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Using patterns of distribution and diversity of Kenyan birds to select and prioritize areas for conservation

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Patterns and environmental correlates of species distributions and richness are identified for Kenyan birds at a quarter degree-square scale. This information is used together with iterative complementarity analyses, which employ species richness, taxonomic dispersion and range-restrictedness, to identify priority areas for possible conservation attention. Bird species apparently not conserved by existing protected areas in Kenya are identified.

Six avifaunal zones (and one transitional zone) are distinguished based on distributions of suites of bird species. Variation in biotope diversity (the number of forest and aquatic systems) accounts for 79% of the observed variation in Kenyan bird species richness. Although both rainfall and altitudinal range are significantly correlated with species richness, they only explain an additional 3% of the observed variation. The priority areas identified are situated mainly within highlands and coastal lowlands. Although few priority areas are identified in northern Kenya, this region also constitutes a priority, as it contains a suite of xeric species with habitats that are not represented elsewhere in Kenya. The papyrus yellow warbler, *Chloropeta gracilirostris*, William's bush lark, *Mirafra williamsi*, white-winged dove, *Streptopelia reichenowi*, and Jubaland weaver, *Ploceus dichrocephalus*, are identified as endemics or near-endemics that are probably not adequately conserved in Kenya at present.

Keywords: Kenya; birds; conservation; protected areas.

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Introduction

The selection and prioritization of areas for protectionist-oriented conservation has, until recently, been driven primarily by three criteria: (1) the availability of non-arable and non-habitable land with acceptably large populations of wildlife, (2) the preservation of larger mammals and birds in general (IUCN, 1987), and (3) the preservation of 'flagship' species (and Red Data Book species in particular) with which humans can identify. This strategy cannot ensure the effective conservation of representative components of a biota or important biological processes. In the past decade, more systematic approaches for the selection of areas for conservation attention have been developed (e.g. Kirkpatrick, 1983; Margules *et al.*, 1988; Vane-Wright *et al.*, 1991; Margules *et al.*, 1994; Pressey *et al.*, 1994; Vane-Wright *et al.*, 1994). These procedures are implemented through the use of iterative reserve selection algorithms (Margules *et al.*, 1988; Vane-Wright *et al.*, 1991).

The Kenyan avifauna is one of the richest in Africa (Pomeroy and Lewis, 1987). It includes a diversity of community assemblages, reflecting a diverse range of habitats from montane forest in the west to semi-arid scrub in the north and mangrove forests in the southeast (Fanshawe and Bennun, 1991). In addition, Kenya is located on a major migration flyway for waterbirds, raptors and passerines *en route* from the Palaearctic to their non-breeding grounds in sub-Saharan Africa (Fanshawe and Bennun, 1991). Having such a rich and diverse avifauna charges Kenya with national and global conservation responsibilities (Fanshawe and Bennun, 1991). The importance of conserving Kenyan birds is further emphasized by the fact that bird watching is an important component of Afrotourism. Such tourism contributed as much as US $230 million in foreign currency directly to Kenya's national economy in 1992 (D. Turner, 1994, *in litt.*).

Previous studies on the conservation of Kenyan birds have concentrated on species of global and national importance and habitats crucial to their conservation (e.g. Fanshawe and Bennun, 1991). This study of the Kenyan avifauna aims to:

(i) identify patterns of distribution and species richness, defining areas with suites of representative Kenyan bird species,
(ii) identify environmental correlates of species richness, and
(iii) use the above information together with iterative algorithms to identify priority areas for conservation.

Methods

Data base

Distributional data for 970 of the 1065 species of Kenyan birds presented in Lewis and Pomeroy (1989) were digitized using WORLDMAP computer software (version 3.06: Williams, 1993) on a quarter-degree square (QDS) scale, defined as 30 by 30 minutes (Fig. 1). Only species recorded in Kenya since 1970 (Lewis and Pomeroy, 1989: 7) were included in this analysis. Vagrant species and those represented only by anecdotal records were specifically excluded.

The phylogenetic relationships of these species were displayed in a cladogram (branching pattern) according to Sibley and Monroe's (1990) classification. Nodes (branching points) on this cladogram were numbered sequentially in order to assign a unique numerical cladistic (taxonomic) code to each species within the database (Williams, 1993).

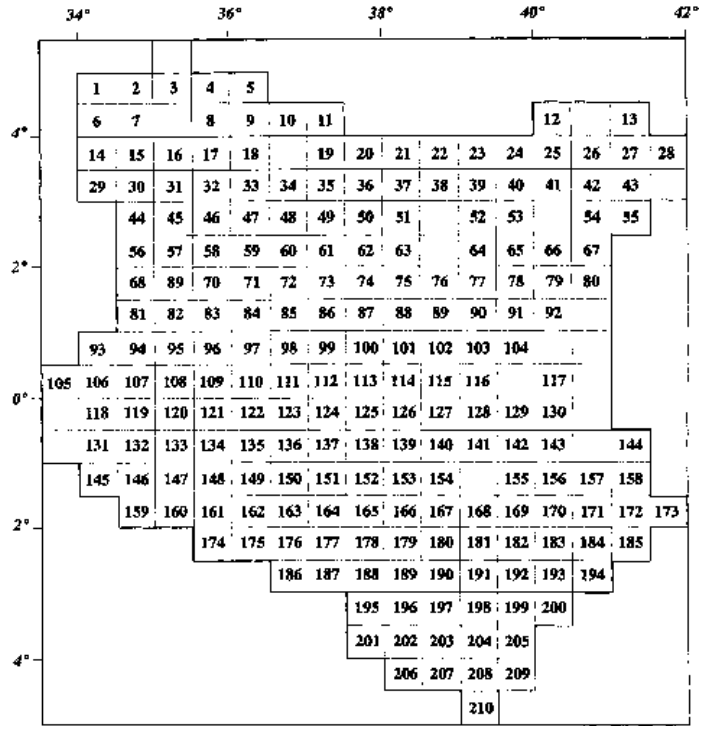

Figure 1. The quarter-degree square grid system used to digitize distributional data from Lewis and Pomeroy (1989). Quarter-degree squares for which no data were given have been left blank.

Digitized boundaries of protected areas were extracted from the WCMC (1994) database of Afrotropical protected areas. Protected areas with the status of IUCN categories 1 (Scientific Reserves/Strict Nature Reserves) and 2 (National Parks) (IUCN, 1987), as well as Forest Reserves, were included. To qualify as a 'protected square', a square had to contain a minimum total area of 100 km^2 which is afforded protected status. This (arbitrary) criterion was set to avoid including squares with a few very small protected areas, unlikely to harbour viable populations of bird species.

