BIOLOGICAL CONSERVATION 127 (2006) 383–401

available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/biocon

Factoring species, non-species values and threats into biodiversity prioritisation across the ecoregions of Africa and its islands

Neil D. Burgess[a,b,*], *Jennifer D'Amico Hales*[a], *Taylor H. Ricketts*[a], *Eric Dinerstein*[a]

[a]*WWF-US, Conservation Science Program, 1250 24th Street NW, Washington DC 20037-1193, USA*
[b]*Conservation Biology Group, Zoology Department, Cambridge University, CB2 3EJ, UK*

ARTICLE INFO

Article history:
Received 3 September 2004
Available online 11 October 2005

Keywords:
Africa
Biodiversity
Species
Non-species biological values
Threat

ABSTRACT

Biodiversity in Africa, Madagascar and smaller surrounding islands is both globally extraordinary and increasingly threatened. However, to date no analyses have effectively integrated species values (e.g., richness, endemism) 'non-species' values (e.g., migrations, intact assemblages), and threats into a single assessment of conservation priorities. We present such an analysis for the 119 ecoregions of Africa, Madagascar and smaller islands. Biodiversity is not evenly distributed across Africa and patterns vary somewhat among taxonomic groups. Analyses of most vertebrates (i.e., birds, mammals, amphibians) tend to identify one set of priority ecoregions, while plants, reptiles, and invertebrates highlight additional areas. 'Non-species' biological values are not correlated with species measures and thus indicate another set of ecoregions. Combining species and non-species values is therefore crucial for assembling a comprehensive portfolio of conservation priorities across Africa. Threats to biodiversity are also unevenly distributed across Africa. We calculate a synthetic threat index using remaining habitat, habitat block size, degree of habitat fragmentation, coverage within protected areas, human population density, and the extinction risk of species. This threat index is positively correlated with all three measures of biological value (i.e., richness, endemism, non-species values), indicating that threats tend to be focused on the region's most important areas for biodiversity. Integrating biological values with threats allows identification of two distinct sets of ecoregion priority. First, highly imperilled ecoregions with many narrow endemic species that require focused actions to prevent the loss of further habitat leading to the extinction of narrowly distributed endemics. Second, less threatened ecoregions that require maintenance of large and well-connected habitats that will support large-scale habitat processes and associated area-demanding species. By bringing these data together we can be much more confident that our set of conservation recommendations serves the needs of biodiversity across Africa, and that the contribution of different agencies to achieving African conservation can be firmly measured against these priorities.

1. Introduction

Many elements of biodiversity (species, habitats, ecological processes) are in decline as the human domination of the natural world continues to gain pace (Groombridge and Jenkins, 2000; Hilton-Taylor, 2000; GEO3, 2002). Some scientists predict a major extinction event in coming years as elements of biodiversity are rendered non-viable (Pimm et al., 2002).

* *Corresponding author*: Tel.: +1223 440155.
E-mail address: neilburgess01@hotmail.com (N.D. Burgess).
0006-3207/$ - see front matter
doi:10.1016/j.biocon.2005.08.018

One of the responses by conservationists has been to prioritise geographical regions of the world for conservation investment to maximise the amount of biodiversity persisting into the future. Some of these schemes are global in scope (ICBP, 1992; Stattersfield et al., 1998; Olson and Dinerstein, 1998, 2002; Mittermeier et al., 1998, 2004; Myers et al., 2000). Others have focused in more detail at continental scales – such as Africa (Brooks et al., 2001; Lovett et al., 2000; La Ferla et al., 2002; Burgess et al., 2002, 2004).

These schemes have proven of great value to conservationists in prioritising areas for investment and conservation focus. However, all schemes have limitations defined by the methodology they have adopted. First, most use species distribution data from a single taxon, such as birds (Stattersfield et al., 1998) or plants (Mittermeier et al., 1998; Myers et al., 2000). Although high congruence between biodiversity priorities for birds, mammals, and amphibians are observed (e.g., Moore et al., 2003), lesser congruence often exists between vertebrates and plants or invertebrates (e.g., Ricketts et al., 1999a). In Africa, for example, plant endemism peaks in the Mediterranean habitats of the Fynbos and Succulent Karoo of South Africa, and again in North Africa (Mittermeier et al., 1999), but the same areas are of fairly low importance for endemic birds (Stattersfield et al., 1998). Basing prioritisation on a single taxon group might therefore leave out areas of importance for other biological groups.

Second, species-based conservation prioritisation schemes fail to recognize other important elements of biological diversity, such as areas of intact species assemblages, species migrations, ecological or evolutionary phenomena, and important ecological processes (Mace et al., 2000). Here, we define these elements as "non-species values". Recent analyses have prioritised elements of these non-species values, identifying areas of intact habitat (Sanderson et al., 2002; Mittermeier et al., 2002), or important concentration and migration bottlenecks for birds (Fishpool and Evans, 2001). However, these approaches are not inclusive in their coverage of non-species biological values – for example they overlook migratory congregations of mammals and places where ancient species persist – two factors of particular relevance to African biodiversity; they also fail to locate those areas where speciation is still occurring.

Third, only a few prioritisation schemes systematically incorporate the relative degree of threat. For example, hotspots (Myers, 1988, 1990; Myers et al., 2000) by definition have lost at least 70% of their original habitat, whereas high biodiversity Tropical Wilderness Areas (Mittermeier et al., 2002) retain at least 70% of their habitat. Threat has not been used as a discriminator within other conservation prioritisation schemes, for example in the identification of Endemic Bird Areas (Stattersfield et al., 1998) or Centres of Plant Diversity (WWF and IUCN, 1994), although BirdLife used threat scores to rank EBAs once they were identified using avian values.

In this paper we present the results of an ongoing attempt to integrate species distributions, non-species values, and threats systematically into priority setting. Here our focus is on Africa and its islands, but the paper represents part of a global project to develop quantified biodiversity priorities for the terrestrial ecoregions of the world (Dinerstein et al., 1995; Olson and Dinerstein, 1998, 2002; Ricketts et al., 1999a,b; Olson et al., 2001; Wikramanayake et al., 2002; Burgess et al., 2004).

2. Methods

2.1. Analytical units

The analytical units used for analysis are the 119 terrestrial ecoregions mapped across Africa and its islands (Olson et al., 2001; Burgess et al., 2004; www.worldwildlife.org/ecoregions). Simply put, ecoregions are relatively large areas of land that share the majority of their species and ecological processes (Olson and Dinerstein, 1998). The African ecoregions were based upon the floral divisions of White (1983), sub-divided and refined according to expert opinion and patterns of plant and animal biodiversity (see Burgess et al., 2004 for details). African ecoregions are nested within 9 habitat-based biomes, out of the 13 terrestrial biomes recognised by WWF globally (Olson et al., 2001).

