Chelonian Conservation and Biology, 2001, 4(1):59–65

Deforestation and Habitat Loss for the Malagasy Flat-Tailed Tortoise from 1963 Through 1993

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ABSTRACT. – **Analyses of satellite images from 1963, 1973, 1984, and 1993 indicate a 32% reduction in the primary, dense, dry-tropical forests which are the required habitat for the Malagasy flat-tailed tortoise (*Pyxis planicauda*), or kapidolo. Deforestation rates are increasing, and as much as 50% of the 76,000 ha remaining in the southern portion of the kapidolo's range may be destroyed before 2010. A 50% reduction in the remaining 73,000 ha of habitat in the northern portion of its known range may occur by 2040.**

KEY WORDS. – **Reptilia; Testudines; Testudinidae; *Pyxis planicauda*; kapidolo; tortoise; Madagascar; Menabe; conservation; deforestation; habitat loss; satellite imagery**

The Malagasy flat-tailed tortoise (*Pyxis planicauda*) or kapidolo, as it is known locally, is a small (carapace length < 20 cm; Kuchling and Bloxam, 1988) threatened species that is only known from the Menabe region along the west coast of Madagascar (Fig. 1). Its range extends from the Tsiribihina River south to at least the Morondava River. It has not been found in surveys south of the Maharivo River (Behler et al., 1993; Bloxam et al., 1993). Although individuals have been reported from degraded forests, large populations of adult individuals appear to be restricted to primary dense forests of deciduous, dry-tropical trees (Kuchling and Bloxam, 1988; Bloxam and Hayes, 1991). It is active during the rainy season from November through April and estivates in leaf litter during the dry season. Because it is only active in the rainy season when roads and rivers are nearly impassable, little is known of its biology. It has been reported to: 1) feed on fruits and foliage of native trees and shrubs (Kuchling and Bloxam, 1988); 2) live at least 20 yrs (Kuchling and Bloxam, 1988); 3) require more than 7 yrs to mature (Kuchling and Bloxam, 1988; Bloxam and Hayes, 1991); 4) produce clutches of a single, large egg (Bour, 1981); and 5) occur in low densities (Bloxam et al., 1996).

Due to the kapidolo's dependence on primary dense forests for both food resources and estivation habitat, it is subject to risks from deforestation or forest degradation. Deforestation from logging, charcoal production, subsistence agriculture, and burning for conversion to grazing occurs throughout Madagascar (Gade, 1985; Sussman et al., 1994; Smith, 1997) and has been reported for the Menabe region (Kuchling and Bloxam, 1988; Ganzhorn et al., 1990; Smith, 1997). This deforestation has been suggested to be the main threat to the species (Jenkins, 1987; Durrell et al., 1989; Glaw and Vences, 1994), and deforestation rates may be increasing due to recent road construction for oil exploration (Kuchling and Bloxam, 1988). Smith (1997) suggested a decline in forest area in western Madagascar from 12.5% of land surface in 1950 to 2.8% in 1990 based on comparisons of 1950 maps with two sets of more recent satellite data. However, this estimate is for all types of forests in western Madagascar. Using these maps and satellite data to estimate forest loss for specific forest types in local areas is complicated by differences in spatial scales and image interpretations among time periods (Smith, 1997).

The purpose of this study was to analyze the loss of primary dense forest in the kapidolo's range using the most consistent methodologies and spatial scales that the existing satellite data would permit. Principal objectives were: 1) to document the loss of primary dense forest at approximately 10-yr intervals from 1963 to 1993; 2) to evaluate the proximity to major and secondary roads in affecting deforestation rates; and 3) to use the results of this analysis to infer continuing deforestation rates after 1993. The design of the study and the selection of satellite imagery were based on the published northern limit of the kapidolo's range being the Tsiribihina River, but surveys in 1998 observed some animals north of this river (Raktombololona, 1998). The implications of these observations on the results of the study are also discussed.

