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The effects of forest fragmentation on the population density and distribution of the globally Endangered Ibadan Malimbe *Malimbus ibadanensis* and other malimbe species

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Summary

The Ibadan Malimbe *Malimbus ibadanensis* is a globally Endangered but poorly known forest species endemic to a small region of south-western Nigeria, where almost all forest has been severely fragmented. We carried out the first comprehensive survey of Ibadan Malimbe, and tested whether forest fragmentation is important in determining the distribution of this and related species in south-west Nigerian forest patches. Ibadan Malimbes were found at 19 of 52 sites surveyed but these were all clustered in a relatively small part of what appears to have been the former range. Unlike other malimbes, Ibadan Malimbes were less abundant in, or absent from, relatively isolated forest patches. Red-headed Malimbe *M. rubricollis*, Red-vented Malimbe *M. scutatus* and Crested Malimbe *M. malimbicus* were significantly more abundant in forest patches that retained vegetation characteristic of primary forest (i.e. tall trees and high tree densities). The average density of Ibadan Malimbes was 0.22 birds/ha (95% confidence limits (CL): 0.14–0.34) across all sites, but varied with degree of isolation, with densities of 0.06 birds/ha (0.03–0.14) in the 50% of fragments that were most isolated, compared with 0.33 (0.19–0.56) in the 50% of fragments that were least isolated. This gives a population estimate of 2,469 individuals (1,401–4,365) for the remaining potentially occupied forest area of 112 km^2. Given that our survey covered most forest patches within the majority of the historical range of Ibadan Malimbe this can probably be considered a reasonable maximum world population estimate. Ibadan Malimbes appear to be restricted to a small number of relatively small forest patches most of which are highly vulnerable to further destruction, degradation and fragmentation. Conservation effort should urgently focus on the protection of currently occupied sites and increasing the number and extent of forest patches within and around the existing range.

Introduction

The Ibadan Malimbe *Malimbus ibadanensis* is a poorly known forest species endemic to a small region of south-west Nigeria and is considered to be globally Endangered (BirdLife International 2000). Until recently it was classified as Critically Endangered (Collar *et al.* 1994) but its conservation status was down-graded in the light of evidence suggesting a preference for secondary rather than primary forest, which is now of very limited extent within south-west Nigeria (BirdLife International 2000, Nason

1992). However, the low population density and small range combined with very few recent records suggest that the population must be small and vulnerable even if secondary forest is preferred (Johns 1996). This paper reports on the first comprehensive attempt to assess the density and distribution of Ibadan Malimbe in south-west Nigeria.

Ibadan Malimbe was first described as a species from specimens collected in a garden at the University College Ibadan (now University of Ibadan) (Elgood 1958). Pairs or groups of 3–5 individuals were then often encountered at this site during the 1960s and 1970s. Other sight records from the period came from Olokemeji, 40 km west of Ibadan, Gambari Forest, 25 km south of Ibadan, and at Iperu, 60 km south-south-west of Ibadan. There were also breeding records from Ife, 70 km east of Ibadan, and from Ilaro, 110 km south-west of Ibadan, during this period (Elgood 1975) (Figure 1). These localities suggest a historical species range in excess of 12,000 km^2 (Collar and Stuart 1985). The Ibadan Malimbe population has probably declined dramatically in recent decades, with almost no records of the species during the last 20 years (Collar and Stuart 1985, Ash 1991). Possible reasons for the apparent population decline are unclear, but widespread and intensive deforestation within the known breeding range offers one plausible mechanism (Richards 1939, Hopkins 1962, Elgood and Sibley 1964, Nason 1992).