Patterns of distribution

Patterns of distribution of Kenyan birds were identified in a two-stage process. First, a cluster analysis employing the Bray-Curtis similarity measure and the centroid clustering algorithm (BMDP-2M: Dixon, 1990) was used to detect groups of QDSs with relatively homogeneous suites of bird species. Second, the matrix of similarity values was inspected along north-south and east-west gradients to assign any remaining squares to these groups on a 'nearest-neighbour' basis (Crowe and Crowe, 1985). Once this exercise was complete, a map representing the geographical distributions of the QDS-clusters was superimposed over the species distribution maps to identify characteristic species, defined as those whose distributions largely coincide with zone boundaries. QDS clusters are termed avifaunal zones (Crowe and Crowe, 1982). Those species whose distributions within Kenya are restricted to a single zone, but whose ranges do not characterize a zone, are discussed

separately in the results. These patterns, while determined at a national level, are interpreted with reference to species' global distributions, and compared with avifaunal zones defined on an African scale by Crowe and Crowe (1982).

Patterns of species richness and its correlates

Patterns of species richness were determined with WORLDMAP software (version 3.06: Williams, 1993) and then simplified into contour maps with the Kriging method implemented through the use of SURFER software (version 4.14, 1989). Kriging calculates the autocorrelation between data points and produces the minimum variance unbiased estimate of contour lines to show bird species richness over the landscape. Inverse distance (SURFER, 1989) was used to check the above results.

Correlation and step-wise multiple linear regression analyses (BMDP-2R: Dixon, 1990) were used to identify relationships between bird species richness and measures of certain environmental variables. Log_{10}, mixed and linear models were employed to identify patterns of statistical relationships between species richness and environmental predictor variables. Environmental variables considered were altitudinal range (difference between the maximum and minimum altitudinal regions encountered in a QDS), rainfall and biotope diversity (number of types of forest and aquatic systems; Table 1) as identified in Lewis and Pomeroy (1989).

Observed QDS species richness values were compared with those predicted by the regression analysis (BMDP-2R: Dixon, 1990) based on biotope diversity, altitudinal range and rainfall, in order to identify areas with unexpectedly high bird species richness values.

Table 1. Environmental predictor variables for each quarter-degree square (QDS), and the scores which were assigned to each variable. The biotope diversity score was derived from the sum of the number of forest types and aquatic systems in a particular QDS

Altitudinal range						
Altitudinal difference (masl)	0	2000	4000	6000	8000	10000
Score	1	2	3	4	5	6
Rainfall						
Mean annual rainfall (mm)	0	250	500	1000		
Score	1	2	3	4		
Biotope diversity						
Forests						
Highland forest						
Forest islands						
Lowland forest						
Aquatic systems						
Oligotrophic lakes						
Temporary flood-waters						
Permanent rivers						
Algal lagoons						
Carbonate lakes						
Coastal waters						

Sampling bias

Different QDSs had widely different sampling efforts (Lewis and Pomeroy, 1989). To test for the robustness of the results, the correlation and regression analyses were rerun excluding 'badly sampled' QDSs, and the results compared with those obtained from analysis of the full database. 'Badly sampled' QDSs were defined as those with bird species richness values of less than 100 (D. Turner, 1995, *in litt.*).

Priority-areas analysis

This section of the study had two foci. First, in broad terms and irrespective of the existing system of protected areas, the regions important for the conservation of Kenyan birds were identified. Second, and more specifically, those species apparently not currently conserved in existing protected areas were identified.

Regions of concern for the conservation of Kenyan birds were determined from the dispersion of priority areas as identified by iterative priority area analyses. Iterative algorithms are based on the concept of complementarity (Margules *et al.*, 1988; Vane-Wright *et al.*, 1991) and aim to select the smallest number of areas that incorporate all the species contained in a database at least once. WORLDMAP software (version 3.06: Williams, 1993) was used to implement the algorithm. Key conservation regions were identified using species richness, taxonomic dispersion and range-restrictedness. These different conservation criteria do not necessarily identify the same priority areas, and results obtained using the three measures are compared.

Species richness is the most traditional measure of conservation value (e.g. Margules and Usher, 1981), whereas many authors have argued that taxonomic (phylogenetic) diversity is a key parameter in identifying areas for conservation (e.g. McNeely, 1988; Williams *et al.*, 1991; UNEP, 1992; Faith, 1994; Williams and Humphries, 1994). Taxonomic dispersion (diversity) takes into account the number of species, phylogeny and the evenness of the cladistic spread amongst species (Williams *et al.*, 1991). Range-restrictedness (termed endemism in the WORLDMAP manual) is calculated as the inverse of the number of QDSs in which a particular species occurs (Williams, 1993). These results are compared to the Endemic Bird Areas identified through the use of a set range-size criterion of 50 000 km^2 (ICBP, 1992).

Kenya already has an extensive system of protected areas, and it is thus important to identify those bird species which may not occur in any of these areas. This was done to identify the set of areas required, in addition to the existing protected areas, to conserve all Kenyan bird species. The assumption is that all species recorded in a 'protected' QDS (as defined in the Methods) occur within the protected areas themselves in viable populations. This is unlikely to be the case, but the assumption was used, in the absence of definitive lists, to allow a preliminary understanding of which species are most likely to require future conservation attention. Once the bird species which do not, according to definitions used in this analysis, occur in any of the existing protected areas were identified, degree of threat (as identified by Fanshawe and Bennun, 1991) and degree of geopolitical endemism (defined by national and geographic borders) were determined. National endemics are those species which have global distributions confined within the borders of Kenya (e.g. Aberdare cisticola, *Cisticola aberdare*). Regional endemics are those species which have very small distributions, but which fall across the confluence of two or more countries (e.g. northern pied babbler, *Turdoides hypoleucus*, which occurs only in the bushland extending from northeastern Tanzania to central Kenya, or white-winged dove, *Streptopelia reich-*

enowi, which is confined to riparian vegetation in southeastern Ethiopia, southern Somalia and northeastern Kenya). Results from the iterative analysis are interpreted in the light of this information to provide 'real world' recommendations.

Results and discussion

Patterns of distribution

Based on the co-occurence of suites of species, six avifaunal zones (and one transitional zone) can be distinguished in Kenya (Fig. 2). The arid northeastern zones (B, C and transition zone G) are less strongly defined than the mesic western and southern zones (D, E and F), largely due to the relatively low species richness and wide dispersions encountered in northern Kenya (Figs. 3 and 4).

