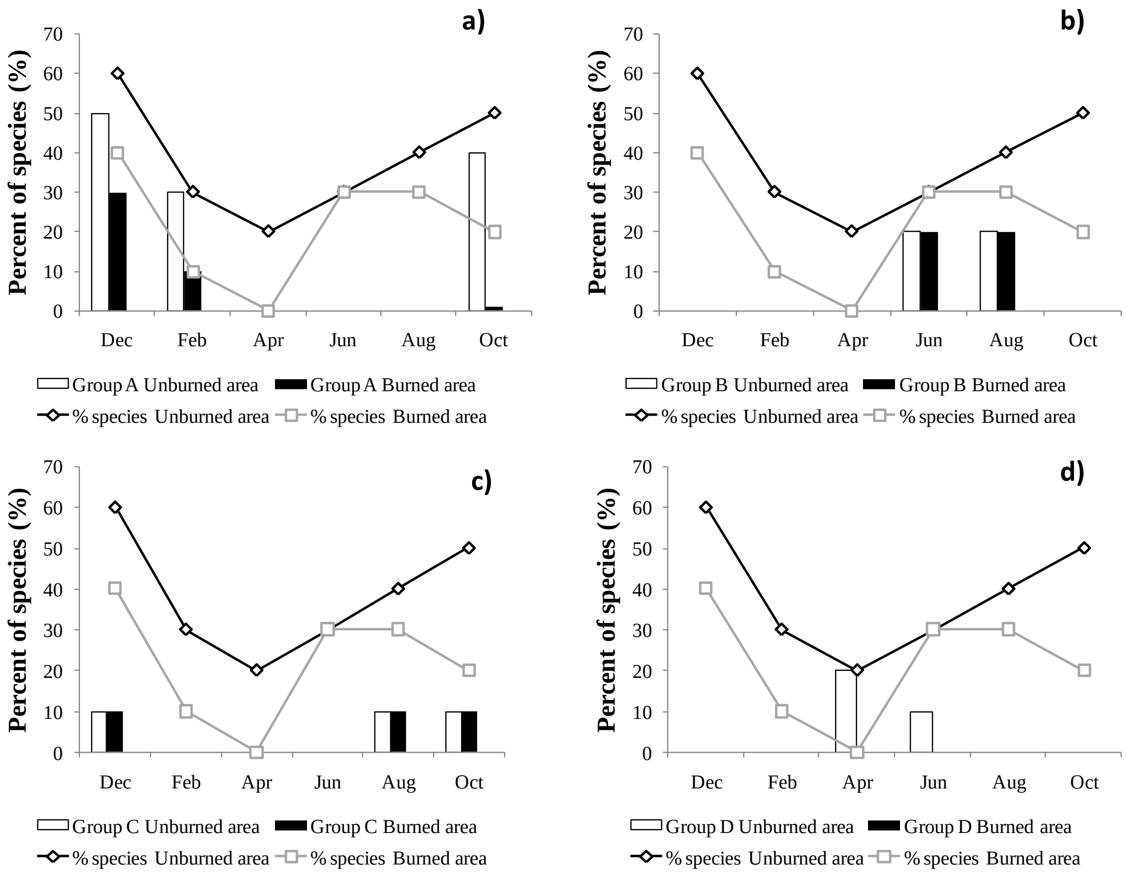

Figure I-4: Flowering phenology for 10 target species (% de species with flowers): a) Group A (*Abrahamia ibityensis Dioscorea hexagona, Pentachlaena latifolia, Philgamia glabrifolia* and *Xerochlamys bojeriana*); b) Group B (*Aloe capitata* var. *quartzicola* and *Pachypodium brevicaule*); c) Group C (*Uapaca bojeri*) and d) Group D (*Dialypetalum compactum* and *Distephanus polygalifolius*).

No in-situ germination was recorded for Abrahamia ibityensis, Aloe capitata var. quartzicola, Dialipetalum compactum, Dioscorea hexagona, Xerochlamys bojeriana or

Pentachlaena latifolia. Germination was recorded for only four species: 1) Distephanus polygalifolius and Philgamia glabrifolia had a peak of germination in June, with a total of 106 and 19 seedlings recorded, respectively, only in the unburned area; 2) Pachypodium brevicaule, which had a germination peak in April, had 14 seedlings in the burned area and 2 in the unburned area; and 3) peak germination for U. bojeri occurred in February for both burned and unburned areas, with more seedling in the burned area (87) than the unburned area (5 seedlings).