We aimed to determine the current distribution of Ibadan Malimbe and to identify factors influencing its density and distribution. Specifically, we tested whether the

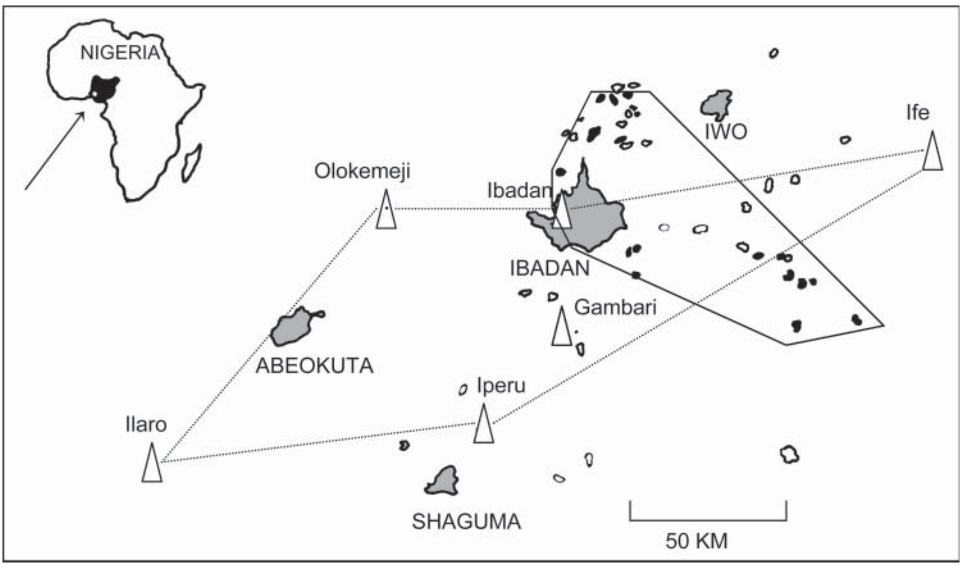

Figure 1. Map of the current and historic distribution of Ibadan Malimbe. Triangles are the very few locations where the species was recorded prior to this survey (see Fry and Keith 2004) and each is labelled by the nearest town name: a dashed line encloses the minimum "historical" range. Black-filled shapes show sites visited during this study where Ibadan Malimbes were recorded; unfilled shapes show sites visited during this study where Ibadan Malimbes were not recorded; an unbroken line encloses the minimum current range. Note that the triangle in Ibadan also denotes a current distribution record (at IITA in Ibadan). Shaded shapes are cities and towns, with the names of major urban areas in capitals. The inset map shows the location of the study area within Nigeria and Africa.

vegetation, size or isolation of forest patches influence the distribution or density of Ibadan Malimbe and other malimbe species that are not thought to have declined. This will provide a potentially useful comparison when determining the general effects of fragmentation on forest species. If all malimbe species are being affected in a similar way then this suggests that some general process of fragmentation (such as increased probability of extinction and reduced colonization probability) is responsible. If, however, only the Ibadan Malimbe is affected by fragmentation this suggests that this malimbe species may have some unique characteristics that makes it particularly susceptible to fragmentation relative to the other malimbe species.

Methods

Bird survey

Fifty-two forest patches were surveyed, which represented almost all the remaining forest fragments within the historic range of Ibadan Malimbe in south-west Nigeria (see Figure 1). One area (Ilaro; see Figure 1) in the extreme west of the historical range was not surveyed as this apparently no longer contains forest fragments. A single observer (S.M.) carried out a single line transect in each fragment, recording all individuals of all malimbe species seen or heard using the line transect method (Bibby *et al*. 2000). At each site the single observer walked slowly along predetermined transects (existing forest trails and paths) listening, looking for and recording all bird species encountered. A pair of 7×40 binoculars was used to confirm identification of birds located by eye. For each malimbe seen the perpendicular distance of the bird from the transect line was recorded. Birds flying over the forest patches were also recorded (but were not used for density estimates). Bird counts and vegetation data (below) were recorded separately for each 200 m section of each transect.