2.2. Representation

Our approach to setting biological priorities among ecoregions is based on the concept of representation, aiming to ensure that every biome has at least one priority ecoregion. We ensure representation by analyzing the biological values of every biome separately. This ensures, for example, that biologically important ecoregions from the savanna woodland biome or the flooded wetland biome can be ranked as highly as the important tropical moist forests, which otherwise tend to dominate prioritised lists due to their intrinsically higher rates of species richness and endemism. This approach has been utilised in previous ecoregional assessments funded by WWF and the use of a similar methodology allows comparisons with these other studies (Dinerstein et al., 1995; Ricketts et al., 1999a; Wikramanayake et al., 2002).

This approach differs to those that have applied a complementarity analytical methodology (see Margules and Pressey, 2000) to setting priorities among the vertebrate and plant assemblages at the scale of one-degree grid cells across Sub-Saharan Africa (e.g., Brooks et al., 2001; Burgess et al., 2002; Burgess et al., 2005; Lovett et al., 2000; Küper et al., 2004). It also differs from approaches that seek to utilise specialist software that are able to integrate a wide range of biological and non-biological values, such as C-Plan that has been utilised for conservation planning in Australia and South Africa (Cowling et al., 2003). However, although our methodology is not formally one of complementarity, a representation approach driven by endemism (see below) will perform a similar task of forcing the selection of areas that are different in their species assemblage.

2.3. Biological distinctiveness index

We construct a biological distinctiveness index (BDI) by combining species and non-species biological data. Endemism scores are weighted much more heavily than either species richness or non-species values, with these last two attributes being used to fine tune the selection of Globally Outstanding ecoregions (Table 1). Other scoring approaches (for example through scoring all three components equally) would generate a different BDI.

Species data. Species lists per ecoregion were compiled for birds, mammals, reptiles and amphibians. Data come from the literature, unpublished species distribution databases (especially those held at the Zoological Museum in the University of Copenhagen, Denmark), and by working with expert taxonomists (Burgess et al., 2004). Compiled data are held in the Ecoregions database of WWF-USA in Washington DC, USA. Summary data tables are available from the corresponding author upon request.

Species endemism. Species endemism was quantified for each taxon group for every ecoregion. For vertebrates a species was regarded as endemic to an ecoregion when it was either wholly confined to that ecoregion (strict endemic) or when at least 75% of its range occurs there (near-endemic). Plant and invertebrate endemism were derived from expert opinion provided by experts at a workshop in Cape Town in 1998 (hereafter the 'expert workshop').

Species richness. Species richness was firstly assessed as the number of vertebrates in each ecoregion. Plant species richness data were provided by the BIOMAPS project of the University of Bonn, Germany (Mutke et al., 2001; Kier et al., 2005), and invertebrate richness data were provided by experts at the 1998 expert workshop.

However, the 119 African ecoregions vary widely in area, a factor that is often strongly correlated with species richness (Rosenzweig, 1995). Across the ecoregions of Africa species richness scores are highly correlated with ecoregion area, whereas endemism scores were not correlated with area. To address this potential bias in our results, we corrected raw species richness scores for the effects of area using the equation:

$$SA = S/A^z,$$

where z is the species–area exponent, S is the number of species, A is area (km^2) and SA is the number of species corrected for area. We set z to 0.25 on mainland ecoregions and to 0.2 for island ecoregions as these values correspond to empirical results from a wide variety of taxa and ecosystems (Rosenzweig, 1995). In reality the shape of the species–area curve will vary between biomes and to a lesser degree within biomes. A more precise result for of correcting species numbers for area would be achieved if adequate data were available to calculate a more differentiated set of z values. Such data, derived from a series of studies within individual biomes, were not available and thus a general z value was used.

Non-species biological data. We assessed each of the 119 ecoregions against a number of non-species biological attributes. These attributes have been selected following expert workshops and are also the same as applied on other regional analyses books developed by WWF. For each attribute (see below) we awarded scores to every ecoregion of 1 for globally significant, 0.5 for regionally significant and 0 for insignificant.

1. Evolutionary or ecological phenomena
   (a) *Extraordinary adaptive radiation of species*. This attribute identifies those ecoregions that contain extensive radiations of newly evolved (and evolving) species.
   (b) *Intact large vertebrate assemblages*. This attribute determines if the ecoregion contains intact assemblages of large carnivores, herbivores, and frugivores and other feeding guilds.
   (c) *Migration or congregations of large vertebrates*. This attribute identifies those ecoregions that are important for their large mammal migrations or that support enormous aggregations (millions) of migratory birds.
2. Global rarity of habitat types. This attribute seeks to assess if an ecoregion provides one of the few opportunities globally to conserve a particular habitat type as identified against the list of globally rare habitats presented in Appendix A.
3. Higher taxonomic uniqueness. This attribute aimed to identify those ecoregions that contain endemic families of plants or vertebrates, or where more than 30% of the genera are believed to be endemic (see Appendix A).
4. Ecoregions harboring examples of large relatively intact ecosystems. This attribute identified those ecoregions identified by Conservation International as wilderness areas (Mittermeier et al., 2002), modified to fit within our ecoregional framework.

Assembling the 'biological distinctiveness index'. To derive this index, we combined the species and non-species biological attributes of every ecoregion.

First, endemism (strict and near-endemic species – see above) scores for each taxon were normalized to a range of 0–100 within biomes, allowing a relative comparison among taxa. The expert-derived classes of plant and invertebrate endemism were also converted to numerical scores within biomes ('very high' translated to a score of 100, 'high' to a score of 67, 'medium' to a score of 33, and 'low' to a score of 1). The endemism scores for all taxa were totalled and ecoregions assigned to quartiles within each biome. Ecoregions in the top quartile within each biome were assigned as 'globally outstanding', then for the second quartile to 'regionally outstanding', for the third quartile to 'bioregionally outstanding', and to the fourth quartile to 'locally important' (Table 1).

Table 1 – Summary criteria for assigning ecoregions within biomes to different priority levels

Category	Endemism	Species richness	Non-species values
Globally outstanding	Top quartile for endemism within biome	Top 10% for species richness within biome	Score of more than 1.5
Regionally outstanding	Second quartile for endemism within biome		
Bioregionally outstanding	Third quartile for endemism within biome		
Locally important	Fourth quartile for endemism within biome		

Second, these endemism-based rankings within each biome were adjusted using area-corrected species richness (Table 1). Only the richest 10% of ecoregions within each biome were then elevated to globally outstanding, regardless of their endemism ranking. This procedure elevated seven ecoregions.

Finally, the endemism-based rankings were adjusted using non-species biological scores for each ecoregion. Those ecoregions scoring above 1.5 for non-species biological values (an arbitrary choice) were elevated to globally outstanding in our biological distinctiveness index, regardless of their values for species richness or endemism (Table 1). This procedure elevated five ecoregions.

