Spatio-Temporal Change in Crowned (Propithecus coronatus) and Decken's Sifaka (Propithecus deckenii) Habitat in the Mahavavy-Kinkony Wetland Complex, Madagascar

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Spatio-temporal Change in Crowned (*Propithecus coronatus*) and Decken's Sifaka (*Propithecus deckenii*) Habitat in the Mahavavy-Kinkony Wetland Complex, Madagascar

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Abstract: The crowned sifaka (*Propithecus coronatus*) and Decken's sifaka (*Propithecus deckenii*) are Endangered lemurs endemic to west and central Madagascar. Both have suffered habitat loss and fragmentation throughout their ranges. The goal of this study, conducted in the Mahavavy-Kinkony Wetland Complex (MKWC) in northwestern Madagascar, was to assess the effects of historical change in the species' habitats, and to model the potential impact of further land-use change on their habitats. The IDRISI Andes Geographical Information System and image-processing software was used for satellite-image classification, and the Land Change Modeler was used to compare the natural habitat of the species from 1973 to 2005, and to predict available habitat for 2050. We analyzed two forests in the MKWC occupied by *P. coronatus* (Antsilaiza and Anjohibe), and three forests occupied by *P. deckenii* (Tsiombikibo, Marofandroboka and Andohaomby). The two forests occupied by *P. coronatus* contracted during the period 1949–1973, but then expanded to exceed their 1949 area by 28% in 2005. However, the land change model predicted that they will contract again to match their 1949 area by 2050, and will again lose their corridor connection, meaning that the conservation gains for this species in the complex are at risk of being reversed. The three forests occupied by *P. deckenii* have declined in area steadily since 1949, losing 20% of their original area by 2005, and are predicted to lose a further 15% of their original area by 2050. Both species are therefore at risk of becoming even more threatened if land-use change continues within the complex. Improved conservation of the remaining forest is recommended to avoid further loss, as well as ecological restoration and reforestation to promote connectivity between the forests. A new strategy for controlling agriculture and forest use is required in order to avoid further destruction of the forest.

Key Words: *Propithecus coronatus*, *Propithecus deckenii*, threats, deforestation, fragmentation, prediction, conservation

Introduction

Sifakas (*Propithecus*) are endemic to Madagascar. Of the nine species currently recognized (Mittermeier *et al.* 2010), four are classified on the IUCN Red List as Critically Endangered, and five, including the crowned sifaka (*P. coronatus*) and Decken's sifaka (*P. deckenii*), as Endangered (Andriaholinirina *et al.* 2014a, 2014b). Crowned and Decken's sifaka are found in dry deciduous forest in west and central Madagascar. In the north of its range, the crowned sifaka is found between the Mahavavy and Betsiboka rivers, and recent surveys have shown that its full distribution extends southwards through the fragmented forests of the Boeny, Betsiboka, Bongolava and Menabe regions towards the rivers Tsiribihina, Mahajilo, and Mania (King *et al.* 2012, 2014; Rakotonirina *et al.* 2014; Salmona *et al.* 2014). Decken's sifaka is found to the west of the Mahavavy River, its distribution extending south to the Manambolo River (Mittermeier *et al.* 2010; King *et al.* 2014).

Sifaka color variations occur towards the lower reaches of the Mahavavy and Manombolo rivers, at sites in the Melaky and Menabe Regions, with melanistic forms reported in populations of both crowned and Decken's sifakas (King *et al.* 2014; Rakotonirina *et al.* 2014). Similar color variations have also been reported in populations of Decken's sifaka further north, including that of the Mahavavy-Kinkony Wetland Complex (Curtis *et al.* 1998; Thalmann *et al.* 2002; Rumpler *et al.* 2011; Rakotonirina *et al.* 2014).

Three new protected areas in western Madagascar will help conserve the crowned sifaka; the Mahavavy-Kinkony Wetland Complex (MKWC), Bombetoka-Belemboka, and the forest station of Antrema, with the MKWC providing approximately two-thirds of the protected area occupied by this species (Rasoavahiny *et al.* 2008). Decken's sifaka is also present in the MKWC and several other protected areas, including three national parks (Mittermeier *et al.* 2010). The

MKWC is, therefore, important for the conservation of these two sifaka species.