4.2.3. Spatio-temporal evaluation of vegetation dynamics

Between 1991 and 2000, a small decrease was observed in cover for sclerophyllous forest and gallery forest, and a sharp decrease was recorded for herbaceous grassland (Table I-3). On the other hand, an increase in cover was observed for the woody savanna, *Eucalyptus* savanna, and pseudo-steppe (Table I-3).

Table I-3: Evolution of cover for each major vegetation type on Ibity Massif between 1991 and 2000.

Vegetation type	Area in hectares (% of total)	
	1991	2000
Sclerophyllous forest = Tapia woodland	35 (24.9%)	34 (24.2%)
Galery forest	1.4 (1%)	1.3 (0.9%)
Loudetia simplex herbaceous grassland	91 (64.8%)	83 (59.1%)
Pseudo-steppe	6.5 (4.6%)	10 (7.1%)
Eucalyptus tree savanna	6.5 (4.6%)	8.1 (5.8%)
Eucalyptus shrub savanna	0 (0%)	4 (2.8%)

In 10 years, the cover of woody savanna and *Eucalyptus* savanna increased to the detriment of the herbaceous grassland (Table I-3), a result of an increase in the area reforested by HOLCIM S.A., which operates a nearby cement factory, and by the villagers living in the region. Tapia woodland presents signs of disturbance, and the understory of wooded grassland is poor in woody species. On the other hand, other pyrophytic woody species, such as *Philgamia glabrifolia* and *Pentachlaena latifolia*, began to colonize grasslands and to spread.

4.2.4. Human demands on resources and environmental capacity to satisfy them

Although the Ibity massif is not permanently habited, the surroundings are populated. Three rural districts (Sahanivotry, Mananadona and Ibity) have a total estimated population of about 34,000 people living in 16 villages that cover an area of ca. 10,000 ha within 5km of the massif, yielding a population density of 3.1 persons/ha (Birkinshaw *et al.* 2006). Old tombs found on the massif suggest human presence dating back many centuries. Today, most members of the local population belong to the Vakinankaratra ethnic group, with a minority of Merina and Betsileo.

The main economic activity of the local population is agriculture, in particular rice cultivation, but also of cassava, corn, and sweet potato, along with raising livestock (zebus, pigs and poultry). Other secondary activities around the massif are include fishing, extraction of precious stones, raising silkworms (*Borocera madagascariensis*) to make wild silk cloth and, in the private sector, the industrial exploitation of marble by the HOLCIM S.A.cement factory. The fruits of Tapia (*Uapaca bojeri*) are collected mainly for local consumption or for sale in the local market. *Uapaca bojeri* is the main tree present on the Ibity massif, and it is cut and used for construction or as fuel wood. The local population uses some plants for traditional medicine and for cultural purposes. Traditional practitioners from areas farther away from the massif (Ambositra, Fandriana, Faratsiho, etc.) collect plants on Ibity to cure various diseases. *Pachypodium brevicaule* is illegally harvested in great quantities by storekeepers from Antsirabe, and the local population is paid to collect it. This species, which is listed in CITES Annexe II (PNUE-WCMC 2011), is sold and exported illegally (MBG 2012). Mammals, such as *Tenrec ecaudatus*, *Setifer setosus*, *Hemicentetes nigriceps* and *Pteropus rufus*, as well as birds, such as *Buteo brachypterus*, *Numida meleagris* and *Margaroperdix madagascariensis*, are hunted and consumed by the villagers.

While Ibity massif is rich in semiprecious stones (mainly quartz and beryl), there are few mines andonly one operates with a legal authorization. In 2011, gold was found in Ambohipo in the southeastern sector of Ibity. Exploitation began in January, and 500 people migrated in from rural districts close to the massif. Three months later a peak in activity was reached, with 4000 people present, many coming from much farther away. Currently gold exploitation has decreased and the number of people working at Ambohipo has come down to 500. The

Missouri Botanical Garden, working with the local population, implemented a control system to forbid exploitation within the limits of the protected area. Only the lower slopes outside the NPA are authorized for this activity.

Through interviews, fire was identified by the local population as the most significant threat to the natural and semi-natural ecosystems of Ibity (Birkinshaw *et al.* 2006). Fires that impact the massif are mainly accidental in nature, escaping the control of local people burning to renew grass for cattle or to clear fields. Together with human exploitation of Ibity's ecosystems, fire is responsible for the decrease in gallery forest area observed in the study of vegetation dynamics conducted over the past nine years, and these factors have also led to modification of the structure of tapia woodlands.