2.4. Conservation status index

We constructed a conservation status index (CSI) for all the ecoregions using the following variables. Only for the habitat blocks analysis was this assessment related to attributes of the biome (see Appendix B).

Habitat loss. Habitat loss per ecoregion was estimated as the percentage of converted habitat derived from two sources of data. The first was the University of Maryland (UMD) Global Landcover data (Hansen and Reed, 2000; Hansen et al., 2000; which was derived from AVHRR imagery from 1992). The classes classified as "urban" and "cropland" were used to define areas of converted landcover. The second was population density, derived from the LandScan Global Population 1998 database, which depicts population density and total numbers of people, by 1 km gridcells (Dobson et al., 2000). A population density of ⩾10 persons per km^2 was used to determine where population pressures start to negatively impact the environment. Because the Landscan data modelled populations along all roads, including Protected Areas, we removed the population information within all Protected Areas of IUCN categories I–IV, because population pressure within Protected Areas should be negligible. We combined the Global Landcover data and the Landscan Global Population data into a single GIS layer to assess habitat loss – as in combination this combined data provided the best 'fit' against our field knowledge of the situation on the ground in different parts of Africa. The percent estimations of habitat loss were then scaled so that they provided a maximum of 40 points to the Conservation Status Index (Table 2).

Remaining habitat blocks. Habitat blocks were identified within biomes using the following approach. The 'intact' habitat identified in the habitat loss analysis was buffered using roads from the *Digital Chart of the World* combined with updated roads for Central Africa from the CARPE programme (http://carpe.umd.edu/). A conservative buffer distance of 15 km was chosen to reflect areas beyond which resource exploitation drops significantly. Information was not available to tailor buffer distances to each biome, although in forests, 80 % deforestation takes place within two km of a road, while in open habitats intense resource degradation can extend one days walk from a road (ca. 40 km). Areas of roads and their associated buffers were removed within Arc View to leave remaining intact blocks of habitat. Size thresholds for different habitat blocks were set separately for each biome, according to the expertise of staff at the Conservation Science Programme at WWF_USA. This attribute contributed a maximum of 25 points to our index (Appendix B).

Degree of fragmentation. Fragmentation was calculated as the edge to area ratio of the remaining habitat blocks within each biome identified using the land cover map outlined above. This attribute contributed a maximum of 20 points to our index (Table 3).

Degree of protection. We calculated the percentage protection of each ecoregion using Version 5.0 of the Protected Areas databases from UNEP-World Conservation Monitoring Centre (UNEP-WCMC, 2002). Only Protected Areas classified under IUCN categories I–IV (IUCN, 1998) were considered, leaving out some forms of reserves (local and private parks, and government Forest Reserves). We have no information on how well managed these various reserves are and have to accept that they all have equal value for biodiversity conservation, which is unlikely to be the case. The percentage protection was assessed for every ecoregion and contributed a maximum of 15 points to our index (Table 4).

Future threat. Future threat was measured in terms of potential future habitat loss and the potential for species extinction. Potential future habitat loss was calculated using human population density projected to the year 2025 (WRI unpublished), based on data in CIESIN (2000) and UNDP (1999). A threshold of 10 people per square kilometer was assumed to

Table 2 – Points assigned to the minimum amount of habitat loss in each ecoregion

Percent of habitat loss	Point value contribution to conservation status index
⩾80%	40
60–79%	30
40–59%	20
20–39%	10
0–19%	0

Table 3 – Points assigned to the degree of fragmentation in each ecoregion

Edge:area ratio	Points
>1.0	20
0.50–1.0	15
0.25–0.49	10
0.10–0.24	5
0–0.09	0

Table 4 – Points assigned to different levels of ecoregion protection

Percent of ecoregion protected	Points
0–2%	15
3–6%	12
7–10%	8
11–25%	4
Over 25%	0

provide a significant impact on habitats. Potential species extinction was derived using the number of threatened birds and mammals in different categories of threat within an ecoregion (BirdLife International, 2000; Hilton-Taylor, 2000). A compound score for extinction threat was derived by summing 3 for every critically endangered species found in an ecoregion, 2 for each endangered species, and 1 for each vulnerable species.

Assembling the index. Firstly, we summed the scores for habitat loss, habitat blocks, habitat fragmentation and habitat protection to produce an assessment of the Current Conservation Status Index of every ecoregion (maximum score = 100). A score of 80–100 was given a threat level of citical, 60–79 as endangered, 40–69 as vulnerable, 20–39 as relatively stable and 0–19 as relatively intact. The logic of these categories is similar to those employed in IUCN Red Data Books for threatened species (Mace and Lande, 1991; Hilton-Taylor, 2000). The final (threat-modified) conservation status index was calculated for every ecoregion by modifying current conservation status using the summed estimates of 'future threat' (see above). Those ecoregions ranking highest (top 30%) for future threats were elevanted by one level in the conservation status index, for example an endangered ecoregion scoring highly for future threat would be elevated to critical.

2.5. Integrating biological distinctiveness index and conservation status index

We integrated the two above indexes (BDI and CSI) using a matrix developed by Dinerstein et al. (1995) and modified by Ricketts et al. (1999b) (Table 5). Based on BDI and CSI levels, ecoregions are assigned to one of 20 cells in the matrix, and each cell is assigned to one of five classes (I–V) that reflect the intervention required for effective biodiversity conservation.

Class I. Globally Outstanding ecoregions that are highly threatened. Conservation actions in these ecoregions must be immediate to protect the remaining native species and habitats and to prevent extinction.

Class II. Regionally Outstanding ecoregions that are highly threatened. Conservation actions must be immediate to protect the remaining native species and habitats, but the overall biological value is lower than the Class I ecoregions.

Class III. Ecoregions with Globally or Regionally Outstanding biodiversity values which are not particularly threatened at the present time. These ecoregions represent some of the last places where large areas of intact habitat and associated species assemblages might be conserved.

Class IV. Bioregionally Outstanding and Locally Important ecoregions that are highly threatened. Conservation actions are needed to protect the remaining native species and habitats, but the overall biological values are lower than either Class II and much lower than Class I ecoregions.

Class V. Bioregionally Outstanding and Locally Important ecoregions that are not particularly threatened at the present time. These ecoregions represent some of the last places where large areas of intact habitat and associated species assemblages might be conserved, but they are less important biologically that the Class III ecoregions.

3. Results

3.1. Biological distinctiveness index

Species richness. Vertebrate and plant species richness corrected for area is highest across the tropical band of Africa (Fig. 1(a)), as shown in other studies (e.g., for animals Crowe and Crowe, 1982; Brooks et al., 2001; de Klerk et al., 2002 and for plants Lebrun, 1960; Malyshev, 1975; Barthlott et al., 1996, 1999; Lovett et al., 2000). There is also a peak of species richness at the southern tip of South Africa that is caused by the exceptional diversity of plants in the Cape Floral Kingdom (Fig. 1(a)). The offshore islands around the coast of Africa have significantly lower rates of richness when compared with the African mainland, except for eastern Madagascar which is also globally exceptional for plant diversity.