Habitat destruction, degradation and fragmentation are the principle drivers of population declines of both crowned and Decken's sifakas (Andriaholinirina *et al.* 2014a, 2014b). Historical changes in forest habitat are due to various factors, among which anthropogenic factors are the primary contributors (ZICOMA 1999; McConnell 2002). This research was undertaken in the MKWC in order to analyze the direction and rate of change of the natural habitat of crowned and Decken's sifakas to inform conservation strategies for their survival within the site.

Study Site

The Mahavavy-Kinkony Wetland Complex (MKWC) is located in the Boeny Region of northwest Madagascar (45°28' to 45°56'E, 15°46' to 16°12'S) at low elevations up to 150 m above sea level (ZICOMA 1999; Andriamasimanana and Rabarimanana 2011). The complex extends across 275,000 ha (Razafindramanana *et al.* 2013) to 300,000 ha (Andriamasimanana *et al.* 2013), incorporating the Mahavavy River delta, the Kinkony Lake, Marambitsy Bay, and several dry, deciduous forest fragments (BirdLife International 2014). The site is an Important Bird and Biodiversity Area (BirdLife

International 2014); all the wetland bird species of western Madagascar have been recorded there. Threatened lemurs in the MKWC (Müller *et al.* 2000; Razafindramanana *et al.* 2013) include crowned and Decken's sifakas, mongoose lemur (*Eulemur mongoz*), and rufous brown lemur (*Eulemur rufus*).

A supervised classification of Landsat satellite images of the region from 2005 was conducted by Andriamasimanana *et al.* (2013) using the IDRISI Andes Geographical Information System and image processing software to define the major forms of land use in the complex (Fig. 1). Andriamasimanana *et al.* (2013) found that dry forest—the primary habitat for lemurs in the MKWC—dominated more than one-third (37%) of the complex (Table 1). This is followed by savannah, which covers a quarter (26%) of the surface area, whilst over one-fifth of the surface is occupied by wetland (18%) and mangrove (4%). The remainder of the complex consists of sand (7%), cultivated areas (7%), and salt marsh (1%).

Based on occurrence data for 19 threatened taxa (nine birds, three lemurs, three fishes, three bats and one reptile), Andriamasimanana *et al.* (2013) identified eight priority sites for biodiversity conservation in the MKWC. The eight priority sites included the reed marshes of Lake Kinkony, two mangrove areas, and five forest fragments (Andriamasimanana *et al.* 2013).
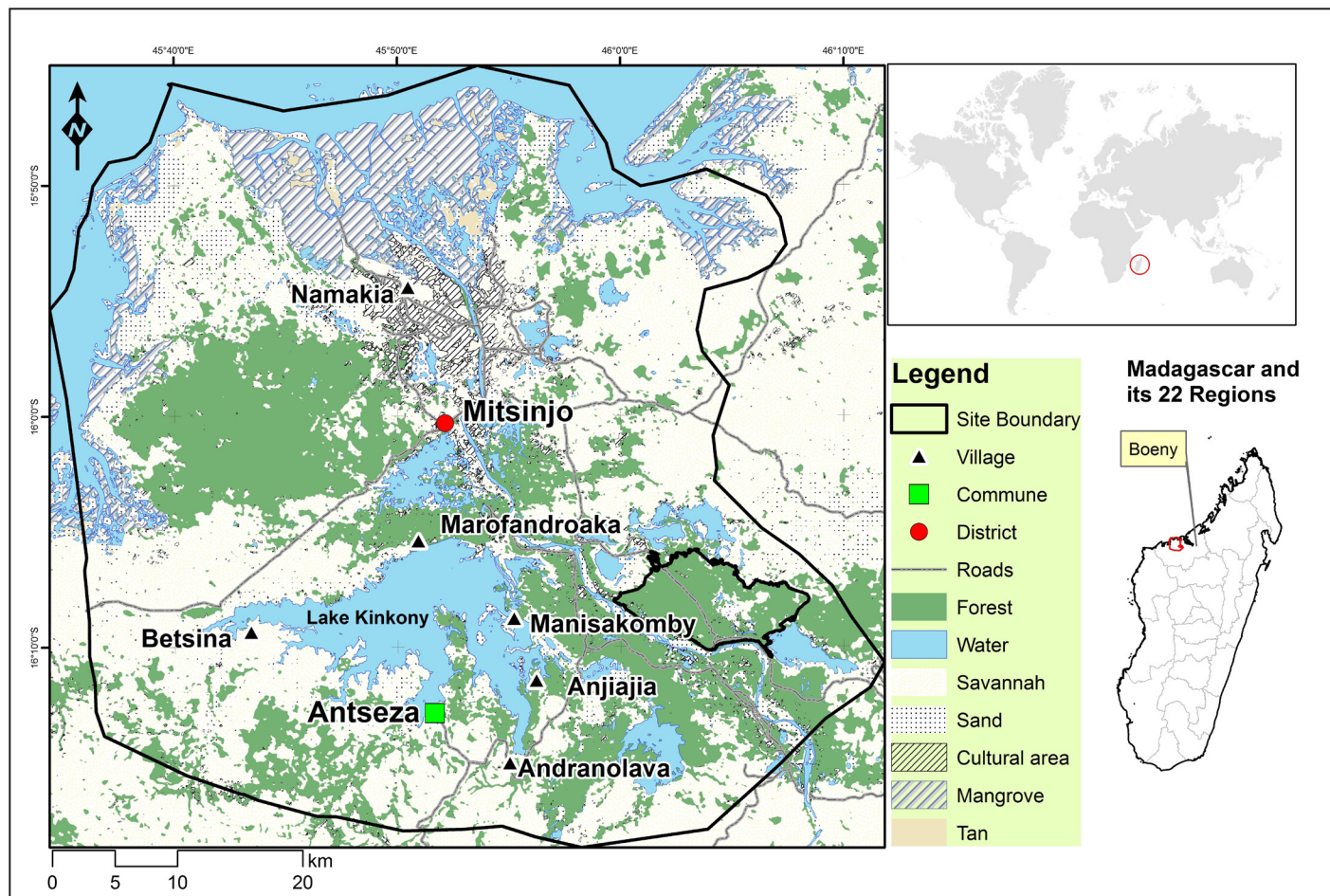
Figure 1. Map of the Mahavavy-Kinkony Wetland Complex and its main land-use classes in 2005.