STUDY SITE

The Menabe region is a sparsely populated area with a few major roads connecting the larger settlements of Morondava, Mahabo, and Belo sur Tsiribihina (Fig. 1). The region is dissected by the Tsiribihina, Tomitsy, Morondava, and Maharivo rivers with the Morondava being damned and diverted for irrigation along its northern shore. The population density in the 1960s was < 5 persons per km^2 with most people living in villages of < 1000 (Gourou, 1966). Secondary roads connected these villages, and additional secondary roads were constructed for oil exploration in the 1980s (Kuchling and Bloxam, 1988). These new roads formed a

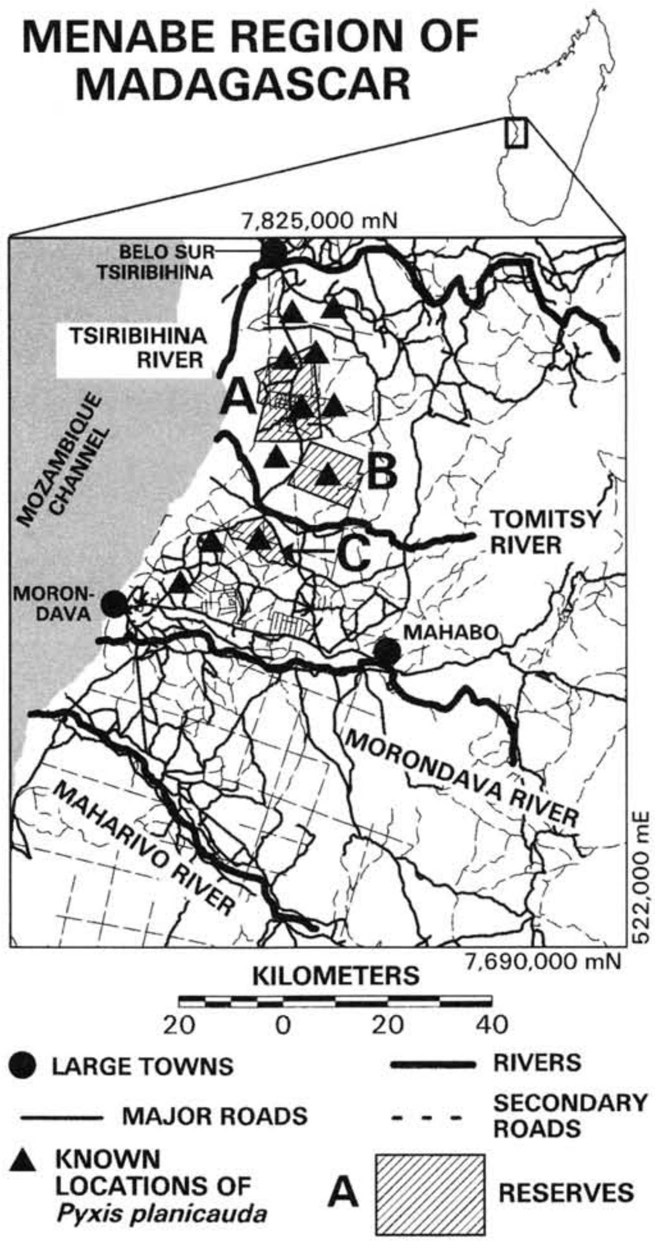

Figure 1. The Menabe area of western Madagascar showing major rivers, major roads, secondary roads, and large towns. The long, straight secondary roads running west-northwest to east-southeast and south-southwest to north-northwest were constructed as part of oil exploration activities in the 1980s. The m N and m E are World Geographical System 1984 Universal Transverse Mercator coordinates where the equator is 10,000,000 m N and 45°E longitude is 500,000 m E. Areas of at least partially protected lands in the northern Menabe region are shown as diagonally striped polygons and labeled A = Analabe Reserve , B = Kirindy Forest and C = Reserve Special d'Andranomena. Known areas of kapidolo (*Pyxis planicauda*) occurrence are shown as filled triangles. Because of travel difficulties, most of these areas are along the main road from Belo sur Tsiribihina and Morondava.

network of straight lines and provided access to more remote areas (Fig. 1). By 1993, population densities had increased to > 5 persons per km^2 (Madagascar Census Bureau, 1993).

The climate is dry tropical with mean annual precipitation of < 1 m and mean annual temperatures of 26°C (Koechlin et al., 1974; Ganzhorn et al., 1990). The vegetation changes from mangroves and marshes along the coast to deciduous dry tropical forests on sandy and lateritic clay soils. These forests extend to 70 km inland where they grade into shorter-stature forests on basic soils and woody savannas (Humbert and Cours Darne, 1965). Undisturbed forests have a dense, 15-m tall canopy composed of numerous genera including *Adansonia, Commiphora*, and *Pachypodium* (Rauh, 1973; Koechlin et al., 1974).