Species richness is strongly correlated between all pairs of taxa (Table 6). When the richness data are corrected for area effects, all correlations remain significant, but the level of significance declines somewhat between birds and invertebrates and between mammals and invertebrates.

Species endemism. Combined endemism for vertebrates peaks in the tropical montane forest ecoregions of the Cameroon Highlands of western Africa, the Albertine Rift of central Africa and the Eastern Arc of eastern Africa (Fig. 1(b)). For reptiles, however, endemism is low in montane forest ecoregions and higher in ancient dry regions of the Horn of northeastern Africa and the Namib in southwestern Africa. Like richness, endemism patterns for plants and invertebrates differ somewhat from those for birds, mammals and amphibians, showing higher endemism in the Mediterranean habitats at the northern and southern ends of Africa. Overall, however, species endemism is highly correlated between all pairs of taxa, with little change in the significance of the results if the data are corrected for area (Table 7).

Table 5 – Integration matrix used to assign ecoregions to different classes of conservation priority

Biological level	Threat level				
	Critical	Endangered	Vulnerable	Relatively stable	Relatively intact
Globally outstanding	I	I	I	III	III
Regionally outstanding	II	II	II	III	III
Bioregionally outstanding	IV	IV	V	V	V
Nationally important	IV	IV	V	V	V

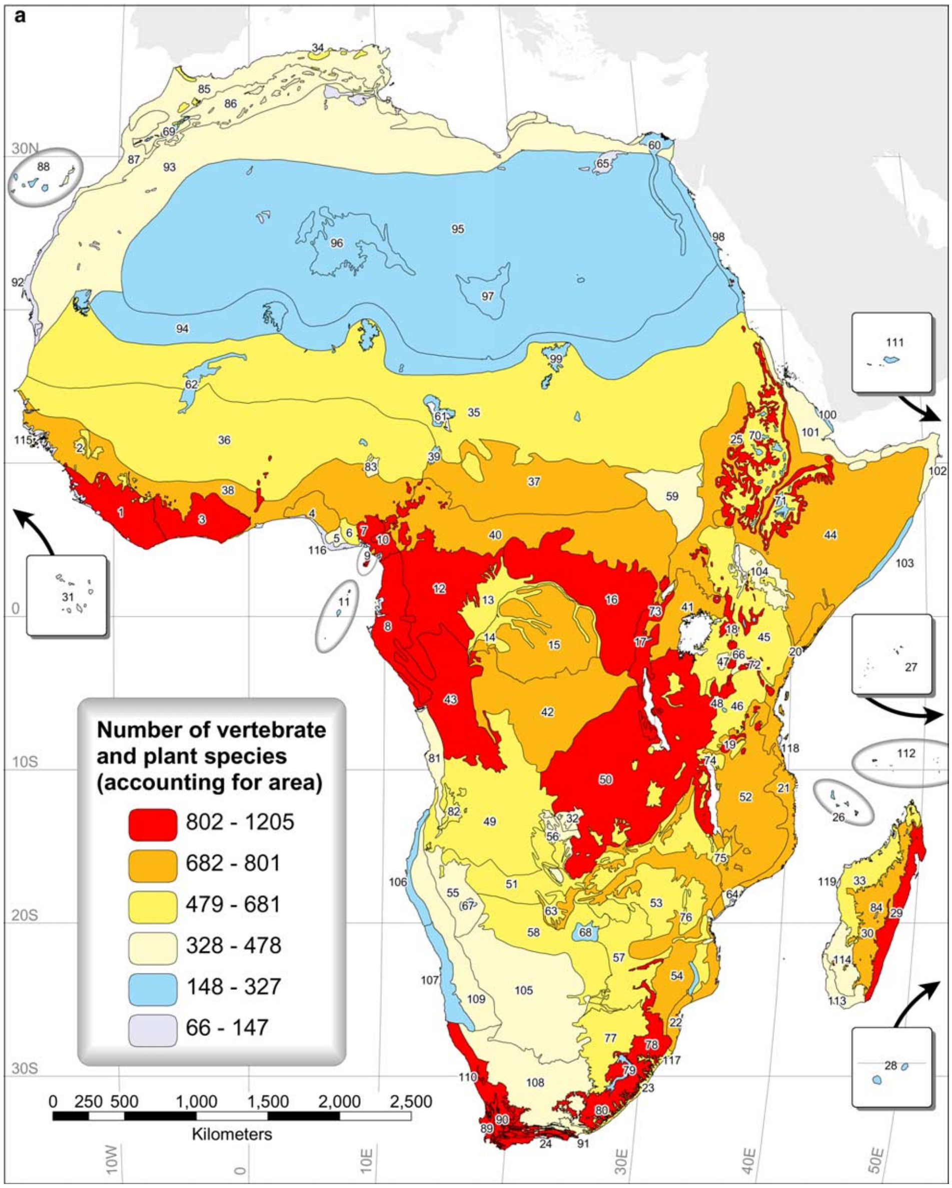

Fig. 1 – Building the biological distinctiveness index for African ecoregions. (a) Area corrected species richness for vertebrates and plants, (b) species endemism for vertebrates, (c) summed non-biological values of ecoregions, (d) compiled biological distinctiveness index (note that this graphic shows the results of all the biome-based prioritisations compiled into a single figure – separating the priorities into the different biomes would indicate more clearly the individual sets of priorities).

Non-species values. Ecoregions of the highest importance for summed non-species biological value include western Madagascar, the Cape region and Namib desert of southern Africa and the Canary Islands (Fig. 1(c)). These are all areas of recent evolution combined with ancient relict families. Of slightly lower importance for non-species values are the remainder of Madagascar (for evolution and the persistence of ancient families), the savannas of south-west Kenya and northern Tanzania (large mammal assemblages and migrations), the Sudd swamp in Sudan (large mammal assemblages and migrations), and the high mountain tops of Eastern Africa (recent evolution and rare habitats). Overall non-species values of Africa are not correlated with either total species richness (Rs = −0.07, ns) or total endemism (Rs = 0.11, ns).

Compiled biological values. The compiled endemism, richness and non-species biological values form our Biological Distinctiveness Index (Fig. 1(d)) which summarises overall biological value of ecoregions when analysed on a biome-by-biome basis. In this analysis there are 56 Globally outstanding, 17 regionally outstanding, 23 bioregionally outstanding and 23 locally important ecoregions.