Table 1. The seven main classes of land use of the Mahavavy-Kinkony Wetland Complex from the supervised classification of satellite images from 2005, following Andriamasimanana *et al.* (2013).

Classes	Area(ha)	Land cover (%)
Dry forest	111,559	37%
Savannah	76,533	26%
Water	54,860	18%
Cultivated area	21,774	7%
Sand	215,822	7%
Mangrove	10,885	4%
Salt marsh	1,863	1%
Total	299,056	

Methods

In this paper we considered the five priority forest fragments identified by Andriamasimanana *et al.* (2013) for analysis with respect to sifaka populations, although sifaka are known to occur in several other, mostly smaller, forest fragments in the MKWC (Curtis *et al.* 1998; Salmona *et al.* 2014). Crowned sifakas occur in the two study forests located to the east of the Mahavavy River (Antsilaiza and Anjohibe), and Decken's sifakas occur in the three study forests to the west (Tsiombikibo, Marofandroboka and Andohaomby); melanistic sifaka are found in the forests along the western bank of the Mahavavy River (Curtis *et al.* 1998; Thalmann *et al.* 2002; Rumpler *et al.* 2011; Rakotonirina *et al.* 2014), especially in the Andohaomby fragment.

We evaluated changes in forest cover from 1949 to 2005 for the five forest fragments by comparing the remote sensing results from 2005 with previous Landsat satellite images from 1973 and 1995, classified by Andriamasimanana *et al.* (2013), and with digitized topographic maps of the region from 1949, from Foibe Taosaritanin'i Madagasikarain (Andriamasimanana *et al.* 2013).

We then explored future changes in habitat in the five study forests by making a map of predicted forest cover in 2050 using the Land Change Modeler module in Idrisi Andes (Andriamasimanana *et al.* 2013). The first step consisted of developing potential transition maps from historical land-use changes through its integrated Neural network algorithm (Bhadeshia 1999). We used the Landsat satellite images from 1973, 1995, and 2005 for this model. The 1949 map was excluded because it was from a different source. The choice of factors used to create the potential transition maps was dictated by an understanding of the causes of change on the ground. Changes are largely driven by traditional agriculture, locally called *hatsaky*. This kind of agriculture needs previously forested land, near to water, easily accessed, and not far from the villages where the farmers live. Six factors were used to model the potential habitat transitions between 1973, 1995, and 2005. Two static factors (that do not change over time) were distance from rivers and slope. Four dynamic factors (that do change over time) were residential areas, roads including trails, the human population by *fokontany* (an administrative subdivision unit in Madagascar), and changes in the area of forest. This last dynamic factor was included in order to capture all other factors that could cause local changes, but which could not be identified from the literature and field surveys.