Mean transect length was 1022 ± 40 m SE (range 600–1600 m) with a total of 122 km being covered in total. Longer transects were carried out in larger patches as some patches were so small that only transects of less than 1000 m could be carried out within them. The effect of variable survey effort was controlled for statistically by including transect length as an independent variable in predictive models (see below). Transects were always started at the edge of the forest fragment and finished in the interior. We therefore also controlled statistically for the possibility of variation in the relative importance of edge effects (as a consequence of shorter transects occurring in smaller fragments) by classifying transect data as either being from the first 200 m of the transect or from greater than 200 m, and including this classification as an independent variable in predictive models (see below). The order of visits to sites was randomized to minimize any effects of season or year on presence or detectability of species. Surveys were always started shortly after dawn and lasted approximately 4 hours. Transects were only carried out on dry, non-windy days.

Site characteristics

At the start of each 200 m section of each transect (i.e. 3–8 independent records per transect), a series of vegetation variables were recorded to characterize habitat structure. Mature tree density was estimated as the number of trees greater than 2 m in height within a $10\ m \times 10\ m$ square. In addition, five $2\ m \times 2\ m$ square quadrats were randomly selected from within the 10 m × 10 m quadrat and the following measurements recorded:

1. the number of trees taller than 1 m that were seedlings (trunk diameter <1 cm), saplings (1–10 cm) and mature trees (>10 cm);
2. the circumference at breast height and visual estimates of the height (to the nearest 5 m) of mature trees (i.e. diameter >10 cm);
3. the number of palm trees (various species);
4. the number of trees emerging from the canopy (emergents);
5. the number of woody climbing species such as *Alchornea cordifolia*, *Adenia cissameloides* and *Combretum* spp.
6. the percentage ground cover (to the nearest 5%), estimated by eye;
7. the percentage visible sky estimated by viewing the sky through the canopy from the wrong end of a pair of binoculars (Jones *et al.* 1996);

The area and an index of isolation were determined for most of the forest patches using coordinates recorded from each corner of the patch using a Garmin 12 Global Positioning System. ArcView software (Applegate 1999) was used to overlay these coordinates onto a Landsat image and land-use maps. ArcView was used to calculate forest patch areas and an index of forest patch isolation that was the total area of forest within 15 km of the patch in question. Similar results were obtained whether the index was based on total forest areas within 6 km to 40 km, and the 15 km index generally accounted for most variation in models attempting to account for variation in malimbe numbers or occurrence. Patch area varied between 0.1 and 4.5 km^2 (mean 2.2 ± 0.2 km^2), while the total area of forest within a 15 km radius varied between 0 and 30.8 km^2 (mean 15.2 ± 1.3 km^2).

Data analysis

Variables influencing the density and distribution of Ibadan Malimbe, Red-Vented Malimbe *M. scutatus*, Red-headed Malimbe *M. rubricollis*, Blue-billed Malimbe *M. nitens* and Crested Malimbe *M. malimbicus* were determined in two ways. First, we used DISTANCE software (Buckland *et al.* 1993) to estimate the bird densities within forest patches surveyed, and for various area and isolation subsets of patches (see below). Secondly, we built multivariate regression models to identify factors predicting variation across forest patches in the counts of each of five malimbe species.

Average densities of Ibadan Malimbe and other malimbes were estimated using data from all 52 forest patches surveyed using the Distance software. The best fitting of the three detection probability plots was used for each species. Distances to malimbes were not truncated because most birds were sighted relatively close to the transect line (over 50% of sightings were at less than 10 m and the maximum distance was 30 m). For species for which abundance differed according to forest patch area or isolation index (according to regression models), densities were estimated separately for larger and smaller patches or for relatively isolated and unisolated patches. These subdivisions assigned 50% of forest patches to each category. Note that only sight records of non-flying birds were used for the Distance analysis.