In terms of representation, all nine African biomes contain a Globally outstanding ecoregion except for the mangroves,

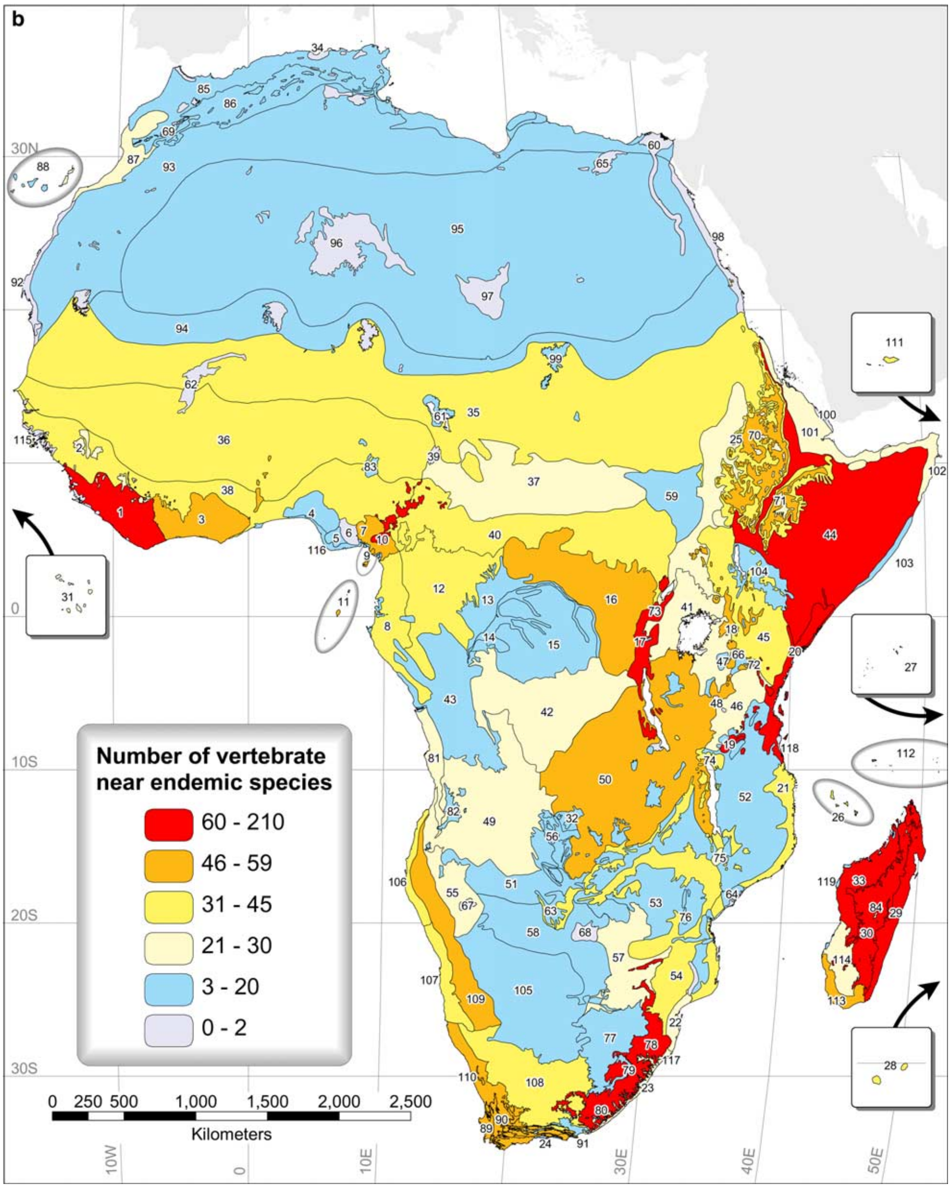

Fig. 1 – *continued*

which are notably species poor in Africa. The majority of biomes contain ecoregions in the various categories of biological importance (Table 8), indicating that the goal of achieving broad representation has been successful, especially in those biomes with more than a handful of ecoregions.

3.2. *Conservation status index*

The level of threat varies widely across the ecoregions of Africa (Fig. 2(a)). Across the study area there are 25 critically threatened, 32 endangered, 10 vulnerable, 31 relatively stable and 21 relatively intact ecoregions.

Critically threatened or endangered ecoregions are found in Northern Africa the Nile Delta and the forests of the Atlas Mountains (Fig. 2(a)), together with many of the lowland forest ecoregions of West Africa, and the forests of the Eastern Arc and lowland coastal forests in eastern Africa. Several offshore islands are also critically threatened, for example Comoros, Granitic Seychelles, and Cape Verde Islands. Critically threatened grassland ecoregions include the Highveld of South Africa, the Jos Plateau in Nigeria, and the Lowland Fynbos and Renosterveld of South Africa. The endangered ecoregions are typically found in geographical proximity to the critically threatened ecoregions.

Our assessment of future threat to ecoregions indicates no major changes to the geographical distribution of threat, only a heightening of threat to habitat and species in already imperilled areas (Fig. 2(b)). All the major mountain regions of Africa (Cameroon Highlands, Albertine Rift, Eastern Arc, Ethiopian Highlands and Kenyan Highlands) are predicted to enter the Critically Threatened category in the next 20 years. These will be joined by the lowland forests