Zone A (Fig. 2) lies between the mesic west and xeric northeast and is defined by species whose ranges are centred on the dry, open bushed and wooded country of northeastern Uganda, southern Sudan, central Ethiopia and northwestern Kenya, such as Jackson's hornbill, *Tockus jacksoni* (Appendix 1).

Zone B is weakly distinguished, being defined by a few species (e.g. William's bush lark, *Mirafra williamsi*) which are confined to the short grass plains of the black lava soils which characterize the hills east of Lake Turkana. Zone C is similarly weakly defined by a few arid-zone specialists whose ranges extend into southern Somalia (e.g. collared lark, *M. collaris*).

In the mesic west of Kenya, zone D is the most strongly defined, reflecting the high topographic and habitat diversity of this region. This zone supports several species en-

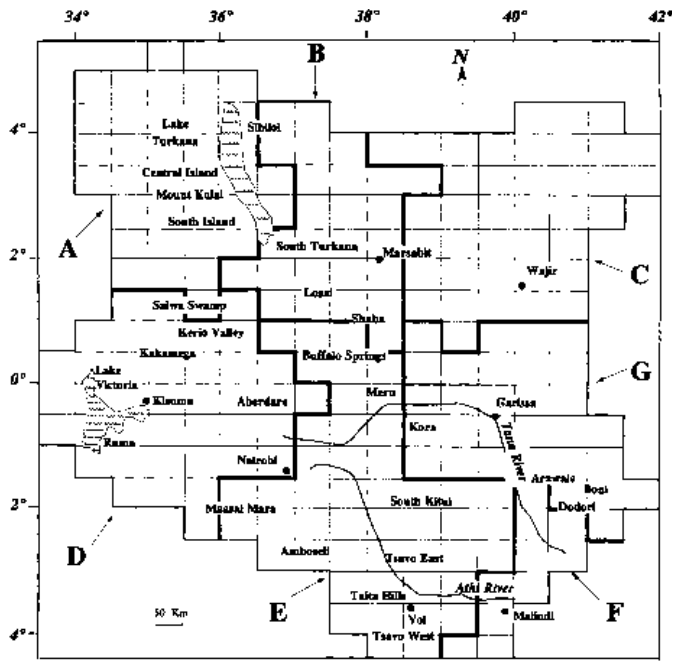

Figure 2. Avifaunal zones for Kenyan birds as indicated by the distributions of suites of bird species.

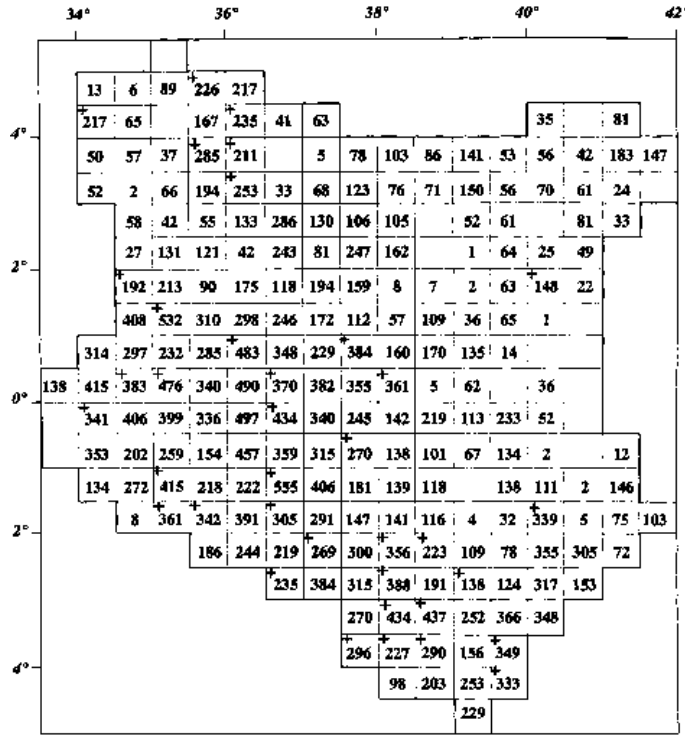

Figure 3. Species richness for each quarter-degree square sampled. Quarter-degree squares which have a higher number of species than was predicted by biotope diversity, altitudinal range and rainfall are indicated by + in the upper left-hand corner.

demic to the forests of eastern Africa (e.g. Hartlaub's turaco, *Tauraco hartlaubi*) as well as a few species endemic to the high altitude grasslands of Kenya (e.g. Aberdare cisticola, *Cisticola aberdare*).

Zone E is largely defined by species which are at the northern limits of their ranges (e.g. violet-crested turaco, *Tauraco porphyreolophus*), but also includes a few species endemic to the bushland which extends from northeastern Tanzania to central Kenya (e.g. northern pied babbler, *Turdoides hypoleucus*), as well as the Kenyan endemic, Hinde's pied babbler, *Turdoides hindei*, confined to the foothills of the highlands and surrounding plateau country.

Zone F is characterized by shore and seabirds (e.g. crab plover, *Dromas ardeola*, and crested tern, *Sterna bergii*) as well as species with ranges restricted to coastal vegetation, especially forest (e.g. Sokoke pipit, *Anthus sokokensis*).

North and south of the Tana River is a transitional zone, G, which has therefore been merged into zones E and C; it lacks characteristic species and is essentially defined by default (Guillet and Crowe, 1986). QDSs along and south of the Tana River (indicated by dashed line in Fig. 2) include many species which are typical of zone E, including a number that reach their northern limits here (e.g. smaller black-bellied sunbird, *Nectarinia nectarinioides*, Appendix 1), whereas QDSs to the north of the Tana River largely follow the patterns seen in zone C.

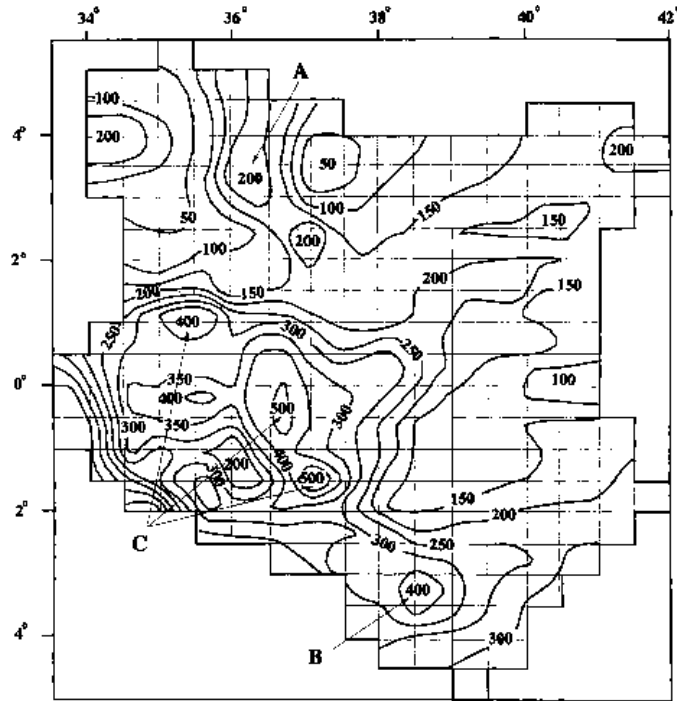

Figure 4. Contour map describing geographical variation in Kenyan bird species richness.