Generalized Linear Mixed Models (GLMMs; McCulloch and Searle 2001) were used to identify variables influencing the maximum counts of each malimbe species in 48 forest fragments for which we had all relevant area and isolation data. Data from one exceptionally large forest site (Omo, 2,328 km^2) was excluded because its large

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area had a strong influence on GLMMs. Total count on each occasion within either the outer 200 m transect (edge) or summed across the remaining (inner) transects was taken as the dependent variable, with forest patch being declared a random variable and specifying a Poisson error distribution and log link function. The influence of a range of potential fixed effect predictors (below) of malimbe counts was tested by their stepwise inclusion in GLMMs. Each potential predictor was included in the model in turn and that with the most significant effect (i.e. smallest $P < 0.05$ from a Wald test) was selected for inclusion in the final model. Once the first predictor had been selected, the process was continued by including in the model in turn each of the remaining potential predictor variables in the presence of the first significant predictor. This step-up approach continued until no further predictors accounted for any of the remaining variation in the count data. We tested the following subset of potential predictors for an influence on malimbe counts: year (3-level factor: 2000, 2001, 2002), season (4-level factor: 3-month quarters beginning with January–March), edge (2-level factor: inner, outer), survey start time, length of the transect, forest patch area, forest patch isolation index, mature tree density, sapling density, palm density, climbers density and percentage ground cover (all continuous variables as defined above). The other habitat variables (above) were excluded because they were correlated (Spearman's rho >0.4) with one or more of the included habitat variables. Unlike some previous studies (e.g. Beier *et al.* 2002), the lack of any correlation between forest patch area and isolation index (Spearman's rho = −0.03, $P > 0.8$) gave our study statistical power to distinguish between these potentially important landscape variables. Note that for maximum counts we used all records including flying birds and calling birds that were not sighted, resulting in much larger sample sizes of records than for the Distance analysis, particularly for more vocal species.

We checked whether variation in malimbe detectability might have compromised our usage of raw counts in the GLMMs by comparing the frequency distributions of distances from the observer for all Ibadan Malimbe records across four similarly sized subsamples of the data split according to tree density, forest patch area and isolation index. The distance frequency distributions did not differ according to tree density, forest patch area or forest patch isolation (Kruskal–Wallis one-way ANOVAs: $\chi^2_3 = 0.6$, $P = 0.90$, $\chi^2_3 = 0.7$, $P = 0.87$ and $\chi^2_3 = 1.1$, $P = 0.78$ respectively). As there was no evidence that Ibadan Malimbe detectability varied according to tree density, patch area or isolation we considered raw total bird counts to provide an unbiased measure of true abundance for use in the GLMMs.

Results

Current distribution

Ibadan Malimbes were sighted in 19 forest patches distributed within the study area (Table 1, Figure 1). The closest sites (IITA and Moniya) were 8 km apart while the furthest sites (IITA and Shasha) were 63 km apart. The limited extent of the 19 occupied forest patches within the much larger survey area (Figure 1), suggests that the current range of the Ibadan Malimbe is much smaller (approximately 66% smaller) than the range implied by previous sightings (Collar and Stuart 1985, Fry and Keith 2004). The largest single flock of Ibadan Malimbes comprised four individuals. At Alade, a fledged juvenile was seen with a female. Sightings of Ibadan Malimbes were

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Table 1. Sites in south-west Nigeria where Ibadan Malimbes were recorded 2001–2002.

Site name	Latitude N	Longitude E	Total maximum count	No. of visits where seen
IITA	07′29	03′53	7	4
Akanran	07′18	04′0	4	2
Oosa	07′18	04′15	2	1
Moniya	07′33	03′55	5	1
Ayepe	07′16	04′17	6	1
Jakankan	07′16	04′18	5	2
Orile-Owu	07′14	04′19	6	2
Motako	07′16	04′17	2	2
Ajegunle	07′08	04′20	2	1
Monye	07′18	04′01	1	1
Alade	07′36	04′01	5	1
Faritosa	07′37	04′00	3	1
Oyada	07′38	03′58	2	1
Kuku	07′32	03′59	2	1
Sokinloju	07′37	03′56	4	1
Arikoko	07′17	04′15	4	1
Orile-Owu (north)	07′14	04′20	4	2
Sooko	07′28	04′19	1	1
Shasha	07′08	04′23	3	1

distributed throughout the year with the largest numbers of sight records in October (11 records), September (6) and July (5).