In order to test the ability of the land use change model to predict past habitat change, a performance test (Area Under the Receiver Operator Curve index; Fielding and Bell 1997) was undertaken using the result of the model of land-use change for 2005 (built from the 1973 to 1995 maps), and the classification of the 2005 Landsat image.

The second step was to run the land-use change model forward to make a prediction for the future; once the prediction was judged to be of high performance, the same parameters were kept and the model was projected forward to 2050. Future habitat vulnerability was determined by overlapping the predicted forest map for 2050 with the forest map of 2005. The areas that were covered only by 2005 forest were assumed to be vulnerable to change. As the analysis of habitat vulnerability is based on the land-use change model, the underlying assumptions are the same as those in the model: that there are no changes in conservation actions and that the existing pressures will continue into the future.

Results

The Area Under the Receiver Operator Characteristic curve value that resulted from the validation test between the result of the land use change model for 2005 and the Landsat image classification for 2005 was 0.87, which is indicative of high performance (Pontius *et al*. 2000; Fielding and Bell 1997). Our spatial analysis showed that the three study forests occupied by Decken's sifaka—Andohaomby, Tsiombikibo and Marofandroboka—have suffered from continual deforestation from 1949 to 2005, each decreasing in size by 20%, 16% and 41%, respectively, and losing a total of 20% between them (Table 2). The land change model for 2050 predicts that

Table 2. Forest change between 1949 and 2005 and, predicted, between 2005 and 2050.

Forest	Forest area in hectares					Area change (%)		Sifaka[1]
	1949	**1973**	**1995**	**2005**	**2050**	**1949–2005**	**2005–2050**	
Anjohibe	287	302	586	757	699	164%	−8%	Crowned
Antsilaiza	2,373	1,172	1,870	2,646	1,968	11%	−26%	Crowned
Andohaomby	9,743	7,661	8,785	7,751	4,325	−20%	−44%	Decken's
Tsiombokibo	27,960	25,705	22,745	23,490	20,730	−16%	−12%	Decken's
Marofandroboka	5,800	4,160	5,177	3,430	3,170	−41%	−8%	Decken's

[1]Melanistic sifaka occur in some forests in the MKWC; see text.

Decken's sifaka may lose a further 15% of its 1949 habitat in the MKWC by 2050 (Table 2; Figs. 2 and 3).

The two study forests occupied by the crowned sifaka contracted from 1949 to 1973, but then expanded to exceed their 1949 area by 28% in 2005 (Table 2; Fig. 3). The land-use change model predicts, however, that they will contract again to match their 1949 area by 2050 (Fig. 2 and 3). Further to this, the model predicts that the connecting corridor that formed between the two forests from 1949 to 2005 will be lost again by 2050 (Fig. 2).

