Preventing Deforestation in Madagascar: is Kirindy Mite National Park effective?

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Madagascar, one of the world’s biodiversity hotspots, is losing habitat of native species at an alarming rate. Frequently overlooked by researchers, dry deciduous forests have been destroyed by logging and fires for subsistence agriculture. Kirindy Mite National Park encompasses one of the largest continuous tracts of dry forest in Madagascar. However, the current state of the Park is largely unknown by the Association Nationale pour la Gestion des Aires Protégées (ANGAP) managers in Morondava due to lack of funding and technology, an issue faced by many park managers in developing countries. In order to assess whether the Park is preventing deforestation within its boundaries and if the disturbed forest within the Park was rebounding, satellite images from 1990, 2000, and 2006 were used to map forest cover within the Park and a 5km buffer outside the Park. Comparisons of deforestation and afforestation rates between the Park and buffer were used to gauge the effectiveness of the Park for forest conservation. Overall, the boundary or knowledge of it plays a role in deterring anthropogenic deforestation with Kirindy Mite. However, this and the remoteness of the Park were not enough to completely prevent the Park from losing forest cover from 1990 to 2006.
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Introduction:

Madagascar consistently ranks as one of the world’s top biodiversity conservation priorities, owing to its high concentration of endemic species and extreme levels of habitat loss. Madagascar endemics make up 3.2% of the world’s plant species and 2.8% of the global vertebrate species (Myers et. al. 2000). This critical combination of factors, contained within a relatively small, isolated island area increases the risk and importance of effective conservation on Madagascar (Myers et. al. 2000).

Madagascar’s primary vegetation has been decreased to an extent of 9.9% (Myers et. al. 2000), and some consider this an overestimate (Dollar, 2006). This reduction in forest cover has severely fragmented native habitats throughout Madagascar (Green & Sussman 1990). Forest fragmentation is a grave threat to the island’s diversity because the remaining patches of forest are often too small to support viable populations. This exacerbates the loss of numerous animal communities (Ganzhorn et. al. 2000a, Ramanamanjato 2000). It is predicted that degradation of the western dry forests and eastern littoral forests has become so great that the remaining fragments will be incapable of supporting viable populations by 2040 (Ganzhorn et. al. 2001). This may, in fact, be a generous estimate of projected time to retain viability (Dollar 2006).

Reforestation – whether natural or anthropogenic - can be a key tool in preventing further species loss, possibly even leading to increased diversity and abundance in animal and plant populations. However, Madagascar consistently suffers from a paucity of reliable field data necessary to implementing successful conservation and management plans (Ramanamanjato & Ganzhorn 2001). The majority of information gathered on conservation efforts in Madagascar to date has focused on the eastern evergreen
rainforest. The dry deciduous forest of western Madagascar, such as the forest of Kirindy Mite National Park, has been relatively ignored, despite estimates that over 97% of this forest type has been lost (WWF 2001). The remaining dry forests have become fragmented to the point that, even in more sizeable forested areas, species are increasingly and almost universally affected by human influences on the forest (Ganzhorn et. al. 2001).

The primary catalysts of Madagascar’s deforestation are subsistence agriculture and logging (Green and Sussman 1994). Overcoming these problems requires a combination of conservation research and social change (Ganzhorn et. al. 2001). Even though National Parks and Reserves protect some areas from logging, illegal logging still reduces forest cover by a considerable amount (Ganzhorn et. al. 2001). Forests and savannas face a high danger from burning by villages to clear land for agriculture or by nomadic tribes whose cattle need young grasses for grazing (Dollar 2006). An effective solution to end the deforestation caused by poverty is to provide the populace with improved agricultural techniques and other means of earning a living, such as participation in ecotourism (Sussman 1994).

In order to address both the symptoms and the causes of habitat and species loss, the Association Nationale pour la Gestion des Aires Protégées (ANGAP) managers in Morondava plan to expand Kirindy Mite National Park. Kirindy Mite is one of the largest dry forest protected areas in Madagascar and contains what are likely the largest remaining contiguous tracts of dry forest. Even though forests within the park are recovering from previous logging, the destructive effects are still evident and need to be addressed in a management plan (Dollar 2005). The purpose of the Park’s expansion is
twofold: first, to increase the amount of protected habitat, especially in areas where the risk of species loss is high, and also open up more of Madagascar’s western dry forests to research and ecotourism. The creation of a series of management suggestions for the expansion and development of Kirindy Mite, through this project, will not only strive to address current management concerns, but also determine an expansion plan that will benefit Madagascar’s endemic species and the local populace.