Density

The overall density of Ibadan Malimbe was 0.22 birds/ha (95% CL: 0.14–0.34) in the forest fragments surveyed. Densities were higher than for Blue-billed Malimbe and Crested Malimbe but lower than for Red-vented Malimbe and Red-headed Malimbe (Table 2). Densities of Ibadan Malimbes in isolated patches were much lower than those in less isolated patches (0.06 birds/ha (0.03–0.14) compared with 0.33 (0.19–0.56). Densities of other malimbe species did not differ significantly between isolated and less isolated, or between larger and smaller forest patches.

Factors affecting the abundance of malimbes in forest patches

With the exception of transect length, most predictors of malimbe counts were species-specific (Table 3). It may be significant that Ibadan Malimbe was the only species whose abundance was strongly related to the isolation status of forest patches.

Table 2. Density estimates of malimbes (per ha) in south-west Nigeria in 2001–2002.

Species	Density (per ha, 95% confidence limits)	Ubiquity (% of 52 patches occupied)
Red-Vented Malimbe	0.49 (0.37–0.64)	94
Red-headed Malimbe	0.45 (0.36–0.55)	96
Blue-billed Malimbe	0.12 (0.07–0.19)	81
Ibadan Malimbe	0.22 (0.14–0.34)	38
Crested Malimbe	0.10 (0.06–0.17)	31

Table 3. Predictors of malimbe counts in south-west Nigeria.

Species	Predictors of counts:	
	Methodological	Landscape/vegetation
Ibadan	Transect length*** (+) Year *** (2001>2002>2000)	Forest patch isolation *** (–)
Red-headed	Transect length*** (+)	Palm density*** (+) Tree height*** (+)
Red-vented	Transect length*** (+) Season*** (4 > 3 = 1 >> 2)	Forest patch area*** (–) Tree height** (+) Palm density* (+) Ground cover* (+)
Blue-billed	Transect length*** (+) Time of day* (–)	Tree height (*) (–)
Crested	Transect length*** (+) Time of day*** (+)	Sapling density*** (–) Tree density*** (+)

Significant predictors from generalized linear mixed models (GLMMs) are listed, along with their statistical significance (***$P < 0.005$, **$P < 0.01$, *$P < 0.05$, (*)$P < 0.07$) and, in parentheses, direction/ranking.

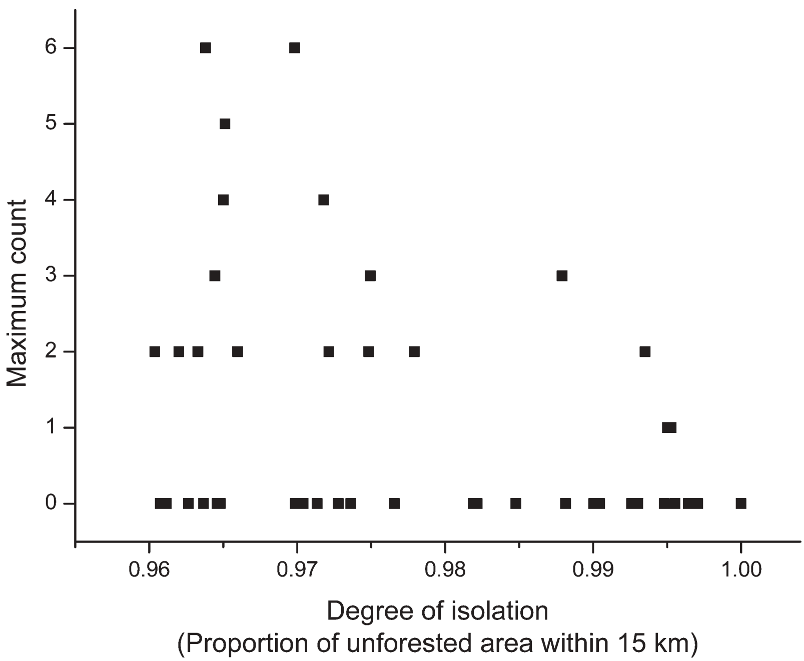

Figure 2. Abundance of Ibadan Malimbes in south-west Nigeria in relation to the degree of isolation of a forest patch (1 – [the combined area of forest patches within a 15 km radius of each patch/total area within a 15 km radius of each patch]).