Discussion

Although interpretation of the Area Under the Receiver Operator Characteristic curve is rather subjective, the high value (0.87) falls within the range that is widely accepted as
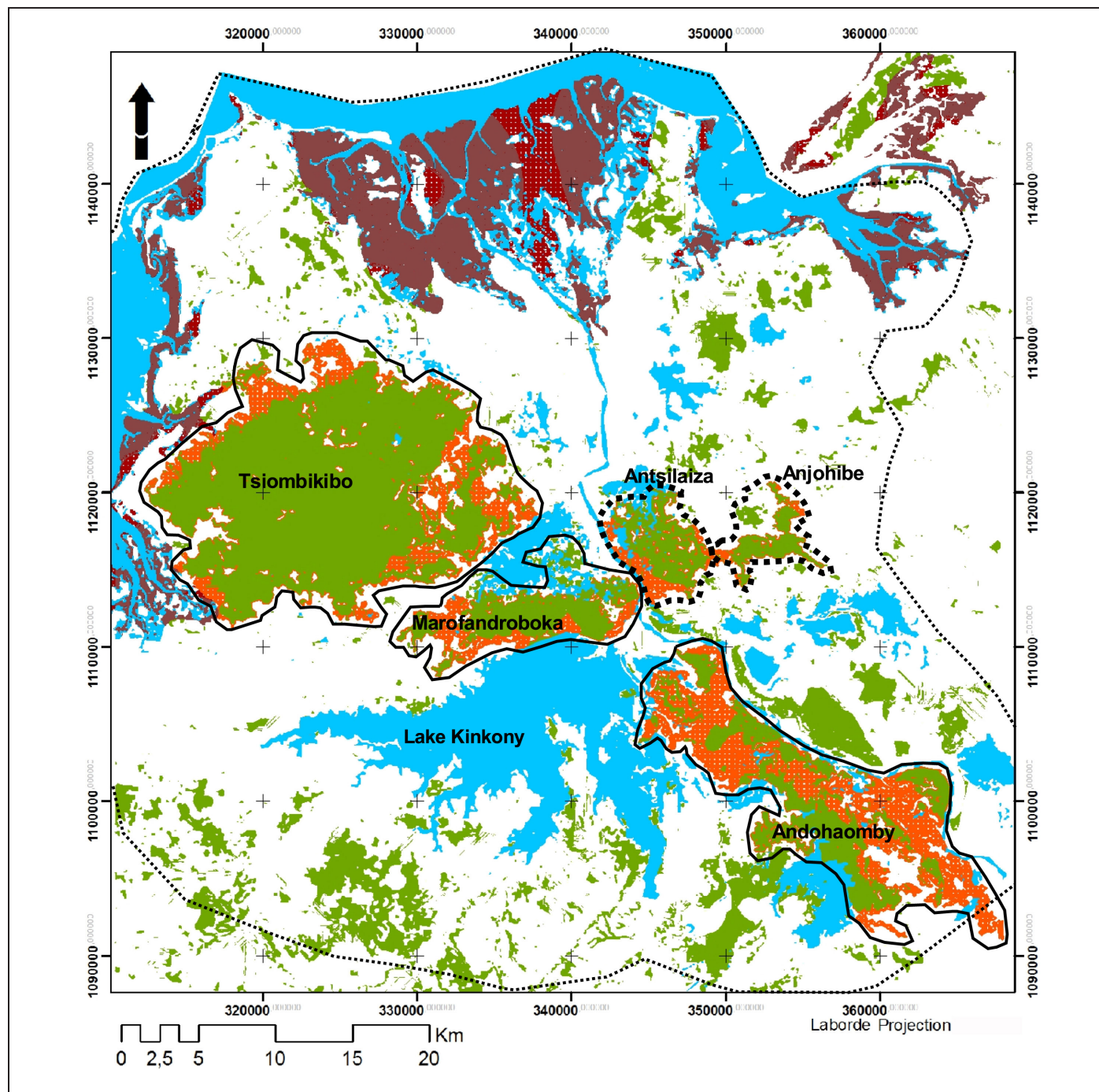

Figure 2. Prediction of habitat vulnerability in 2050 of the crowned sifaka (*Propithecus coronatus*) and Decken's sifaka (*Propithecus deckenii*) in the five study forests in the Mahavavy-Kinkony Wetland Complex. Vulnerable forest (orange) and remaining forest (green) are shown in the study forests occupied by crowned sifaka (within the heavy dotted lines) and those occupied by Decken's sifaka (solid lines). Other habitats include water (blue), remaining mangrove (purple) and vulnerable mangrove (red).

"excellent" (Pontius *et al*. 2000; Fielding and Bell 1997), indicating that the land-use change model is relatively robust and informative. While the results of the analysis of past habitat change are likely very robust because they rely on real data, it should be remembered that the modelled habitat change for 2050 is based on an assumption of "business as usual"—there will be no change (a) in conservation action, (b) in the ways in which the local population use their land for agriculture, (c) in mineral extraction, and (d) in external factors such as international economic pressures. The intention of providing this business-as-usual scenario is to inform the conservation strategy for the two sifaka species in the MKWC, providing the means to avoid any dire future that the model may predict.

Of the five forests analyzed in our study, the two located to the east of the Mahavavy River (habitat for crowned sifaka) increased in size between 1949 and 2005, while the three to the west (habitat for Decken's sifaka) shrank. The Anjohibe forest, the smallest of the study forests occupied by crowned sifaka, underwent a considerable increase in size of 164%; from 287 ha in 1949 to 757 ha in 2005. This increase is related to the geological structure on which this forest is located, and the fact that it is far from towns such as Mitsinjo and Namakia. The Anjohibe forest sits on a limestone formation (Du Puy and Moat 1997) that is unfavorable for agriculture. The Antsilaiza forest, the second supporting crowned sifaka, also lies on a limestone formation (Du Puy and Moat 1997). It also increased in size, but by less—12% between 1949 and 2005—due to it being closer to Mitsinjo. The future land-change model indicated that, as pressure for agricultural land increases, and if no interventions are planned, it is likely that, despite their marginal agricultural value and historical increase in size, both Anjohibe and Antsilaiza will shrink substantially to the extent that their combined area in 2050 might equal that of 1949 (Table 2).