**Objective:**

The objectives for this project include creating usable, accurate maps of Kirindy Mite National Park to be used by ANGAP for future Park management. By examining the changes in forest cover in and around the Park, the effectiveness of the Park in terms of forest preservation will be evaluated. Forest cover change will also be the basis for suggestions of future Park management and expansion.

**Methods:**

Forest cover and change within the Park and surrounding area were determined using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images from 1990, 2000, and 2006 for World Reference System 2 (WRS2) Path 161 Row 74. A TM image from July 10, 1990 and an ETM+ image from June, 21, 2000 were downloaded from the Global Land Cover Change Facility (http://glcf.umiacs.umd.edu/index.shtml). The June 26, 2006 ETM+ image was purchased from the Unites States Geographic Survey Eros Data Center. Because of the Scan-Line Correction malfunction of ETM+, missing data were interpolated (i.e., “gap
filled”) with phenologically similar images from the same area: May 27, 2006, September 13, 2005, August 9, 2004 and July 16, 2002. Differences among the contributing images will affect the accuracy of the analyses using the compiled image to an unknown degree; however, these errors are preferable to using the image with the empty bands remaining.

**Data Preparation:**

To increase precision among multiple sensors, the 1990, 2000, and 2006 images were georectified and converted to radiance and then surface reflectance before analysis. All three images were georectified using ERDAS Imagine, with the 2000 image as the reference image. The 1990 TM image was converted to radiance using the conversion for Level 1 products of Chander and Markham (2003), and the 2000 and 2006 ETM+ images were converted using the methods of Williams (2007). Radiance images were converted to estimates of surface reflectance by simple dark object subtraction (DOS1) (Song et al. 2001), substituting a threshold radiance value for the equivalent terms in the equation.

**Village and Road map:**

One of the main gaps in the ANGAP’s geographic data is current location of roads or vehicle-navigable trails around and within the Park. The coordinates for the roads were taken using the tracking ability of GPS units, which periodically records the units’ location over time as points. These locations were then downloaded into ArcMap, and points were connected into lines with the “Draw” tool. Other, more remote roads were traced on the 1990 TM image, aided by descriptions of road locations provided by
ANGAP (pers. comm. Olide Venty, 2006) (Figure 1). Heavy precipitation and resulting floods erode the dirt making up the roads, shifting their locations unpredictably from year to year. Further analyses will be performed to provide even more accurate maps of the roads within the Park, but given the variability in road location, this rough estimate is sufficient for the current project and requests of the ANGAP.
Figure 1: Roads within Kirindy Mite National Park
Study Area:

This project has two study areas, the forested area within Kirindy Mite National Park (referred to as “the Park”) and the area within a 5km buffer of the Park boundary (Fig. 2). The total area included in this study – both within the buffer and the Park itself - is 140,087.52 hectares. The study area within Kirindy Mite National Park was determined by examining the satellite images and masking out large major river beds, salt flats, and coastal/tidal areas. These areas either do not contain forest, or the forest therein is not relevant to study or management action owing to extremely small patches or isolation. Removal of these areas decreased the study area within the Park from 86,736 hectares (the total of the Park) to 78,868.26 hectares. The 61,219.26 hectare buffer encompasses up to a 5 kilometer buffer around the Park’s border, with the salt flat and coastal areas removed. The buffer distance measured for this study was determined by the shortest distance to the villages to the southeast of the Park, which is less than 10 kilometers. If the Park Service does decide to expand Kirindy Mite in the future, a final distance of 5 kilometers from the nearest village would help prevent conflict between villagers and Park regulations, based on this analysis. In all the analyses, values for the buffer were determined by subtracting the Park values from the entire study area.
Figure 2: Kirindy Mite National Park and Study Area
Analysis:

2006 Land Cover:

Land cover within the study area was estimated by Maximum-Likelihood (supervised) classification. 131 Training points consisted of 64 ground-truth points taken in areas of forest and savanna in June to August 2006 and 67 points taken from areas of forest, savanna, and bare ground determined by examining 2007 aerial photographs accessed by Google Earth (www.earth.google.com). The land cover gradient from bare ground to forest was binned into three classes: bare ground, savannah and forest. The bare areas in this classification are areas that have recently been burned or are part of a well-traveled dirt road. The forested points were in regions with well defined tree cover, which obscured the ground area as seen using Google Earth. Areas categorized as savanna were grassy, with few trees and shrubs. In ArcMap, these points were used to create a signature file from the 2006 reflectance image. To reduce apparent anomalies in the 2006 image and avoid incorporating atmospheric noise in the model, bands 1 and 2 were not used in the classification.

Change Detection:

The 1990, 2000, and 2006 images were converted to binary maps of forest/nonforest cover using the Normalized Difference Vegetation Index (Rouse et. al. 1973, Jensen 1996). NDVI was used because the red and near-infrared bands used to calculate it are sensitive to vegetation cover but insensitive to atmospheric noise. A single NDVI threshold was used for all the images to discriminate forest from nonforest. The threshold of 0.232019674 was chosen and verified visually through histograms and maps, the former by a clear separation between two independent modes of the NDVI.
distribution and the latter by correspondence to known and photo-interpreted forest and nonforest patches. Forest and nonforest percentages of the total area of the Park and buffer were calculated and compared aspatially. Then the images were compared spatially for the periods 1990 to 2000 and 2000 to 2006, to map changes in forest cover. For each pixel, a change from “forest” to “nonforest” was defined as deforestation, and change from “nonforest” to “forest” as afforestation. Deforestation was tallied as percentages of the total Park and buffer areas. Afforestation within the Park and buffer were divided by the respective areas of nonforest at the beginning of the time period to determine the percentage of deforestation that had regrown. These percentages were both divided by the number of years in their respective time periods to determine rates of deforestation (loss per year) and afforestation (regrowth per year). The rate of deforestation and afforestation was then compared between the Park and buffer as well as between the 1990-2000 and 2000-2006 time periods.

Cumulative and net deforestation were estimated over the 16-year time period using the 1990, 2000, and 2006 maps. Cumulative deforestation was calculated by adding the areas of deforestation from both periods, providing a metric of the total amount of disturbed area. This metric does not account for forest rebound within the overarching period, so net deforestation was also calculated, by subtracting the 2006 map from the 1990 map. These metrics were converted to rates of loss per year.

A continuous-scale or “sub-pixel” analysis was also performed to locate areas of forest-cover change. NDVI images were paired for the periods 1990 to 2000, 2000 to 2006, and 1990 to 2006, and differences between early and late images were examined for evidence of minor deforestation or afforestation events such as small fires or selective
logging. Whereas the discretization of the previous analysis removed phenological variability at the expense of sub-pixel information, retention of phenological noise limited this analysis to visual inspection.

**Results:**

**2006 Land Cover:**

The Park study area is covered by 300 ha (0.4%) bare ground, 12,402 ha (15.7%) savanna, and 66,167 ha (83.9%) forest (Fig. 3). The buffer is covered by 562 ha (1%) bare ground, 25764 ha (42%) savanna, and 34864 ha (57%) forest. The land cover of the entire study area (Park and buffer) is composed of 891.5 ha (0.64%) bare ground, 101030.7 ha (72.12%) forest and 38165.4 ha (27.24%) savanna. The Park has a greater percentage of forest and less bare ground and savannah than the buffer (Fig. 4).
Figure 3: 2006 Land cover within Kirindy Mite National Park and buffer.
Figure 4: Land cover in Kirindy Mite and buffer study areas 2006.

**Change Detection:**

The amount of forested versus nonforested area within the Park and buffer area is different for all three years, 1990, 2000, and 2006. Within the Park, the forested hectares increase from 76990.6 ha in 1990 to 77592 ha in 2000, but then in 2006 the amount of forested hectares decreases to 76869 ha. Although the actual percentages of the total forested area change very little, from 97.62% in 1990 to 97.47% in 2006, the Park lost forest over the 16 year time span. In the buffer, however, the percentage of forested area continuously decreases from 1990 to 2000 to 2006 and the nonforested area more than doubles from 6.4% in 1990 to 14.1% in 2006 (Fig. 5).
In all three years there is a large area of nonforest in the buffer around the southeast corner of the Park. The amount of nonforest within this region increases in each image, from 1990 to 2000 to 2006. In 2006, nonforested area is dispersed throughout the buffer area. The central area of the Park, however, remains mostly forest for the duration of the 16 year time span (Fig. 6).