After allowing for effects of transect length and year, counts of Ibadan Malimbe declined markedly as forest patches became more isolated from neighbouring forest patches (Table 3, Figure 2). Ibadan Malimbes were apparently insensitive to forest area (Table 3), and were able to persist in quite small forest fragments (the area of occupied sites averaged 2.2 km^2 and ranged from 0.2–4.5 km^2).

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Red-vented Malimbes were more abundant in smaller forest patches but no species were more abundant in larger patches (Table 3). Red-headed and Red-vented Malimbes were more abundant in forest patches with taller trees and more palms, whereas Crested Malimbes preferred patches having a relatively high density of trees and a relatively low density of saplings (Table 3). There was some evidence that Blue-billed Malimbes preferred forest patches with shorter trees.

Discussion

This study suggests that the range of Ibadan Malimbe is substantially smaller than that implied from the distribution of the first sightings in the 1950s to 1970s (Elgood 1975). Using a crude comparison between the area of simple maximum convex polygons of the historical range versus the current range (Figure 1), the current range is approximately 34% of the historical range. In this analysis we do not consider the possible records of Ibadan Malimbe from Owerri, south-east Nigeria, or Tafo or Subri River, Ghana (Fry and Keith 2004). If these records prove correct (and it should be noted that the birds in question were originally recorded as *M. cassini*) then they would have important implications for the conservation status of the species: clearly it is an urgent priority to follow up these sight records. It is also important to note that there were no surveys during this study in the Ilaro area 120 km south-west of Ibadan (see Figure 1) where Ibadan Malimbes were recorded historically, because we could not locate any forest patches extant in this area: there were, however, no records of the species during this study west of Ibadan, despite other former historical sites up to 40 km west of Ibadan being visited.

The general insensitivity of the Ibadan Malimbe and the other malimbe species to forest patch area contrasts with the findings of Beier *et al.* (2002) who found that patch area was an important factor affecting the abundance of many bird species in forest patches in Ghana. It should be noted, however, that only very small fragments were remaining within the study area (maximum size 4.4 km^2) so we can only conclude the lack of an area effect for this limited range of already very small forest fragments. Ibadan Malimbes occurred in relatively small forest patches (three occupied patches were less than 1 km^2) and neither preferred nor avoided forest edge. The malimbe species in general seem rather adaptable and can apparently survive in a variety of habitats, which may explain why they occur in small forest fragments and edge habitats.

Our data suggest, however, that Ibadan Malimbes may be sensitive to the effects of forest isolation, in contrast to the other malimbe species. Ibadan Malimbes may therefore have undergone apparently large declines in range and probably abundance because of low dispersal distances, or small home ranges, relative to the four other malimbe species that remain widespread and relatively abundant across western Africa (Borrow and Demey 2001). Although apparently not sensitive to fragmentation, Red-headed, Red-vented and Crested Malimbes were significantly more abundant in forest patches that retained vegetation characteristic of primary forest (i.e. tall trees and high tree densities). This perhaps supports the suggestion above that the lack of a significant effect of isolation on these malimbe species may be because they are better dispersers and not be because they are forest species to a lesser extent than the Ibadan Malimbe.