Boundaries of the Kenyan avifaunal zones largely correspond with those defined on an African scale by Crowe and Crowe (1982). Zone A falls mostly within the southern province of the 'northern savanna subregion' of Crowe and Crowe (1982). Zones B, C, E, and G fall mainly within the savanna district of their 'northeastern arid subregion'. Zone F is largely contained within the eastern province of the 'southern savanna subregion', while zone D corresponds with the northeastern portion of the east-west district of the 'forest subregion' (Crowe and Crowe, 1982). The chief difference is the subdivision of Crowe and Crowe's (1982) savanna district into three Kenyan avifaunal zones, namely B, C and E (with G as a transitional zone). This is no doubt due to the finer scale of data used in the Kenyan exercise, i.e. 30×30 min, as opposed to the scale of 120×120 min used in the African study (Crowe and Crowe, 1982).

Many species have ranges which span two or more of these seven avifaunal zones. Several species occur in both zones D and E, typically ones which reach the eastern edge of their range in western Kenya. Many of these, such as chin-spot batis, *Batis molitor*, have wide distributions in Africa. Many Palaearctic migrants and waterbirds are widespread in a band running from northwestern to southeastern Kenya (zones A, D, E and F) (e.g. steppe eagle, *Aquila nipalensis*, and fulvous whistling duck, *Dendrocygna bicolor*). Some species, such as Senegal plover, *Vanellus lugubris*, reach the northern limits of their range in southern Kenya, being found in zones D, E and F. Zones A, B and C share several species at the southerly limit of their range (e.g. brown-necked raven, *Corvus ruficollis*), while zones B, C and E (including G) share species at the western limits of their ranges (e.g. golden-breasted starling, *Cosmopsarus regius*).

The division into neat zones at the QSD scale is complicated by relief: many species mainly occurring in zone D, for example, are also found in mountain islands of forest in zones B and E, while species of zones A and B also occur in zone D in lower, drier parts of the Rift Valley between highland blocks. At a global scale, zone D includes two Endemic Bird Areas (EBAs, defined as clusters of bird species with global ranges less than 50 000 km^2. ICBP, 1992). These are the 'Kenyan mountains' and the 'Serengeti' (ICBP, 1992), which interdigitate with each other in southwestern Kenya. This zone also includes a species cluster characteristic of the forests of western Uganda and eastern Zaire, centered on Kakamega forest. Zone F (including the lower Tana River) includes a large part of the 'Kenya and Tanzania coastal forests' EBA, with its own set of highly distinctive species.

The 'characteristic' species shown in Appendix 1 are those whose distributions, as presently mapped, closely coincide with the zone boundaries. They do not necessarily include all species whose distributions within Kenya are confined to a particular zone. Apart from vagrants, already excluded by the analysis, most of these zone-restricted species are at the edge of their continental ranges.

Zone D has by far the largest number (108) of zone-restricted but not characteristic species. They fall mainly into two groups. Some 64 species are typical of the forests of western Uganda and eastern Zaire many of them Guineo-Congolian species with populations further west in Africa as well. These species have restricted ranges in Kenya, being mainly or entirely confined to the Kakamega, South and North Nandi Forests (QDSs 107 and 108). Examples are brown illadopsis, *Trichastoma fulvescens*, Petit's cuckoo shrike, *Campephaga petiti*, and honeyguide greenbul, *Baeopogon indicator*. Another eight species are typical of the Lake Victoria basin, especially papyrus swamps, and also have a limited range in Kenya; they include papyrus specialists such as papyrus canary, *Serinus koliensis*, and birds of waterside habitats such as red-chested sunbird, *Nectarinia erythroceria.* The remaining species are either birds that have very patchy distributions (such as green-backed eremomela, *Eremomela pusilla*, and scarlet-tufted malachite sunbird, *Nectarinia johnstoni*) or non-forest species at the northern or eastern edge of their ranges (e.g. Tabora cisticola, *Cisticola fulvicapilla*, and black-rumped waxbill, *Estrilda troglodytes*).

Very few species are entirely confined to zones A or C (one and four, respectively; those in zone C include the characteristic Jubaland weaver, *Ploceus dichrocephalus* and white-winged dove, *Streptopelia reichenowi*; Appendix 1). No species are confined to zone B or transitional zone G. Around ten species are confined to zone E but not listed as 'characteristic'. These include several birds reaching the northern limit of their range in the Chyulu and/or Taita Hills (e.g. stripe-cheeked greenbul, *Andropadus milanjensis*), Mt Kasigau (yellow-streaked greenbul, *Phyllastrephus flavostriatus*) or Taveta (Kretschmer's longbill, *Macrosphenus kretschmeri*, probably now extinct here (D A Turner, personal communication)). Other species, such as grey-olive greenbul, *Phyllastrephus cerviniventris*, are very local within the zone. One species, Taveta golden weaver, *Ploceus castaneiceps*, is a regional endemic confined to border areas of southeastern Kenya and northeastern Tanzania.

Zone F includes eight species mainly confined to East African coastal forests that, because of their local distribution in Kenya, are not considered 'characteristic'. These include the Kenyan endemic Clarke's weaver, *Ploceus golandi*, the near-endemic Sokoke Scops owl, *Otus ireneae*, and more widely distributed species such as greenheaded oriole, *Oriolus chlorocephalus*. All these species are of considerable conservation importance because of their restricted and fragmented habitat.