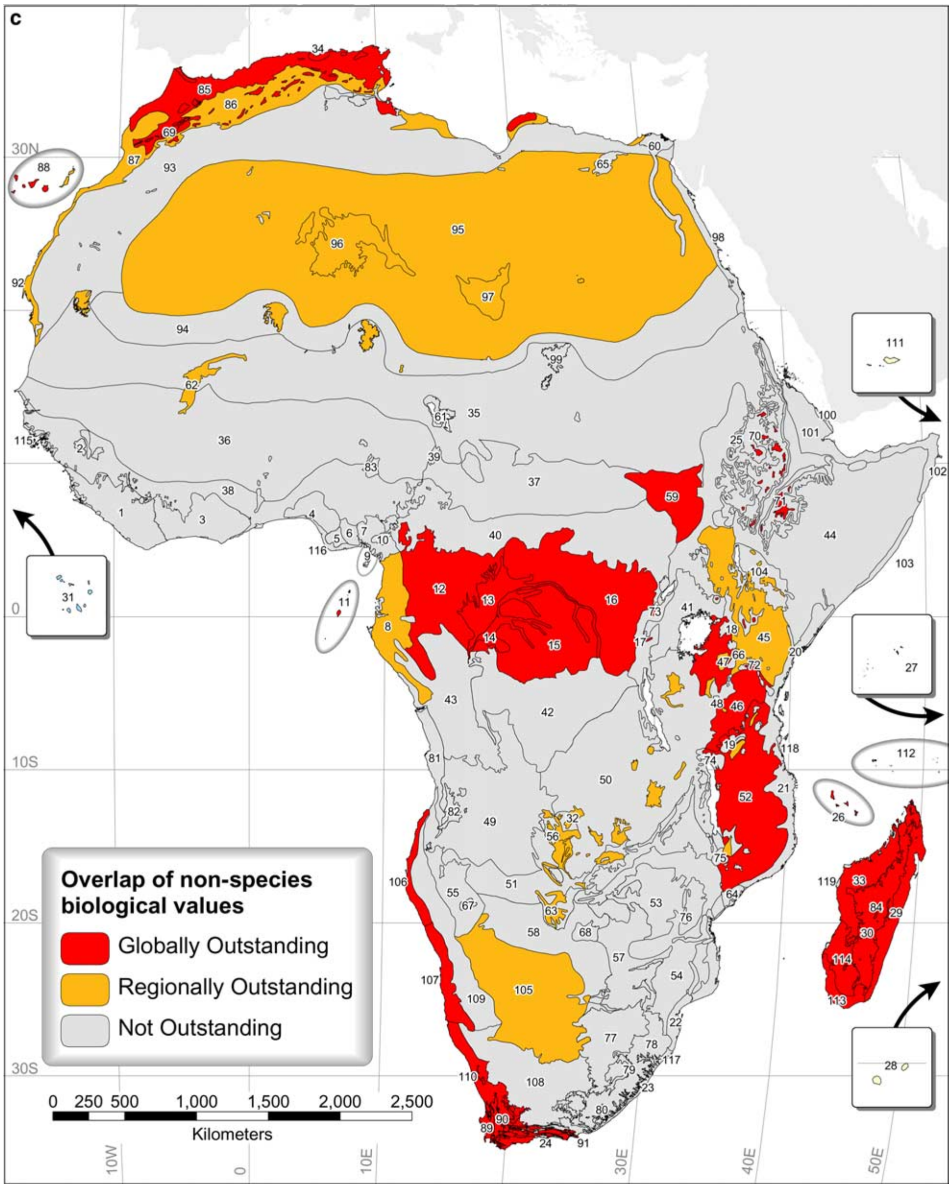

Fig. 1 – *continued*

along the coast of central Africa (Cameroon, Equatorial Guinea, Gabon), those in Uganda, eastern Madagascar and on the Gulf of Guinea Islands (Fig. 2(c)). Those ecoregions that are currently regarded as critically threatened will remain in this condition given current development trends.

3.3. Integrating biological distinctiveness index and conservation status index

Our integration of BDI and CSI data assigns ecoregions to different classes of priority for conservation investment (Fig. 3). Across the study area, 33 ecoregions are found in Class I, 10 in Class II, 29 in Class III, 21 in Class IV and 26 in Class V.

Class I ecoregions (i.e., those with high biodiversity and high threat) occupy the entire island of Madagascar, all the tropical mountains of Africa, and the smaller offshore islands of Canaries, Seychelles, Comoros and Mascarenes. They are also found in the lowland coastal forests of eastern Africa, the western part of the Upper Guinea forest of West Africa, in the lowlands around the Cameroon Highlands, and the forest mosaic of Uganda. Class I non-forest ecoregions occupy the Mediterranean-climate habitats of North Africa, South Africa (Cape Floristic Kingdom), and the forest-grassland mosaics of Pondoland in coastal South Africa. Class III ecoregions (i.e., those with high biodiversity and low threat) occupy the Congo Basin lowland forests, the miombo, mopane and Acacia savannas of North East, Eastern and Southern Africa, and the deserts and semi-deserts of coastal western South Africa and Namibia.

The level of threat facing ecoregions is positively correlated with differences in their mean species richness (vertebrates

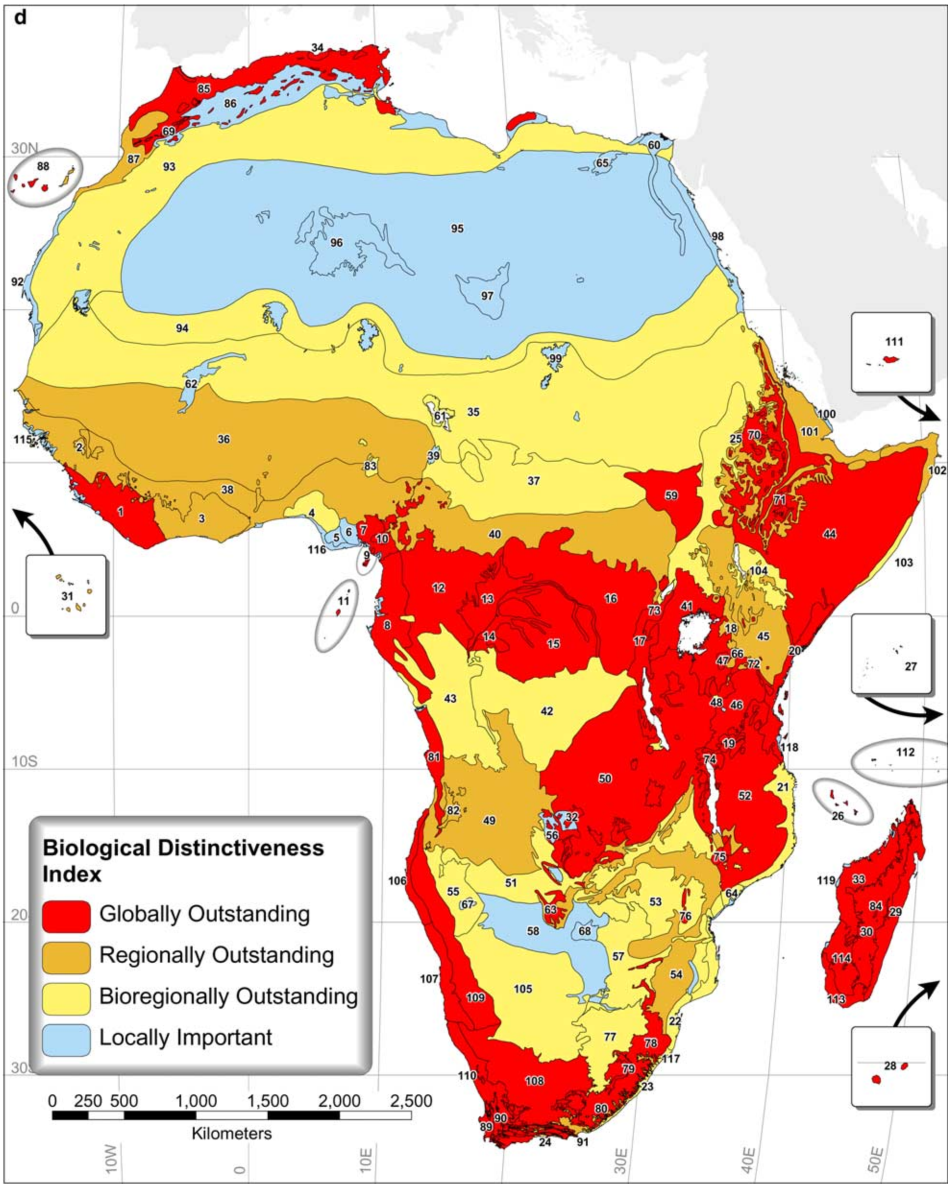

Fig. 1 – ***continued***

and plants), endemism (all vertebrates) and non-species biological values (Fig. 4). However, only for richness (regression analysis; $R^2 = 0.229$; $P = 0.012$) and endemism (regression analysis; $R^2 = 0.171$; $P = 0.063$) are the results statistically significant, or nearly so.