Tsiombikibo is the largest forest in the MKWC. Of the three study forests that support Decken's sifaka, Tsiombikibo had shrunk the least since 1949 (16%). It is, however, threatened with a further reduction of 10% of its 1949 area by 2050. This 26%-loss represents a substantial reduction in the core population for this species in the MKWC. The Andohaomby forest lost a moderate percentage of 20% of its area between 1949 and 2005. It is located on an alluvial plain (Du Puy and Moat 1997) next to the Mahavavy River where silt from flooding replenishes the soil every summer. Its high agricultural potential is offset by its remoteness, being a long way from Mitsinjo and Namakia. The model indicates a future loss, however, of a further 36%, reducing its size to 44% of its area in 1949. Marofandroboka has suffered the largest historical loss of its forest; 41% since 1949. The model predicts, however, that its rate of loss may slow in future, and that it is likely to lose only a further 4% over the next 45 years, with 55% of its 1949 area remaining in 2050.

Lacking measures to reduce human pressure on the forests of the MKWC, the conservation gains benefiting the crowned sifaka in terms of increases in habitat area and connectivity since 1949 are at risk of being reversed, and the population is
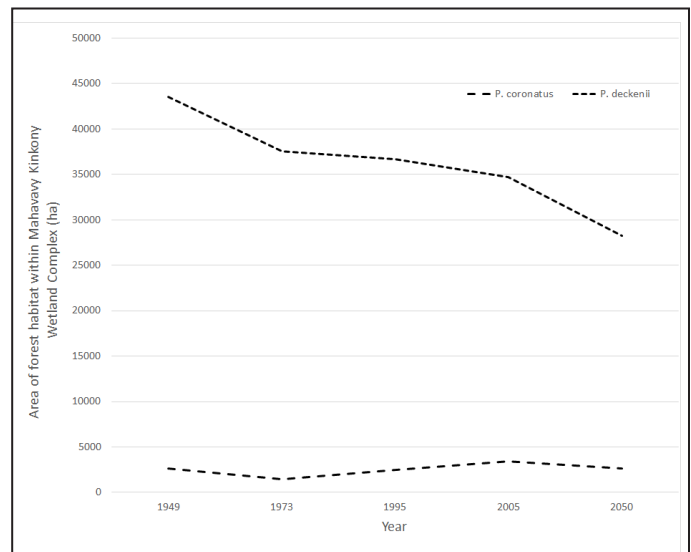
Figure 3. Habitat available for crowned and Decken's sifaka in the five study forests in the Mahavavy-Kinkony Wetland Complex from 1949 to 2050.

likely to decline to its 1949 level (Fig. 3). As crowned sifaka populations are also declining outside of protected areas (King *et al*. 2012; Andriaholinirina *et al*. 2014a), the species will be increasingly threatened unless measures can be taken to promote a recovery of its numbers in protected areas. The corridor that has grown between the Antsilaiza and Anjohibe forests since 1949 helps to maintain vital metapopulation processes. The fragmentation of this population if the corridor is once again lost will be particularly damaging for this large and highly forest-dependent species (Andriamasimanana *et al*. 2001).

The outlook for Decken's sifaka under our business-as-usual model of land-use change is likewise not positive. The areas of the three study forests occupied by Decken's sifaka have declined steadily since 1949 (Table 2), shrinking 20% overall by 2005 (Fig. 3). The model predicts the loss of a further 15% with an increase in fragmentation by 2050 (Fig. 1). Although the total habitat for Decken's sifaka is currently much larger than that for the crowned sifaka (Fig. 3), the population will also decline, compromising its viability, if forest loss in the MKWC is allowed to continue.

A reduction in human pressure on the forests of the Mahavavy Kinkony Wetland Complex will be critical for the conservation of these two sifakas. An important measure for the Andohaomby forest will be the creation of a path, usable during the dry season, to provide access to and allow people to travel through the forest. If access to the forests is restricted then it is essential that measures be put in place to increase the production capacity of the local farmers, promoting a cost-effective agriculture that eliminates the need for deforestation and the destructive collection of firewood. Reforestation is necessary throughout the MKWC to maintain and restore connectivity and the ecological functions of the sifaka's habitats.

69

Acknowledgments

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