Patterns of species richness and its correlates

Western (zone D) and southern (zone E) Kenya support the highest number of bird species in Kenya, peaking at over 500 species just southeast of Nairobi (Figs. 3 and 4). For most of the arid north and east, species richness does not exceed 200 (Figs. 3 and 4). The overall pattern reflects the greater biogeographic and environmental complexity of southwestern and west-central Kenya compared to the north and east. Particular local peaks (Fig. 4) are in areas with strong topographic and habitat gradients (around Kitale, Nakuru and Nairobi, C, and around the Taita Hills, B), in areas that have been intensively sampled in the recent past (around Nakuru and Nairobi, C, and around Mt. Ngulia, B), and where a large aquatic system interrupts a stretch of arid land (Lake Turkana, A). Diversity for African mammals was also found to increase along lake shores (and rivers) in arid regions (Turpie and Crowe, 1994).

Linear models consistently produced the strongest correlation between species richness and environmental predictor variables. Biotope diversity accounted for 79% of the observed variation in Kenyan bird species richness (Table 2). Altitudinal range and rainfall were also significantly, independently correlated with species richness, but accounted for just a further 3% of the observed variation. These variables were also shown to be important in determining the diversity of birds on an Afrotropical scale (Crowe and Crowe, 1982).

Unravelling the effect of sampling effort is a difficult task. Whereas sampling effort undoubtedly has affected observed QDS species richness values, many QDSs have been sampled more intensively precisely because they are known for their diverse avifaunas, and so have attracted birdwatchers (Lewis and Pomeroy, 1989: 9). It seems likely that sampling effort will affect patterns more at a local scale, rather than between avifaunal zones.

With the full set of QDSs in the regression analysis, 37 squares were identified as having higher than predicted species richness values (at least one standard deviation greater than expected) (Fig. 3). Rerunning this analysis excluding 'badly sampled' QDSs (i.e. those with bird species richness values of less than 100, see Methods), 23 (96%) of the 24 unexpectedly rich QDSs identified were congruent with those QDSs identified in the analysis using all

Table 2. Results of correlation and stepwise multiple regression analyses of Kenyan bird species richness (SPEC) against measures of altitudinal range (ALTR), rainfall (RAIN) and biotope diversity (BIOTOP). All correlations listed below are significant at the $p < 0.01$ level. Sample size = 210.

	SPEC	ALTR	RAIN	
ALTR	0.51			
RAIN	0.57	0.41		
BIOTOP	0.79	0.41	0.57	
Summary table				
Step no.	Variable entered	Multiple R	r^2	Change in r^2
1	BIOTOP	0.79	0.62	0.62
2	ALTR	0.81	0.66	0.04
3	RAIN	0.82	0.67	0.01

QDSs. These patterns thus appear to be at least reasonably robust – although most of the poorly-sampled QDSs are in arid areas with little biotope diversity.

As with the overall patterns of species richness, there seem to be a number of reasons why the 37 QDSs contain so many species, several of which may be acting in any one case. These reasons are listed below.

(1) The presence of sizeable protected areas, which occur in at least 14 of these QDSs, or the buffer zones around them. There is a large cluster of QDSs in southeastern Kenya, which contains the Tsavo National Park complex, including Tsavo East and Tsavo West, the Taita Hills, the Taita Game Sanctuary and Galana Ranch, namely QDSs 179, 180, 189, 191, 196, 197, 201, 202 and 203. Other QDSs that may fall into this category include 147, 160 and 161 (Masai Mara Game Reserve and buffer areas); QDS 170 (Tana River Primate National Reserve); QDS 123 (Aberdare National Park); QDS 100 (Samburu, Shaba and Buffalo Springs National Reserves); and QDS 114 (Meru National Park complex). QDSs 177 and 186, adjacent to Amboseli National Park, also show up as richer than expected, though Amboseli itself does not.

Protected areas may have acted in two ways to increase recorded species richness. Protection of habitat may have reduced extinction rates over the last two decades (e.g. Tana River Primate National Reserve). In addition, visitors' attention may have been directed to these sites rather than to surrounding, less accessible areas (e.g. the Samburu-Buffalo Springs-Shaba area).

(2) Uneven sampling effort has probably played at least some part in boosting the species totals of many of these QDSs. Cases where this may have been particularly influential include QDS 150, which contains the capital city, Nairobi; QDS 163, the Kajiado area just south of Nairobi; QDS 97, around Lake Baringo, one of the most accessible sites where species characteristic of northern Kenya occur; and QDSs 349 and 333, north and south of the main coastal city of Mombasa. A cluster of squares around Lake Turkana (4, 9, 17, 18, 33) may also have received more attention than adjacent squares, as may have QDSs in the arid north such as 6 (Lokichokio) and 79 (Wajir), which contain administrative centres and are thus relatively well-visited.

(3) Historical biogeographical reasons. Some squares straddle the boundary between avifaunal zones; for instance, QDSs 82 (Kapenguria), 97 (Lake Baringo) and 111 (Laikipia Plateau) contain species characteristic of both the dry northwest and the central highlands and Rift Valley. QDSs 107 and 108 include the Kakamega and Nandi Forests, which are the easternmost outliers of the forests of central Africa and have Guineo-Congolian biogeographical affinities. As well as characteristic highland forest species, they host a large suite of Guineo-Congolian birds that are absent from other QDSs in Kenya (Fanshawe and Bennun, 1991).

(4) Factors so far unexplained. There is at present no obvious explanation for the relatively high species richness of some squares, for example QDS 118 (with Rusinga Island and the north Winam Gulf, including swamps on the north shores of Lake Victoria); QDS 68 (north of Mt Elgon); and QDS 138 (upper Tana River and dams). This suggests that there may be important additional factors determining species richness that the present analysis has not been able to take into account.

Priority-area analysis

Species richness, taxonomic dispersion and range-restrictedness generally identified the same QDSs as priority areas for the conservation of birds and ranked them similarly (Fig. 5). However, the criterion of range-restrictedness selected the fewest QDSs (24) that together include all bird species in Kenya (Fig. 6c), therefore presenting the most efficient way of representing all the bird species in the database (see also Kershaw *et al.*, 1994). It has been argued that restricted-range species constitute the greatest priority for conservation (ICBP, 1992). Although a species which has a restricted range may be locally abundant (Begon *et al.*, 1990) if the habitat on which it is dependent is threatened, it runs a far greater risk than a species which also occurs in other, less threatened habitats. This analysis is at a national level, however, and birds that have restricted ranges in Kenya may not necessarily be restricted in Africa or the world. Thus, although the discussion below is based on range-restrictedness, global distributions of species are taken into account.