Figure 5: Percent forest and nonforest within study area.
For both the 1990-2000 and 2000-2006 time periods, a high concentration of major disturbance was present in the southeast of the Park and the buffer. However, the majority of the major disturbance occurred in the southeast from 1990-2000, but from 2000-2006, the locations of major disturbance shifted spatially to the North of the Park and buffer area (Fig. 7). For both time periods, a higher rate of disturbance occurred in the buffer area, but a majority of the disturbance areas that started in the buffer bled over into the Park, often stopping at or just over the Park boundary (Fig. 7). However, the deforestation rate within the Park and buffer area increased significantly from 1990-2000.
to 2000-2006, from rates of 0.12 to 0.34 percent of total area per year in the Park and 0.56 to 1.17 in the buffer (Fig. 8).

Figure 7: Deforestation and afforestation within Kirindy Mite National Park and the buffer.
Despite the increase loss of forest cover in the area, the disturbed forest is rebounding. Areas of nonforest in 1990 were detected as forest in 2000 the southeast of the Park and the buffer. From 2000-2006 reforested areas could also be seen in the East and North of the buffer and in the Southwest of the Park (Fig. 7). The rate of afforestation increased from 8.4 percent of deforested area per year to 11.4. In the buffer, however, the afforestation rate remained roughly the same, 4.9 in 1990-2000 and 5.4 in 2000-2006 (Fig. 9).
The amount of forest lost by major disturbance from 1990 to 2006 was different for the cumulative and net calculations. The regrowth that occurred and was factored into the net loss did not affect the overall spatial arrangement of the disturbance. In both comparisons, the major disturbance occurred mostly in the buffer area and to the southeast and north of the Park (Fig. 10). The cumulative loss estimate shows that 2572 ha of forest inside the Park were lost. However, because of regrowth, only 1521 ha of forest were completely lost within the Park, using the net calculations, meaning pixels that were disturbed remained that way. The rate of deforestation was higher in the buffer than in the Park for both the net and cumulative loss evaluations (Fig. 11).
Figure 10: Cumulative and net major disturbance from 1990-2006.
The differences in the NDVI showed one location of unusual deforestation in the 2000-2006 time period in the Eastern area of the Park. This area of deforestation is fairly linear, close to the Park boundary, and bisects a forest between two Park roads (Fig. 12).
Figure 12: Deforestation between Park roads from 2000 to 2006.

**Discussion:**

*Effectiveness of the Park Boundary*

Compared to the unprotected buffer area, the existence of Kirindy Mite National Park does prevent deforestation. There is a higher rate of deforestation from major disturbances outside the Park than within the Park. These higher rates of deforestation in the buffer are consistent for all deforestation calculations, including cumulative and net disturbance, solidly proving that the Park deters forest loss. The causes of these major disturbances are anthropogenic, mainly burning to create grazing areas for cattle or clearcut logging operations (pers. comm. Luke Dollar, 2006). Much of the major disturbance
in the border area, particularly in the southeast of the study site, is burn scars. The smaller areas of disturbance have a higher probability of being from small-scale, illegal logging either for rosewood (*Dalbergia baronii*) or palissandre (*Dalbergia cochinchinensis*). In some cases trees are cut down for harvesting honey, but this deforestation could also be the result from spotting or wind-blown fire (pers. comm. Luke Dollar, 2006). Most of these anthropogenic disturbances to forest cover remain outside the Park, and in many cases seem to stop at the Park’s boundary, which marked by little more than a painted line or rope in most areas (pers. comm. Luke Dollar, 2006). This shows that the idea of a park in Madagascar can enable conservation by deterring further exploitation of an area by the local populace.

**Land cover change**

The forest within the Park is recovering from damage at a faster rate than in the buffer. This is most likely because anthropogenic activities occur annually within the buffer (pers. comm. Luke Dollar, 2006). For example, fires are not a natural part of the landscape on intervals as regular as their current occurrence. Instead cultures such as the Tandroy tribe, near Kirindy Mite, are based on almost nomadic cattle driving. Each year they revisit areas where they set fires to get the “green-bite” for their cattle. Because access inside the Park is limited, the regularity of these illegal burning events is decreased, allowing the forest to regenerate.