4. Discussion

Our analyses have produced a synthetic assessment of conservation priorities for African ecoregions. Although the results are certainly affected by uneven sampling coverage of different regions of Africa they are the best that can be achieved at the present time. Our analysis is based on several measures of biodiversity value (species endemism, species richness, and non-species biological values) combined with measures of threat (habitat loss, habitat fragmentation, habitat protection, future threat to habitats and extinction risk for species), so produces a broad set of priorities. The analysis shows that it is important to include several biological measures, because they point out different places, with particular differences between the areas identified by endemism and 'non-species biological values'. The former tends to identify mountains and islands whereas the latter tends to identify large heterogeneous areas of habitat in the lowlands. This split conforms closely to our division into two broad categories of importance. Our Class I priority ecoregions are those where many endemic species are highly threatened with extinction, and our Class III ecoregions are where extensive habitats still provide opportunities to maintain the ecological processes and area-demanding species over the longer term.

Table 6 – Spearman rank correlation of uncorrected (upper and right) and area-corrected (lower and left) species richness scores between taxonomic groups

	Amphibian	Bird	Mammal	Reptile	Plant	Invertebrate
Spearman ρ						
Amphibian		0.7230	0.7638	0.7438	0.7839	0.4046
Bird	0.6140		0.9478	0.6836	0.6531	0.2686
Mammal	0.6858	0.8787		0.7510	0.7145	0.3354
Reptile	0.7117	0.4235	0.5434		0.7462	0.4915
Plant	0.7439	0.4864	0.5742	0.6938		0.5813
Invertebrate[a]						
P-value						
Amphibian		0.0000	0.0000	0.0000	0.0000	0.0000
Bird	0.0000		0.0000	0.0000	0.0000	0.0031
Mammal	0.0000	0.0000		0.0000	0.0000	0.0002
Reptile	0.0000	0.0000	0.0000		0.0000	0.0000
Plant	0.0000	0.0000	0.0000	0.0000		0.0000
Invertebrate[a]						

a No correlations are presented for invertebrates as data were only available as estimated classes on importance from experts and these could not be corrected for area.

Table 7 – Spearman rank correlation of uncorrected (upper and right) and area-corrected (lower and left) species endemism scores between taxonomic groups

	Amphibian	Bird	Mammal	Reptile	Plant	Invertebrate
Spearman ρ						
Amphibian		0.6331	0.6686	0.5667	0.4949	0.5160
Bird	0.6434		0.5581	0.6564	0.5982	0.6052
Mammal	0.6636	0.5448		0.5872	0.4633	0.4420
Reptile	0.5661	0.6845	0.5323		0.6014	0.3959
Plant[a]						0.5665
Invertebrate[a]						
P-value						
Amphibian		0.0000	0.0000	0.0000	0.0000	0.0000
Bird	0.0000		0.0000	0.0000	0.0000	0.0000
Mammal	0.0000	0.0000		0.0000	0.0000	0.0000
Reptile	0.0000	0.0000	0.0000		0.0000	0.0000
Plant[a]						0.0000
Invertebrate[a]						

a No correlations are presented for plants or invertebrates as data were only available as estimated classes on importance from experts and these could not be corrected for area.

Table 8 – Numbers of ecoregions in the four categories of biological importance (globally outstanding, regionally outstanding, bioregionally outstanding, locally important) across the biomes of Africa

Biome	Globally outstanding	Regionally outstanding	Bioregionally outstanding	Locally important
Tropical and subtropical moist broadleaf forests	20	4	5	2
Tropical and subtropical dry broadleaf forests	2	1		
Mediterranean conifer forests	1			
Tropical and subtropical grasslands, savannas and shrublands	6	6	9	3
Flooded grasslands and savannas	2	0	2	6
Montane grasslands, savannas and shrublands	12	2	2	0
Mediterranean forests, woodlands, and scrub	4	2	0	1
Xeric deserts and shrublands	9	2	5	6
Mangroves				5