Iterative priority area analyses highlight two regions of conservation concern for Kenyan birds. First, the central and western highlands of Kenya (zone D) support a high bird species richness. Over half of the priority QDSs identified by all three measures occur in this region (Fig. 5). There is good congruence between priority areas and the Endemic

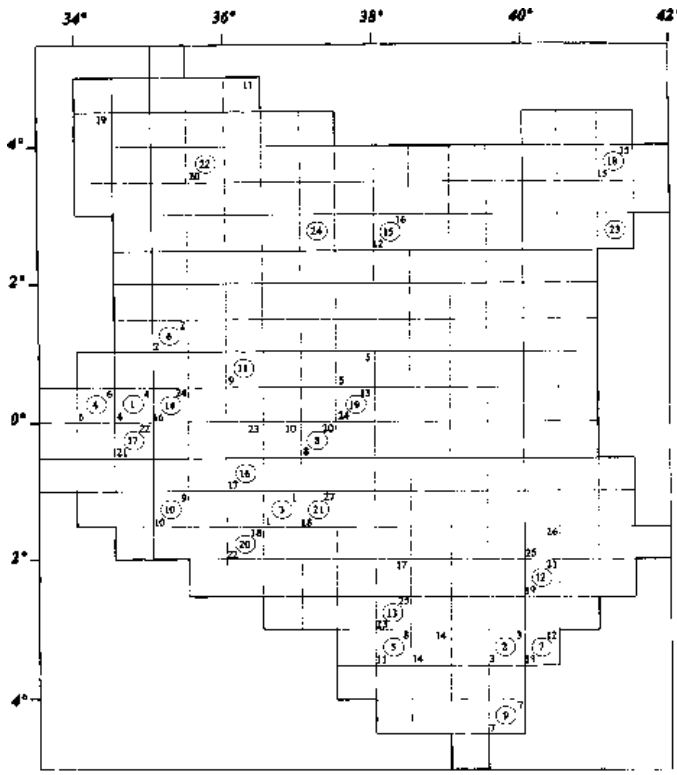

Figure 5. Locality and rank of quarter-degree squares identified by species richness (lower left-hand corner), taxonomic dispersion (upper right-hand corner) and range-restrictedness (encircled), during iterative priority area analysis.

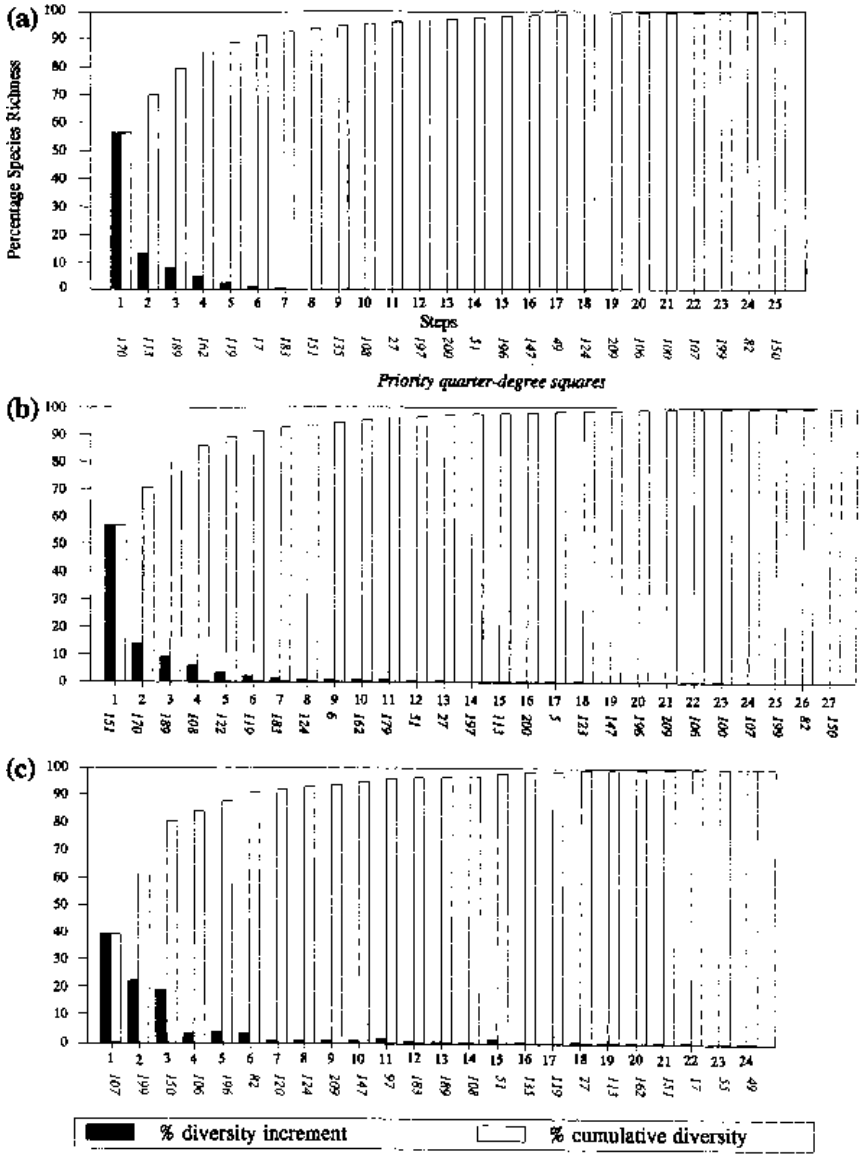

Figure 6. Percentage increment and cumulative diversity, as defined by (a) species richness, (b) taxonomic dispersion, and (c) range-restrictedness added with each step during priority analyses.

Bird Areas (EBAs) identified in this region (ICBP, 1992). Nine of the 13 priority areas recognized in central and western Kenya correspond with EBAs (seven with the Kenyan Mountains EBA and two with the Serengeti EBA).