Although Ibadan Malimbes have been described as a forest edge species (Elgood 1975) and we encountered them slightly more frequently on transects within 200 m of forest perimeters (on average, one bird every 1,575 m compared with 2,265 m along inner transects), the difference was not statistically significant (Wald test, $P = 0.24$). Most of the forest patches occupied by Ibadan Malimbes were thickets and regrowths (Elgood and Sibley 1964) in areas dominated by subsistence agriculture. The vegetation in these thickets is generally similar to that of secondary forest. Ground vegetation is often lacking, with fast-growing trees such as *Ceiba pentandra, Chlorophora excelsa, Bombax buonopozense, Daniellia ogea* and *Terminalia superba* being common, along with oil palms especially along streams and rivers. Two of the occupied sites (IITA and Shasha) had diverse vegetation. The IITA (International Institute of Tropical Agriculture in Ibadan city) west bank site has remained undeveloped and protected since 1965 and Ibadan Malimbes were seen in areas characterized by a patchy upper storey of emergent trees (20–30 m tall) with scattered large trees mainly *Albizia* spp., *Daniellia ogea, Newbouldia laevis, Holarrhenafloribunda, Antiaris africana, Ceiba pentandra, Chlorophora excelsa, Triplochiton scleroxylon* and *Bombax buonopozense.* A nearly continuous lower storey is formed by some of the above species with *Allophylus africanus, Blighia unijugata, Phyllanthus discoidens* and *Spondias monbin.* Basal branching is frequent and scandent, shrubby and climbing woody species such as *Alchornea cordifolia, Adenia cissameloides* and *Combretum* spp. form large tangles (Hall and Okali 1979). Parts of the mixed deciduous secondary forest at Shasha show some evidence of previous farming with the presence of *Elaeis guineensis* along streams. The tallest emergent trees are *Ceiba pentandra, Triplochiton scleroxylon* and *Terminalia superba*, with a lower storey dominated by *Steculia rhinopetala, Bosqueia angolensis, Celtis mildbraedii, C. zenkeri* and *Pterygota macrocarpa.* Lianes such as *Landolphia* spp., *Strichnos* spp., *Combretum* spp. and *Acacia* spp. are common, especially on the forest edge.

Multiplying our average density estimates for Ibadan Malimbe for isolated and less isolated fragments, by the combined area of the 50 survey sites, split into isolated and less isolated fragments, for which area was known and excluding Omo (see below), a total area of 112 km^2, gives a population estimate of 2,469 individuals (95% CL: 1,401–4,365) in 2000–2002. This estimate is based on the certainly false assumption that the Ibadan Malimbe has a uniform distribution across the sites surveyed and occurs in each one (see Figure 1): therefore this should be considered as the absolute maximum world population estimate. Given that our survey covered most forest patches within the vast majority of the historical range of the Ibadan Malimbe this can probably be considered a reasonable maximum world population estimate. One caveat is the status of Ibadan Malimbes within the exceptionally large (2,328 km^2) Omo forest 100 km south-east of Ibadan that is very much on the edge of the historical world range (Figure 1). No Ibadan Malimbes were seen during repeat surveys covering a combined transect length of 9.8 km, but most of this vast forest remained unsurveyed. A larger survey is needed to establish the status of the Ibadan Malimbe in this one large remaining remnant of forest within the Ibadan region: if it is proved that it is present at Omo then the world population may be larger by an order of magnitude. Our estimates of the minimum world population size and range (above) suggest that the current conservation status of Ibadan Malimbe (globally Endangered; BirdLife International 2000) is probably appropriate.

The world population of Ibadan Malimbe probably now depends on a relatively small number of degraded and fragmented patches of secondary forest in south-west Nigeria. Given the apparent sensitivity of Ibadan Malimbes to forest isolation, the preservation of all existing forest patches within and close to the current range (see Figure 1) should constitute an urgent conservation priority for this species. Apart from IITA, most of the occupied and unoccupied forest patches within the known range are community-owned forests. While the protection and preservation of these forests is the immediate responsibility of local communities, successful long-term protection will probably require the relevant statutory authorities and/or local environmental nongovernmental organizations to provide incentives to encourage local communities to value and protect this network of small forest patches.

This study has brought the site records of Ibadan Malimbe from one in 1987 to twenty in 2002. There is some hope that there are a few more pairs in its range and that extinction of this species is less imminent than might have been thought prior to this study. Nevertheless the world population is low at only a few thousand birds. If the range has contracted in the way it seems to have done, this is a worrying pattern. There is probably an urgent need for some sort of protection of the 19 occupied sites and the other patches of woodland in the area.

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