At present, tourist activity is not important in the region; the Ibity massif remains unknown despite its spectacular landscape, waterfalls, natural swimming pools, old tombs, semiprecious stones, caves, bats, and a charming and unusual vegetation with many succulents and orchids. However, given its proximity to the important tourist centers of Antsirabe, Ibity has the potential to develop as a tourism destination and thereby help improve the region's economy.

5. Discussion

5.1. Delimitation of the protected area and the implementation of management plan

5.1.1. The diagnostic

The diagnostic studies carried out by the Missouri Botanical Garden on Ibity Massif (Birkinshaw et. al 2006), the results of which have been summarized above, yielded an understanding of ecosystem dynamics and responses to disturbances. This step is essential to the implementation of biodiversity protection and management programs in protected areas and peripheral zones (Holdgate 1991). Interviews with members of the local population showed that grasslands play a crucial role in providing rural livelihoods, soil protection and the maintenance of the region's livestock system (Birkinshaw *et al.* 2006). Herbaceous species are used to make house roofs, as forage for zebus cattle, and as healing plants. The other natural formations occurring of the massif, mainly tapia woodland and gallery forest, are threatened by other types of anthropological activities. Repeated bush fires during the dry season (from April to September) have been shown to have a negative impact on soils (Rakotoarimanana & Grouzis 2006) and on species diversity at Kiboy (northern Ibity), as has been found in other studies elsewhere (Collins 1992; Guevara *et al.* 1999; Beckage & Stout 2000; Kirkman *et al.* 2001). Fire can temporally increase productivity and species richness in some grassland systems (Collins & Barber 1985). However, an increase in fire frequency above natural levels negatively affects species abundance and richness: fire-sensitive species decrease in abundance until they disappear, while those adapted to fire increase (Collins 1992; Beckage & Stout 2000; Kirkman *et al.* 2001). When burned, tapia woodlands have a reduced cover of shrubs and young trees in the undergrowth, an increased herbaceous stratum, and a fragmented canopy (Alvarado *et al.* 2012). *Uapaca bojeri* is fire tolerant (Kull 2002; Kull et al., 2005) and high fire frequency is thus favorable for this species, which becomes dominant as adults. However, its seedlings, which are less fire-tolerant, become rare. Ibity's trees and shrubs are exploited by local people for timber, handles for tools, and wood for charcoal production (few large trees now remain on the Massif). This activity reduces not only the fertility of trees and shrubs but also fragments the canopy allowing herbs to grow and increase in abundance, which in turn favors fires.

Fire is a traditional management tool, widely used in many parts of the tropics. It continues to play a significant role in various agricultural and social practices (Mistry & Bizerril 2011), as it is the case at Ibity (Kull 2002), where fire is used for pasture improvement and renewal. Successive fires could accelerate the processes of soil erosion and favor the establishment of fast growing herbaceous species such as *Aristida similis* and *Imperata cylindrica* (Kull 2003; Randrianarivelo 2003). Fire also reduces the regeneration of certain woody species such as *Uapaca bojeri* by killing both young seedlings and the cocoons of the wild silk worm, *Borocera madagascariensis* (Gade 1996; Kull 2002a). Grazing is a frequent practice that threatens the massif on mid- and low-elevation slopes, mainly on the districts of Manandona and Sahanivotry (MBG 2012). The upper areas, characterized by steep slopes that exceed 60° in the rocky, quartzitic outcrops, are thus less used for cattle. Ibity appears to be following the same transformation process that took place earlier in the original mosaic of the Malagasy highlands, where humans likewise used fire to raise livestock and for agriculture, reducing forest cover in favor of herbaceous, sometimes exotic species (Dewar 1984; Burney 1987b; Ratsirarson & Goodman 2000).

As human population increases around Ibity, farmers expand their cultivation farther up the massif, whose grasslands are being replaced by fields, and the extension of these zones towards steeper slopes increase soil erosion (Kull 2003). The selective cutting of woody species in tapia woodland, mainly autochthonous species such as *Xerochlamys* spp. and *Sarcolaenaea* spp. often used as fuel wood, can favor in certain cases the dominance of *Uapaca bojeri* (Kull *et al.* 2005). The harvest and the clandestine market for succulent plants such as *Aloe* spp. and *Pachypodium brevicaule*, as well as the collection of seeds of protected species, such as *P. brevicaule, Dypsis* sp. and *Ravenea madagascariensis*, are direct threats for these species. Another factor of disturbance is the introduction of exotic species such as *Pinus kesiya, Pinus patula* and *Eucalyptus* spp., all of which affect certain remnant formations but which are also very useful for the local population (Kull et al., 2012). On the north side of Ibity, the mid- and lower slopes were reforested with *Eucalyptus* by the cement factory. Germination of this fire tolerant exotic species is stimulated by fire, and natural dispersal and regeneration are now being seen on the massif.