Most of Kenya's agriculture and populace are also concentrated in this region, and most of the existing protected areas here are small. The small size of these protected areas, their scattered location, their progressive isolation through the loss of connecting habitat, and increasing edge to area ratios, are cause for concern. In need of particular attention

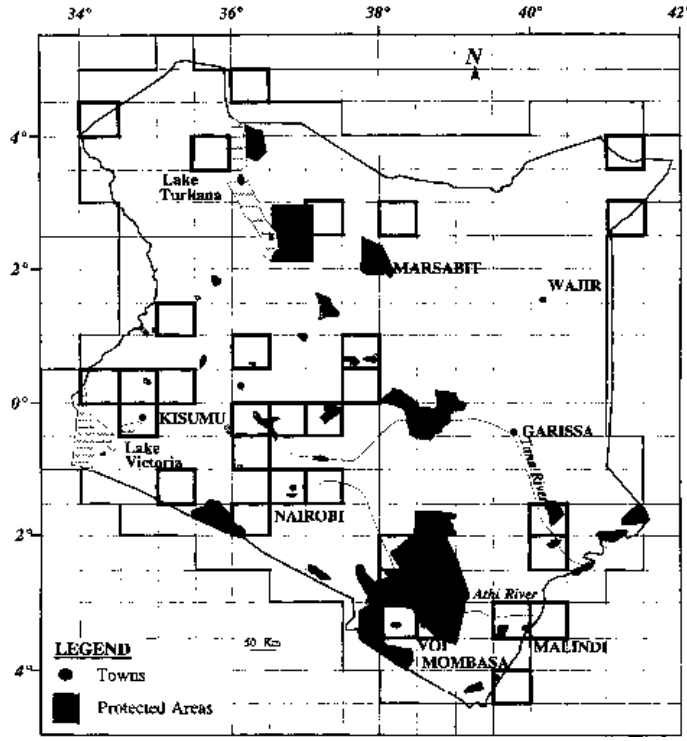

Figure 7. Priority quarter-degree squares identified by species richness, taxonomic dispersion and range-restrictedness, in relation to Kenya's protected areas.

are QDSs 82 (Saiwa Swamp and Kapenguria) and 108 (east of Kakamega), both of which have unusally high species richness values (see above) and currently have little or no protected status.

A second region for conservation concern is the arid northern belt of Kenya. Although this area is relatively poorly sampled (Lewis and Pomeroy, 1987: Fig. 3), five priority QDSs are identified here based on their complement of range-restricted species. Only one of these, QDS 63, contains a protected area (Marsabit National Reserve, which is mainly highland forest and scrub, and may contain few of the species of concern here). This dry northern belt has a number of endemic arid-zone specialists, yet no EBAs are identified in this region, probably because arid-zone species require relatively larger ranges to meet their requirements, and so do not often qualify for the 50 000 km^2 cut-off criterion of the EBA approach (Crowe and Brooke, 1993).

Northern Kenya is characterized by *Acacia* woodland, bushland, subdesert and desert biotopes. Accordingly, its avifauna represents an arid-species suite not present in central and southern Kenya. This is due in part to the fact that the extremes of the arid corridor (in Somalia and southern Africa) are centres of avian endemism (e.g. Crowe and Crowe, 1982; Dean and Hockey, 1989). These arid-zone species, such as white-winged dove, *Streptopelia reichenowi*, and Jubaland weaver, *Ploceus dichrocephalus*, are confined to a small area of southeastern Ethiopia, southwestern Somalia and northeastern Kenya, and so their conservation in Kenya cannot be ignored.

The conservation status of northern Kenya is poor, with only five (11%) of Kenya's 46 protected areas falling in this region. Although the human population density is low and there may appear to be little threat to the biological resources of this region, arid environments are more easily degraded than are more moist environments. In addition, once damaged, arid environments recover more slowly than moister ones (Mainguet, 1991).

Appendix 2 lists the 22 bird species which, according to definitions used in this study, probably do not occur in any sizeable protected areas. Because of the assumptions we have made in defining protected QDSs, the true list is almost certainly longer. However, this list does allow a first estimation of the minimum area required in addition to the existing system of protected areas such that all Kenyan bird species are found in at least one protected QDS. This list could be substantially refined if bird lists were available for all existing protected areas in Kenya.

Thirteen of the 22 'unconserved' species in Appendix 2 are widespread throughout Africa (mainly in the northern tropics) and so do not constitute conservation priorities in Kenya. Seven species are characteristic of the Lake Victoria basin, especially in papyrus swamps. Two others are national or regional endemics confined to the dry north and northeast.

Once 'protected QDSs', and the species which they contain, have been excluded from the database, eight additional QDSs are needed to represent all bird species in Kenya, including the widespread species in Appendix 2. Focusing on the species of conservation concern alone, QDS 106 (northeast of Kisumu, Fig. 1) adds the greatest number of range-restricted species to the complement of 'protected species', namely thirteen. Most of these are from the suite of species confined to papyrus swamps (Appendix 2), a severely threatened habitat in Kenya (and indeed East Africa) (Fanshawe and Bennun, 1991). One of these, papyrus yellow warbler, *Chloropeta gracilirostris*, is globally threatened (Fanshawe and Bennun, 1991). Considering the number of papyrus birds that are not presently conserved, this QDS deserves special conservation attention.

William's bush lark, *Mirafra williamsi*, is endemic to northern Kenya with two disjunct populations, one north of Marsabit (QDS 51), the other from Isiolo (QDS 113) to Garba Tula (QDS 101) (Britton, 1980; Lewis and Pomeroy, 1989). Although QDS 113 is defined in this study as a 'protected QDS' due to the presence of the forest reserves on the slopes of Mount Kenya surrounding Meru (which resulted in William's bush lark not being listed in Appendix 2), these forest reserves do not contain the habitat required by William's bush lark, and occur at too high an altitude. Old records (pre-1970; Lewis and Pomeroy, 1989) occur in QDSs 63 (Marsabit Nature Reserve) and 100 (Samburu, Buffalo Springs and Shimba Game Reserves). However, as William's bush lark is a national endemic, its conservation is important, and these records need to be confirmed in order to ensure protection of this species. It is recommended that both populations should be conserved in order to preserve genetic variation. Jubaland weaver, *Ploceus dichrocephalus*, and white-winged dove, *Streptopelia reichenowi*, are both regional endemics, being confined to southern Somalia, southeastern Ethiopia and northeastern Kenya (Lewis and Pomeroy, 1989). In Kenya, these two species both occur in only three QDSs (13, 27 and 28; Fig. 1). Further investigation is needed to determine the best locality for conservation of these species. The chestnut-banded sandplover, *Charadrius pallidus*, occurs locally on the shores of alkaline lakes in both southern and eastern Africa. However, the populations of eastern Africa constitute a separate subspecies, *C. p. venestus*. In addition, this species was identified as warranting conservation by Fanshawe and Bennun (1991). Lastly, the only

breeding colony of white-collared pratincole *Glareola nuchalis* found in Kenya (QDS 183; Fig. 1) is not protected. Although this species does not appear to be threatened at a continental level, it has a localized, highly specialised distribution throughout its range. As there are few breeding colonies in eastern Africa, the one in QDS 183 is of regional interest.

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Appendix 1. Bird species which are characteristic of the avifaunal zones (A–G: Fig. 2), i.e. which have distributional ranges that largely fall within and coincide with the borders of these zones.