There are few areas of protected forest (Fig. 1) except for: 1) the 7180 ha government-owned Reserve Speciale d'Andranomena where more than 40% of the primary forest has been cut or degraded (Smith et al., 1997); 2) the 11,514 ha Kirindy Forest which is managed for selective cutting by the Centre de Formation Professionelle Forestière Morondava (Ganzhorn et al., 1990; Smith et al., 1997); and 3) a 14,876 ha private Analabe Reserve (Smith et al., 1997) which includes a sisal plantation. These areas are poorly protected (Sayer et al., 1992; Smith, 1997), and all were crossed by oil exploration roads. The remaining area is available for cutting and clearing under Malagasy laws (Keck et al., 1994) or used without legal claims (Smith, 1997).

MATERIALS AND METHODS

For the purposes of analyzing deforestation patterns, the area was subdivided into three regions based on differences in human population density, road density, and the availability of irrigation water. These regions were: 1) between the Tsiribihina and Tomitsy rivers in the north; 2) between the Tomitsy and Morondava rivers; and 3) between the Morondava and Maharivo rivers in the south.

To map the changes in the distribution of forests, satellite-acquired images were compiled from 1963, 1973, 1984, and 1993 (Table 1). The 1963 data were obtained by an American espionage satellite mission (Argon 9058A; McDonald, 1997) and were provided as a panchromatic photograph that was computer scanned to a resolution of 200 m by 200 m. Images for the later time periods were Landsat Multispectral Scanner (hereafter MSS) data provided as digital, 4-band images with a spatial resolution of 79 m by 79 m (Lillesand and Kiefer, 1994). The four bands of spectral data include visible green, visible red, and two infrared bands.

To form a basis for mapping purposes, the 15 May 1984 Landsat MSS data were rectified (Lillesand and Kiefer, 1994) to World Geodetic System 1984 Universal Transverse Mercator (hereafter, UTM; Snyder, 1987) coordinates where locations are expressed as m N (with the equator being 10,000,000 m N) and m E relative to 45°E longitude (which has an assigned value of 500,000 m E). The rectification involved 1) matching features (e.g., major road intersections) in the MSS image to features depicted on 1:200,000 scale maps prepared by the Union of Soviet Socialist Republics (USSR) and 2) rotating and reprojecting the MSS data to UTM coordinates. The other images were rectified to the 15 May 1984 data using similar procedures.

The MSS images were converted to maps of land use/land cover using supervised classification procedures employing maximum-likelihood algorithms (Lillesand and Kiefer, 1994; ERDAS, 1994). This classification procedure uses representative sites within the image to classify the remaining areas of the image. The selection of representative sites was aided by photographs of habitat types at known locations taken in 1995 (Q.M.C. Bloxam, *pers. comm.*). The land use/land cover classes included dense forest, open forest, grasslands, and agriculture. Once classified, the land use/land cover maps were smoothed to reduce misclassifications caused by pixels along habitat margins (Lillesand and Kiefer, 1994) and converted to 200-m by 200-m pixels to match the spatial resolution of the 1963 photographic data. The 1963 panchromatic data were classified as dense forest, open forest, and nonforest areas using level-slicing techniques (Lillesand and Kiefer, 1994). Deforestation was mapped by first assuming that all dense forest pixels in the 1963 data were primary dense forest and then following the fate of each of these pixels in subsequent years. Pixels subsequently mapped as open forest were considered degraded forest. Pixels subsequently mapped as nonforest were considered to be deforested.

Table 1. Satellite image data used in the Menabe analysis.

Year	Data Type	Dates of Images	Spatial Resolution
1963	Panchromatic Photograph	29 August	200 m x 200 m
1973	Landsat Multispectral Scanner	8 August	79 m x 79 m
1984	"	14 and 15 May[1]	"
1993	"	20 and 29 May	"

[1] Multiple dates indicate that two images were required to cover eastern and western portions of the area in Figure 1.

To relate patterns of deforestation to proximity to roads, all major roads and secondary roads depicted on the 1:200,000 USSR maps were digitized into a computer-based Geographical Information System (GIS) that computed the distance from each forested pixel to the nearest major and secondary roads. The GIS system also computed the distance from each forested pixel to the edge of the forest at the beginning of each time interval. The areas of forest patches were determined using the program FRAGSTATS (McGarigal and Marks, 1994).