The total amount of forest within the Park decreased from 1990 to 2006 because afforestation is not rapid enough to offset the increasing deforestation rate within the Park. The deforestation rate increased between the periods 1990-2000 and 2000-2006 in
both the Park and buffer, especially in the north and southeast. This suggests that the causes of these disturbances, mainly of human influence, in increasing in these regions. There is also evidence of anthropogenic deforestation in the more interior regions of the Park. It is possible that this is the result of spotting from fires outside the Park (ashes land causing small scale burns). But some of these major disturbance areas are less than three kilometers away from the villages located within the Park, indicating possible illegal clearing or burning for cattle and agriculture or logging for honey and rosewood. The deforestation in the north of the Park is more diffuse and further away from villages, suggesting logging, and there have also been reports that Park officials have been lax in enforcing logging restrictions in the south of the Park, where more disturbance areas can be seen from the major disturbance analyses (pers. comm. Luke Dollar, 2006). The area of linear deforestation found by the NDVI analyses (Fig. 12) is another location where the Park boundary and management did not completely deter forest destruction. Although potential burn scars lead toward this area from the Southeast, the linear nature and location of this vegetation loss shows that it is most likely a trail for local travelers, cattle, or illegal logging within the Park. It can be concluded that the Park’s remoteness cannot be completely relied on to protect the forest.

*Management implications*

To expand the Park, its borders should take in more area in the north and southeast of the buffer. These regions have experienced increased rates of deforestation, especially within the last 6 years. Because of the deterrent effect of the Park boundary on
deforestation, including these areas within official boundaries will more than likely prevent further burning and allow the vegetation to regrow.

Currently, the management of Kirindy Mite relies on the Park’s remoteness, local respect for the Park boundary, and the sufficiency of the few isolated Park rangers to monitor the area. Although these aid in deterring deforestation, they do not completely prevent it. By increasing the size of the field staff, the Park managers could increase the effectiveness of the conservation measures within Kirindy Mite. Monitoring for deforestation, and possibly catching and preventing illegal logging along roads and Park borders, would be possible with more staff on the ground. The Park service needs better communication and equipment, such as vehicles, and GIS technology to effectively monitor the state of the Park to make their presence more widely known on the ground. Also, by giving Park Rangers police powers, the rules of the Park will be enforced and followed. Rangers can do little more than warn lawbreakers about the consequences of their actions or later report them to the office in Morondava. There is currently not an efficient way to apprehend loggers or fine people for burning within the Park.

Community management projects could be created to incorporate the local villages in the conservation measures of the Park. By working with the local people to manage the Park, creating ecotourism or other sustainable programs so that they will not be reliant on burning the land for agriculture or logging for survival, the management can prevent further forest loss. If people feel like they are a stakeholder in a local resource, then they will work to protect that resource.

Similarly, the Park service should work with the communities on minimizing and controlling burning. This way, the areas outside the Park could not be over-burned and
they could prevent fires from getting out of control and spreading over the Park borders. Within the Park, around its borders, or possibly within an internal park buffer, fire should be managed through prescription. Currently, fire within the Park is managed by absolute suppression. However, the burn regime of this area is unknown. Being a dry forest, if too much fuel builds up along the forest floor, when the forest does ignite, the fire could be more intense than usual for the area possibly destroying the entire Park and surrounding area (Dale 2006).

Conclusions:

Kirindy Mite National Park prevents deforestation and promotes reforestation within its boundaries. The buffer around the Park experiences more deforestation than the forest within the Park, and the disturbances within the Park are regrowing faster than those in the buffer. Although the Park prevents deforestation and enabling vegetation regrowth, it has not completely stopped forest cover loss within its borders. From 1990 to 2006 the amount of forest cover within the Park has decreased despite the higher rate of afforestation. The regrowth is offset by anthropogenic disturbance still occurring within the Park near villages inside the Park, from illegal logging, and from fire spreading over the Park boundary.
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Appendices:

Model for Major Disturbance
Model for Major Rebound

Model for Cumulative Deforestation
Model for NDVI analysis