Zones

A

Fox kestrel *Falco alopex*
Senegal thicknee *Burhinus sengalensis*
Abyssinian roller *Coracias abyssinica*
Jackson's hornbill *Tockus jacksoni*
White-billed buffalo weaver *Bubalornis albirostris*

B

William's bush lark *Mirafra williamsi*
Masked lark *Calandrella personata*

C

White-winged dove *Streptopelia reichenowi*
Collared lark *Mirafra collaris*
Jubaland weaver *Ploceus dichrocephalus*

D

Great crested grebe *Podiceps cristatus*
Rufous sparrowhawk *Accipter rufiventris*
Jackson's francolin *Francolinus jacksoni*
Moorland francolin *Francolinus psilolaemus*
Crested guineafowl *Guttera edouardi*
Chestnut-tailed pygmy crake *Sarothrura affinis*
Bronze-naped pigeon *Columba delegorguei*
Red-fronted parrot *Poicephalus gulielmi*
Blue-headed coucal *Centropus monachus*
Montane nightjar *Caprimulgus poliocephalus*
Bar-tailed trogon *Apaloderma vittatum*
White-headed wood hoopoe *Phoeniculus bollei*
Red-throated wryneck *Jynx ruficollis*
Fine-banded woodpecker *Campethera tullbergi*
Angola swallow *Hirundo angolensis*
Montane oriole *Oriolus percivali*
Black-lored babbler *Turdiodes melanops*
Purple-throated cuckoo shrike *Campephaga quiscalina*
Mountain greenbul *Andropadus tephrolaemus*
Chiffchaff *Phylloscopus collybita*
Wing-snapping cisticola *Cisticola ayresii*
Stout cisticola *Cisticola robusta*
Red-faced cisticola *Cisticola erythrops*
Hunter's cisticola *Cisticola hunteri*
Tinkling cisticola *Cisticola tinniens*
White-chinned prinia *Prinia leucopogon*
Black-throated apalis *Apalis jacksoni*
Chestnut-throated apalis *Apalis porphyrolaema*
Black-collared apalis *Apalis pulchra*
Grey-capped warbler *Eminia lepida*
White-browed crombec *Sylvietta leucophrys*

Appendix 1. (*continued*)

Brown parisoma *Parisoma lugens*
Silverbird *Empidornis semipartitus*
Wattle-eye *Platysteira cyanea*
Rosy-breasted longclaw *Macronyx ameliae*
Sharpe's longclaw *Macronyx sharpei*
Doherty's bush shrike *Malaconotus dohertyi*
Northern double-collared sunbird *Nectarinia preussi*
Tacazze sunbird *Nectarinia tacazze*
Green-headed sunbird *Nectarinia verticalis*
Jackson's widowbird *Euplectes jacksoni*
Grey-headed negrofinch *Nigrita canicapilla*
Abysinnian crimson-wing *Crytpospiza salvadorii*

E
Violet-crested turaco *Tauraco porphyreolophus*
Short-tailed lark *Galerida fremantlii*
Hinde's pied babbler *Turdoides hindei*
Irania *Irania gutturalis*

E + G from the river Tana southwards
Retz's helmet shrike *Prionops retzii*
Smaller black-bellied sunbird *Nectarinia nectarinioides*
Golden palm weaver *Ploceus bojeri*

F
Southern banded snake eagle *Circaetus fasciolatus*
Crab plover *Dromas ardeola*
Madagascar pratincole *Glareola ocularis*
Sooty gull *Larus hemprichii*
Crested tern *Sterna bergii*
Roseate tern *Sterna dougallii*
White-cheeked tern *Sterna repressa*
Bridled tern *Sterna anaethetus*
Sooty tern *Sterna fuscata*
Fischer's turaco *Tauraco fischeri*
Mangrove kingfisher *Halcyon senegaloides*
Black-collared barbet *Lybius torquatus*
Green barbet *Buccanodon olivaceum*
Green tinkerbird *Pogoniulus simplex*
Fischer's greenbul *Phyllastrephus fischeri*
Tiny greenbul *Phyllastrephus debilis*
East coast akalat *Sheppardia gunningi*
Red-tailed ant thrush *Neocossyphus rufus*
Spotted ground thrush *Turdus fischeri*
Forest batis *Batis mixta*
East coast batis *Batis soror*
Little yellow flycatcher *Erythrocercus holochlorus*
Sokoke pipit *Anthus sokokensis*
Malindi pipit *Anthus melindae*
Four-coloured bush shrike *Malaconotus quadricolor*

Appendix 1. (*continued*)

Chestnut-fronted helmet shrike *Prionops scopiforns*
Plain-backed sunbird *Anthreptes reichenowi*
Mouse-coloured sunbird *Nectarinia veroxii*

Appendix 2. Bird species which do not occur within any of the 'protected' quarter-degree squares, with degree of threat (identified according to Fanshawe and Bennun, 1991) and Red Data Book status (Collar *et al.*, 1994) indicated. Regional endemics* (including papyrus endemics[p]), some of which extend to eastern Zaire) are noted, as are those species which are wide spread throughout Africa[w].

Species name	Degree of threat (1991)	Red Book status (1994)
Blue-breasted bee-eater *Merops variegatus*[w]		
White-winged dove *Streptopelia reichenowi*[*]		near-threatened
Bruce's green- pigeon *Treron waalia*[w]		
Four-banded sandgrouse *Pterocles quadricinctus*[w]		
Chestnut-banded sandplover *Charadrius pallidus*	candidate	
Brown-chested wattled plover *Vanellus superciliosus*[w]		
White collared pratincole *Glareola nuchalis*[w]		
Piapiac *Ptilostomus afer*[w]		
Red-shouldered cuckoo shrike *Campephaga phoenicea*[w]		
Papyrus gonolek *Laniarius mufumbiri*[p]		near-threatened
Red-breasted wheatear *Oenanthe bottae*[w]		
Carruthers' cisticola *Cisticola carruthersi*[p]		
White-winged warbler *Bradypterus carpalis*[p]		
Papyrus yellow warbler *Chloropeta gracilirostris*[p*]	globally threatened	vulnerable
Slender-billed weaver *Ploceus pelzelni*[w]		
Northern brown-throated weaver *Ploceus castanops*[p*]		
Jubaland weaver *Ploceus dichrocephalus*[*]		
Orange-winged pytilia *Pytilia afra*[w]		
Brown twinspot *Clytospiza monteiri*[w]		
Bar-breasted firefinch *Lagonosticta rufopicta*[w]		
Black-rumped waxbill *Estrilda troglodytes*[w]		
Papyrus canary *Serinus koliensis*[p*]		