Because the mapping process results in spatial autocorrelation among neighboring pixels (Congalton and Green, 1999), statistical analyses were performed using 2180, 695, and 1077 randomly-selected, non-neighboring pixels in the Tsiribihina to Tomitsy, Tomitsy to Morondava, and Morondava to Maharivo regions, respectively. Rates of deforestation were compared among regions and among time intervals using linear contrasts in a weighted least-square analyses of repeatedly-measured categorical data (Stokes et al., 1995; SAS Institute Inc., 1989a). Statistical analyses of the effects of proximity to major roads, secondary roads, and the forest edge on the rate of deforestation were performed using logistic regressions (Hosmer, 1989; SAS Institute, 1989b). Because roads were not large enough

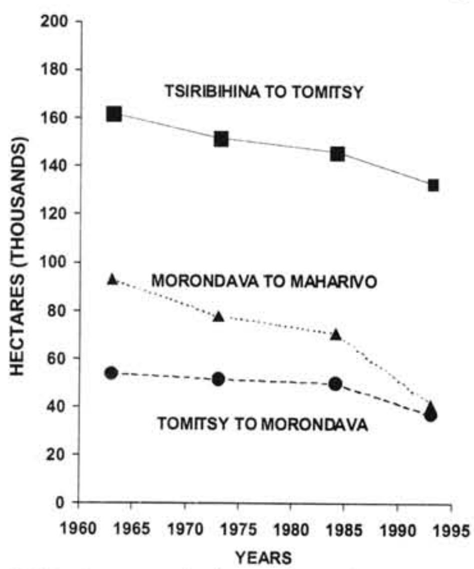

Figure 2. The hectares of primary dense forests in 1963, 1973, 1984, and 1993 for the regions between the Tsiribihina and Tomitsy rivers, between the Tomitsy and Morondava rivers, and between the Morondava and Maharivo rivers.

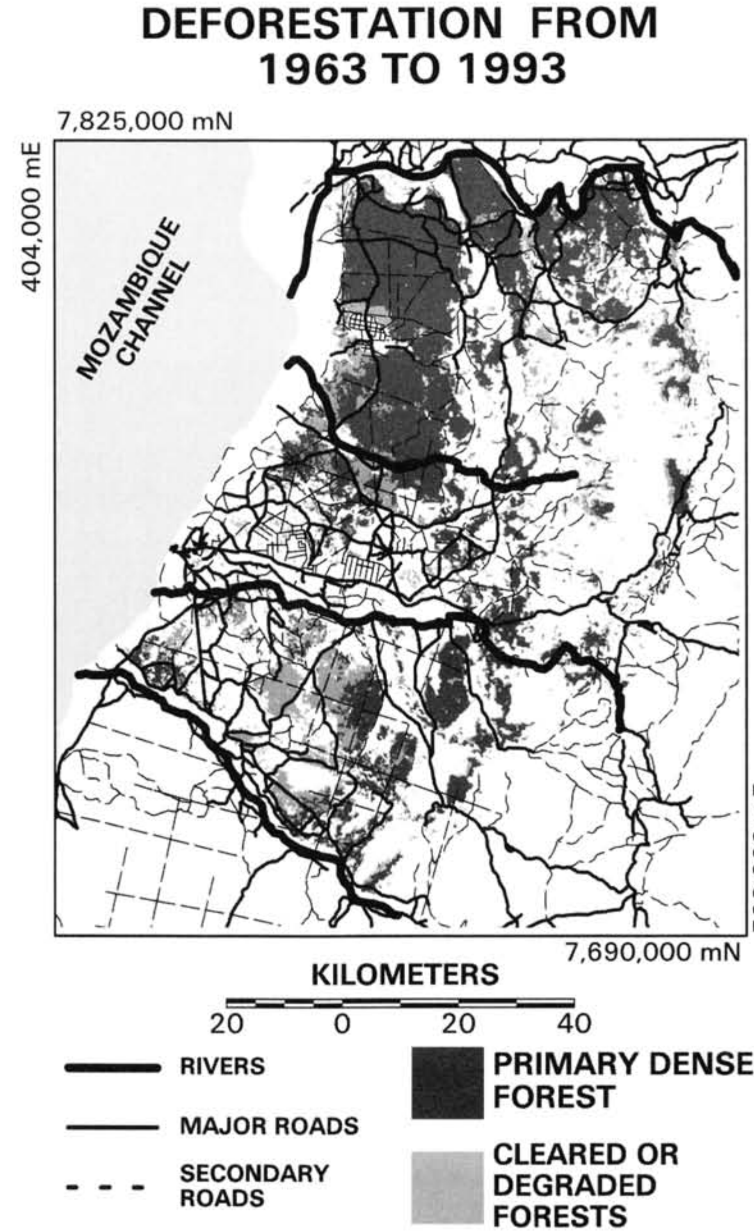

Figure 3. Patterns of deforestation between 1963 and 1993 in the Menabe area.

to be mapped as nonforest areas in the 200-m by 200-m pixels, the variables expressing proximity to roads and forest edges were not confounded measures.