5.1.2. Conservation objectives

The second stage in the process of establishing the Ibity protected area, following a thorough diagnostic, was to identify conservation objectives. The diagnostic studies established that 46 species represented conservation targets, along with three vegetation types: forests gallery, tapia woodlands and grasslands on the rocky outcrops. According to Margules and Pressey (2000), despite of a certain subjectivity in the determination of targets, the value of the conservation objective must be explicit. For example, information about the ecological and biological importance of a given species (e.g., on that is rare, endemic or threatened) must be taken into account so that targets are not excluded or under-represented within the protected site. Acquiring knowledge about vegetation and more generally about biodiversity is therefore crucial in the process of establishing a new protected area (Tuxill & Nabhan 2001; Turpie 2003). Vegetation traits should be used as criteria to select potential sites for conservation. Some traits are precise and can be relatively easily measured (size, diversity) while others are less so (wilderness), some are strictly ecological (diversity, rarity) while others reflect development threats or vulnerability (fragility) (Goldsmith 1991). The general objectives established for the conservation strategy at Ibity were 1) to restore the gallery forests on the massif; 2) to restore tapia woodlands and/or to improve its regeneration; 3) to reduce the risk of extinction of endangered species of restricted distribution, and 4) to manage exotic species inside the Protected Area (Birkinshaw *et al.* 2006).

5.1.3. Implementation of conservation actions

In practice, delimiting a new protected area is complex because of the interactions between ecosystems and humans, who create productive landscapes associated with agricultural systems in which disturbances, transformation towards extensive exploitation systems, and fragmentation occur and often expand (Ranta *et al.* 1998; Margules & Pressey 2000; Brockington, Igoe, & Schmidt-Soltau 2006). The conservation tool offered by a protected area, as perceived in an international and scientific context, is often not fully understood by the local population living in and around a conservation site (Mbile *et al.* 2005). To address the issue of whether and how rural populations can and should be allowed to utilize the resources within a conservation site, two models of sustainable biodiversity management are used in most emerging countries, an exclusive and an inclusive model (Borrini-Feyerabend 1996; Oviedo & Brown 1999). In the first of these, management aims to deflect the interests of the population away from future protected areas, under an anti-participative vision that excludes human presence within the conservation area. The second model focuses on the welfare of those who live and use the resources of the protected area, including them in the planned management. In Africa, the exclusive model has prevailed to date because, at least in part due to the colonial histories of most countries and postcolonial influences (Borrini-Feyerabend 1996; Mbile *et al.* 2005).

Evaluation of the long-standing protected areas containing tapia woodlands confirmed that this vegetation type was inadequately conserved. The establishment of two complementary protected areas on the massifs of Ibity and Itremo was thus proposed (Atlas numerique SAPM 2011). Indeed, Tapia woodland covered only 2,600 km^2 (DEF 1996) in four main parts of Madagascar's central highlands of which just one, Isalo National Park, is included in the country's System of Protected Areas (classified as Category II under the IUCN system). Ibity has benefited from temporary protection since 2008, while Itremo is not yet formally protected. The conservation area on Ibity covers 6136 ha, comprising three zones: a Strict Protection Zone (SPZ, 1598ha), a Buffer Zone or Sustainable Use Zone (SUZ, 4594ha), and a Controlled Activity Zone (CAZ, 14ha) (Table I-4).

Table I-4: Summary of authorized and forbidden activities in Ibity NPA.

Activities	Strict Conservation Zone (SCZP)	**Sustainable Use Zone (ZSU)**	**Controlled Activity Zone (ZCA)**
Research	✓	✓	✓
Grazing	×	✓	✓
Harvest of herbal medicine	×	✓	✓
Harvest of tapia fruits	×	✓	✓
Harvest of native seeds	×	✓	✓
Harvest of cocoons of wild silk worms (Landy Be)	×	✓	✓
Harvest of fuel wood (kitay)	×	✓	✓
Tourism	×	✓	✓
Agriculture	×	×	✓
Wood exploitation	×	×	✓
Wood exploitation for charcoal	×	×	✓
Harvest of *Pachypodium* spp.	×	×	×