RESULTS

Between 1963 and 1993 the area of primary dense forest declined from 162,000 to 133,000 ha in the Tsiribihina to Tomitsy area, from 54,000 to 36,000 ha in the Tomitsy to Morondava area, and from 93,000 to 41,000 ha in the Morondava to Maharivo area (Figs. 2 and 3). The total loss of primary dense forest was 99,000 ha, or 32% of the 1963 forest. Within each time interval, dense forests were cleared to nonforest habitats, degraded to open forests, or burnt. The conversion to open forest appeared to be an intermediate step in clearing the forests. Of the dense forest pixels degraded to open forest pixels in the intervals between 1963 and 1973 and between 1973 and 1984, more than 85% were subsequently converted to nonforest area. The annual rates of deforestation before 1984 were 758, 199, and 1079 ha/yr for the Tsiribihina to Tomitsy, the Tomitsy to Morondava, and the Morondava to Maharivo regions, respectively. After 1984, these annual rates increased to 1490, 1522, and 3318 ha/yr. The 7-fold increase in rates for the Tomitsy to Morondava region was due to extensive clearing and forest degradation in the western portion of the region near Morondava.

Because comparisons of annual rates expressed as ha/yr are complicated by differences in total area and forested area among regions, comparisons were made using proportional deforestation rates, which express forest loss as the percentage of existing forest cleared or degraded per year. Proportion mean annual deforestation rates were 0.4, 0.3, and 1.0%

Table 2. Standardized regression coefficients (SAS Institute Inc., 1989b) from logistic regression analyses of the effects of proximity to major roads, secondary roads, and the forest edge on the probability that a pixel would be deforested in the time interval. The absolute value of the standardized regression coefficients expresses the relative importance of the different variables in affecting deforestation. Negative regression coefficients indicate that the probability of being deforested declines with increasing distance. Positive coefficients indicate that the probability of being deforested increases with increasing distance; * = $p \leq 0.05$, ** = $p \leq 0.01$.

	Standardized Regression Coefficients		
Interval	Major Roads	Secondary Roads	Forest Edge
1963–1973	0.01	0.02	-2.27**
1973–1984	-0.20**	0.00	-1.98**
1984–1993	-0.09**	-0.14**	-0.69**

in the Tsiribihina to Tomitsy, Tomitsy to Morondava, and Morondava to Maharivo regions, respectively, for the period from 1963 to 1984. From 1984 to 1993, proportional mean annual loss rates were 1.1, 2.9, and 4.0%, respectively, for these regions. The increases in rates were statistically significant for all three regions ($p \leq 0.01$). Proportional deforestation rates in the Tsiribihina to Tomitsy and Tomitsy to Morondava regions did not differ significantly before 1984, but the rate for the Tomitsy to Morondava region was significantly ($\chi^2 = 64.8$; df = 1; $p \leq 0.01$) greater than that for the Tsiribihina to Tomitsy region after 1984. The rates in the Morondava to Maharivo region were significantly ($p \leq 0.01$) greater than those in the Tsiribihina to Tomitsy and Tomitsy to Morondava regions for all time intervals.

The proportion of pixels deforested was related to proximity to the edge of the forest and to major and secondary roads, but the importance of these proximities changed with time (Table 2). The proximity to the forest edge was significantly related to the proportion of pixels deforested at all times with greater deforestation occurring near edges. Several large patches were progressively deforested from the edges inward until none of the patch remained in 1993 (Fig. 3). After 1973, deforestation also increased with increasing proximity to major roads. As oil exploration increased the abundance of secondary roads in the 1980s, proximity to these roads also significantly increased the proportion of pixels being deforested. However, the effects of both major and secondary roads were always less important than the effects of forest edge as indicated by the relative magnitude of their standardized regression coefficients.

Table 3. Number of primary dense forest patches in 1963 and 1993, median size of patches in ha, the area in patches > 1000 ha, the number of patches > 1000 ha, and the size of the largest patch in the regions between the Tsiribihina and Tomitsy rivers, between the Tomitsy and Morondava rivers, and between the Morondava and Maharivo rivers.

		Regions		
Patch Statistic	Year	Tsiribihina to Tomitsy	Tomitsy to Morondava	Morondava to Maharivo
Number of patches	1963	338	348	268
	1993	308	339	397
Median size (ha)	1963	8	8	8
	1993	8	8	8
Area in patches > 1000 ha	1963	155,600	47,408	76,304
	1993	125,496	23,324	27,904
Number of patches > 1000 ha	1963	7	8	12
	1993	10	6	9
Largest patch (ha)	1963	87,168	26,912	24,928
	1993	73,212	8,472	7,452

As deforestation progressed, the area of forest contained in ≥ 1000-ha patches declined in all regions (Table 3) with especially large declines in the Tomitsy to Morondava and Morondava to Maharivo regions. The size of the largest remaining continuous patch of forest also declined in these regions. The largest remaining forest patch in 1993 contained 73,000 ha and occurred in the western portion of the Tsiribihina to Tomitsy region. It contained more primary dense forest than either the Tomitsy to Morondava or the Morondava to Maharivo regions.

DISCUSSION

The analysis of the images through time suggests rapid habitat loss in the Menabe region, especially after 1984 in the more southern regions. The analysis is, however, limited because it is not supported by ground-based data collected to assess the accuracy of the interpretation and classification of the images. The use of ground-based accuracy assessments is essential for analyses that attempt to resolve similar habitat types into detailed maps using satellite images (Congalton and Green, 1999), and no such analysis would be considered complete without these data. The absence of ground-based data is not as severe a limitation for this study because the analysis maps the distinct and easily recognized change from dense forest to nonforest. Moreover, while ground-based data could be gathered to assess the accuracy of forest versus nonforest classifications in recent years, it is unlikely that sufficient ground-based data already exist to assess the accuracy for the years of 1963 and 1973.

Although ground-based data are not available, the depiction of forested areas and patches of forested area are consistent with those in other sources for the Menabe area. The areas and patches mapped as primary dense forest are consistent with those depicted in 1:1,000,000 vegetation maps for the 1950s (Humbert and Cours Darne, 1965) and the 1:200,000 USSR maps for the 1980s. The areas mapped as forests are also similar to: 1) those mapped using 1.1 km by 1.1 km satellite data for 1990 (Nelson and Horning, 1993), and 2) those mapped for the Tsiribihina to Tomitsy region in a 1990 analysis of 30 m by 30 m Landsat Thematic Mapper data (Smith et al., 1997). These similarities suggest that the analysis still provides useful, if possibly incomplete, information on deforestation rates in the kapidolo's range.

The annual proportional deforestation rates for the Menabe region were ≤ 1% for the 1963 to 1984 period and approximately 2–3% for the 1984 to 1993 period. These rates are similar to the annual proportion rates of 0.9% observed for the rainforests of eastern Madagascar (Green and Sussman, 1990) and the range of 0.4 to 7.3% observed for other tropical forests (Skole and Tucker, 1993; Alves and Skole, 1996; Chatelain et al., 1996; Fensham, 1996). Deforestation in the Menabe region is less than the 75% loss of forest from 1950 to 1990 suggested for western Madagascar by Smith (1997). The annual deforestation rates, especially those from 1963 to 1984, are not large enough to produce a net reduction of 75%.

Although part of the deforestation in Menabe has resulted from increased access due to road construction, deforestation along forest edges was more important than along roads in all time periods. This greater importance of forest edges reflects the expansion of populations from a mostly preexisting network of roads and villages that had already divided and fragmented the forest. This contrasts with the pattern observed for the Amazon basin (Moran et al., 1994) and the Ivory Coast (Chatelain et al., 1996) where new roads allowed the entry of expanding human populations into previously inaccessible forests.

Continuing patterns of deforestation may be inferred by projecting the rates from 1984 to 1993 into the near future. At these rates it will take only 6 yrs (= 36,000 ha * 0.5/1522 ha/yr) to reduce the primary dense forest in the Morondava to Maharivo region to 50% of the 1993 value. It will take only 12 yrs to achieve a 50% reduction for the Tomitsy to Morondava region. These projections suggest that, unless urgent steps are taken to conserve forest areas, little more than isolated remnants of the kapidolo's original habitat will persist in these regions after 2010, and demonstrate the importance of protecting the remaining habitat in these southern regions.