This process must be followed by the implementation of conservation actions (Margules & Pressey 2000). To facilitate sustainability of the Ibity project over the midterm, a local association was established to enable communication and to insure participation of the surrounding villages in the development of the conservation project. The conservation actions developed to date mainly concern environmental education, with priorities: fire management, management of natural resources exploitation on the massif (in particular of plants and minerals), and the identification and establishment of complementary activities that favor socioeconomic development. Local nurseries have been organized to propagate native plant species (such as *Uapaca bojeri, Abrahamia ibityensis, Aphloia theiformis, Carissa edulis*), including ornamentals that are under pressure from illegal exploitation (*Aloe* spp., *Pachypodium brevicaule*) and certain other species of economic interest (e.g. *Morus alba*, *Voaroihazo*; *Carica papaya*, *Papay*). Propagation efforts are also focusing on exotic, fast growing tree species (e.g. *Acacia* sp.) being used in reforestation efforts implemented outside the protected area to reduce pressure on native tree species.

Given that the long-term ecological viability of protected areas is influenced by and depends directly upon socio-ecological processes that operate beyond their boundaries and adjacent buffer zones (Mistry & Bizerril 2011), a multidisciplinary management approach is necessary. At Ibity, fire was identified as a potential threat for certain vegetation types in the diagnostic studies, and most fires were found to be connected to agricultural activities, and therefore causally independent from the ecosystems on Ibity that they impact (Kull 2000, 2003). In most rural landscapes where fire is used as a tool, cost-benefit analyses of alternative options for managing field cleaning or supplying fresh food for cattle during the dry season shows that the application of measures to limit or eliminate burning have an unfavorable impact on the local population's socio-economic wellbeing (Mistry & Bizerril 2011). Moreover, a recent study has shown that Itremo, the nearby massif where a NAP is now being proposed, has both lower fire frequency and lower plant diversity (Alvarado et al., accepted with minor corrections; Chapitre 2). Many species on Ibity are also fire tolerant and/or require fire to some extent. An optimal fire regime must now be determined by carrying out more detailed studies focusing on this key issue, which is a top management priority for Ibity.

In the tropics, fire has also played a major role in initiating the establishment of many protected areas (Mistry & Bizerril 2011). In Africa, for example, local populations were accused by colonialists of causing land degradation by the use of fire (Kull 2002a; Laris & Wardell 2006). Thus, degradation by fire and the associated supposition of "bad land management" were used as a justification to expel traditional owners and expropriate land rights from local populations. The new protected area at Ibity, established as a Category V protected area (Landscape/seascape conservation and recreation) (IUCN 1994), is a remarkable example of conservation using the inclusive model (Borrini-Feyerabend 1996; Oviedo & Brown 1999). According to the definition provided by IUCN (1994), Category V protection focuses on the interaction between people and nature that has produced a zone whose character differs from the original ecosystem, but which nevertheless has significant ecological, biological, cultural and scenic value and where protecting the integrity of this interaction is essential for the conservation of a diversity of values, including biodiversity. Conservation actions taken without consideration of their social and environmental effects on the local population tends to increase poverty in nearby rural communities (West *et al.* 2006; Wilkie *et al.* 2006). It is for this reason that the establishment of the new protected area at Ibity focused on preserving and maintaining the current landscape and its associated biodiversity along with the other values involving interactions with the local population and their traditional management practices.

6. Conclusions

The final delimitation of the Ibity New Protected Area was the result of extensive discussions and negotiations between the population in the surrounding area, local authorities, mainly representatives of the Environment Ministry, and MBG staff members. Close cooperation between the project managers, the local population and authorities must be maintained in order to minimize the risk of possible conflicts with the legitimate needs of the local population, and to ensure that they benefit directly from conservation activities while being able to continue using the area's natural resources sustainably. Concerning fire management, despite the fact that burning has long been seen as destructive and undesirable (resulting in a dominance of herbaceous species when fire frequencies are high, a reduction of biodiversity, soil erosion, etc.), it is impossible to eliminate fire from Ibity's landscape, as is the case in many tropical areas of the world. Fire is intimately connected to local cultural identity, management practices and ecological durability and diversity. However, many unresolved questions remain concerning the management plan for Ibity's rich and diverse vegetation, and it is now necessary to determine the most appropriate and sustainable fire regime (frequency, timing, etc.) for the different vegetations type. A study is now underway on the impact of fire on grassland vegetation and tapia woodland (focusing in composition and structure, phenology, germination, and impact on post-burning seedling resilience) (see the following chapters). The results of this work will contribute to developing an improved set of management actions throughout the Ibity area and to successful implementation of an integrated conservation strategy.