Although the Reserve Speciale d'Andranomena in the Tomitsy to Morondava region has been partially deforested and degraded and may be of little value in preserving lemur biodiversity (Smith, 1997), the persistence of breeding populations of kapidolo in forest remnants (R. Lewis, *pers. comm.*) warrants the preservation of remaining habitat and the protection of remaining populations from the growing threat of exportation for the pet trade in this reserve (G. Kuchling, *pers. comm.*; R. Lewis, *pers. comm.*; Ozaki et al., 2000). The continuing presence of the kapidolo in an area near the known southern limit of its range may have more important implications for the maintenance of genetic diversity than for the maintenance of mere population numbers.

In contrast to the expected rapid loss of habitat in these southern regions, it should take approximately 45 yrs (i.e., until 2040) to reduce the area of primary dense forest by 50% in the more sparsely settled Tsiribihina to Tomitsy region. The projected 45 yrs for a 50% reduction in the 133,000 ha of primary dense forest remaining in 1993, and the continuous large patch of 73,000 ha in the Tsiribihina to Tomitsy region may promote a false expectation of continuing habitat resources for the kapidolo. Unfortunately, much of the remaining dense forests in this region are further inland where short-stature forests occur on basic soils (Humbert and Cours Darne, 1965). The kapidolo has not yet been found in these eastern forests (Fig. 1; J. Durbin, *pers. comm.*), and its documented occurrences are limited to the 73,000 ha patch in the western portion of the region (Fig. 1; Behler et al., 1993; Bloxam et al., 1993). This patch may be subjected to more rapid deforestation due to its proximity to roads and population centers. Behler et al. (1993) reported logging camps being developed along the major roads just south of the Tsiribihina River, and the beginnings of deforestation along these roads were evident in the 1993 MSS data. Although parts of this large patch are partially protected by being in the Kirindy and Analabe reserves (Smith et al., 1997), a 50% reduction in the size of this patch may occur before 2040.

In 1998, studies north of the Tsiribihina River found kapidolo populations at 3 of 11 survey locations (Raktombololona, 1998; J. Durbin, *pers. comm.*). Only the 1993 MSS data cover this region and indicate that the three survey locations are all located within a relatively isolated 22,000 ha forest patch just north of the river. Populations have not been found in other, nearby patches north of the river. If the kapidolo only occurs north of the river in this single forest patch, then little additional habitat has been found. Even if the kapidolo's range is subsequently found to extend farther north, there are no forest patches in that region that are larger or more protected (Nelson and Horning, 1993; Smith, 1997) than the 73,000-ha patch south of the river. Thus, the major remaining habitat areas that are at least partially protected habitat would still be the ones between the Tsiribihina and Tomitsy Rivers.

Smith (1997) has recommended the establishment of a new biodiversity reserve in the 73,00 ha patch in the Tsiribihina to Tomitsy region whose protection would be supported by international funds. Without the timely establishment of such a reserve, it may be expected that most of the habitat of the kapidolo will be reduced to small, fragmented patches supporting small, isolated populations that may be easily extirpated by continuing deforestation or exploitation for export. This has already happened through much of the southern range of the species, and may be expected to occur in the northern regions by 2040.

Acknowledgments

The research was supported by a Texas Christian University Department of Biology Adkins Grant and by Financial Assistance Award Number DE-FC09-96SR18546 from the U.S. Department of Energy to the University of Georgia Research Foundation. We thank John L. Behler of the Wildlife Conservation Society and Quentin M.C. Bloxam, Joanna Durbin, Lee Durrell, and Richard Lewis of The Durrell Wildlife Conservation Trust for information and insights on this little-known tortoise. We thank Kristy K. Guy and Deno J. Karapatakis for technical assistance with image processing and mapping software. We also thank Joanna Durbin, Lee Durrell, Glenn C. Kroh, and Gerald Kuchling for their comments on earlier versions of the manuscript. It is also important to mention that this study benefited from the declassification and distribution of images and maps compiled by USA and USSR during the Cold War.

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Received: 7 June 1999
Reviewed: 20 January 2001
Revised and Accepted: 8 March 2001