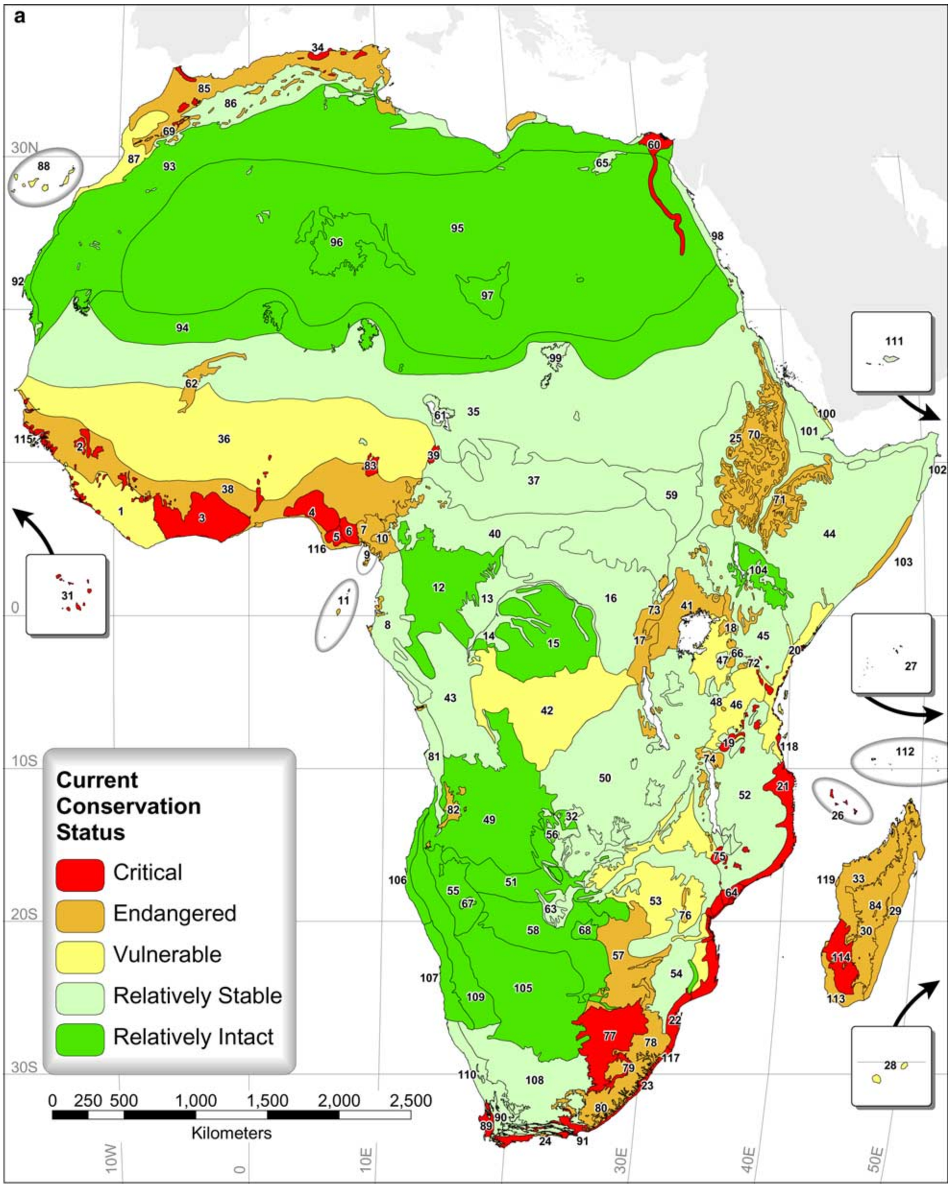

Fig. 2 – The conservation status index for African ecoregions. (a) Current conservation status index, (b) conservation status index modified according to future threat.

4.1. *Variation in biological patterns*

This analysis of African biodiversity priorities includes data for all vertebrates, plants, invertebrates and non-species biological values. The high degree of congruence between the species richness and endemism patterns for vertebrate groups parallels the results found at the 1-degree grid scale across Sub-Saharan Africa (Burgess et al., 2000; Moore et al., 2003). When data on species richness for plants and invertebrates are analysed against those for vertebrates, somewhat lower levels of congruence are seen, although they are still statistically significant. The differences that do exist are found between birds, mammals and amphibians on one hand, and plants and reptiles on the other hand. Geographically these differences peak at the northern and southern ends of Africa, in the ancient deserts of South Africa/Namibia and Somalia, and in the Mediterranean climate habitats of South Africa and Northern Africa close to the Mediterranean Sea.

The non-species biological values of Africa have never been comprehensively mapped and this paper presents a preliminary assessment of the distribution of these values. The sets of ecoregions that are identified for their non-species values are statistically uncorrelated with those identified as priorities for either species richness or species endemism. This is important because focussing only on the species attributes of Africa would tend, for example, to miss those ecoregions with spectacular concentrations of large mammals, something for which Africa is unique. The important non-species biological attributes of Africa are

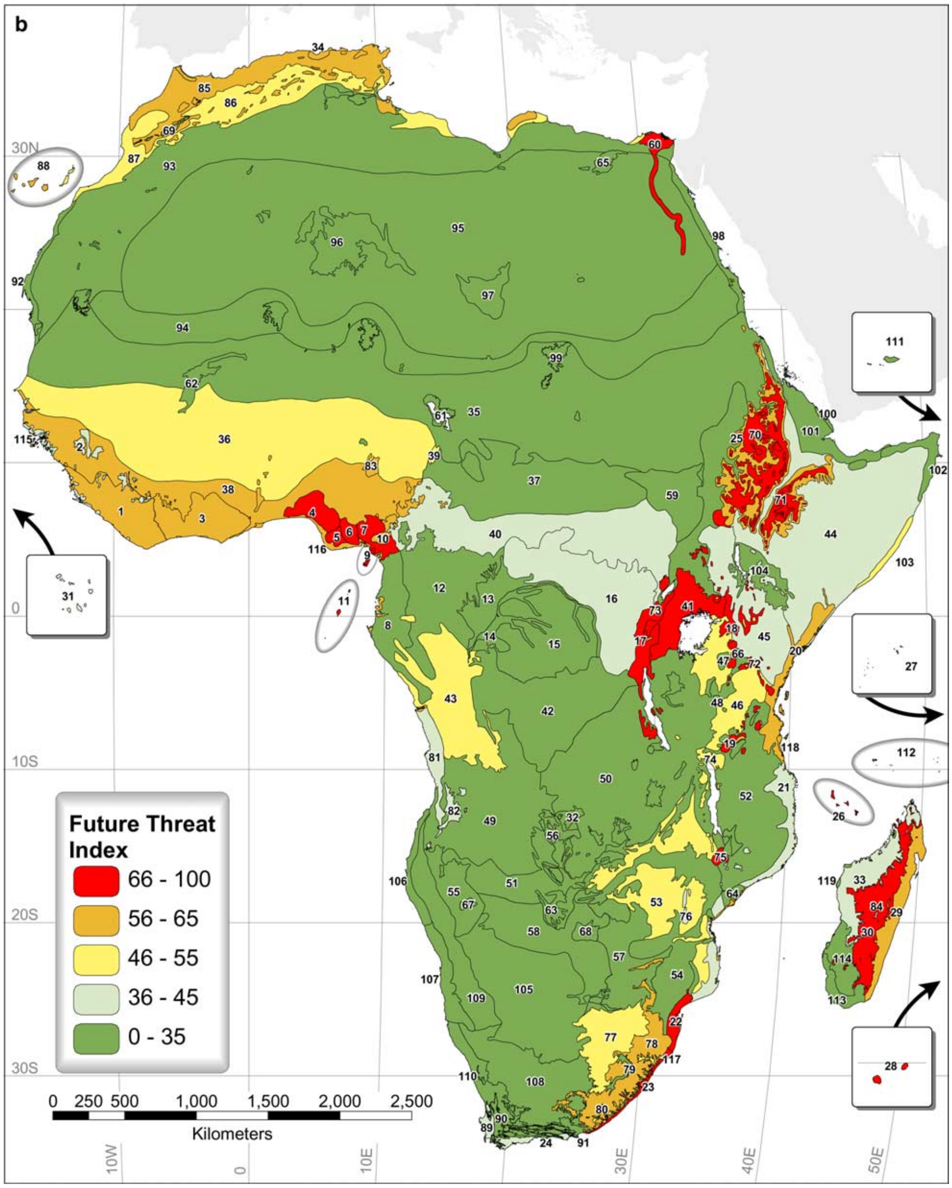

Fig. 2 – *continued*

partly captured in the wilderness prioritisation exercise of Conservation International (Mittermeier et al., 2002) but is largely missed by the species-focused prioritisation schemes (e.g., WWF and IUCN, 1994; Stattersfield et al., 1998; Mittermeier et al., 1999; Myers et al., 2000). Additional work on mapping the distribution of non-species biological values across large regions such as Africa and its islands remains a clear research priority for the coming years (see Mace et al., 2000).

4.2. *Variation in threat patterns*

Our analyses also indicate strong geographical patterns in the distribution of the most threatened ecoregions. Many critically threatened ecoregions have a long history of human habitation and developed agriculture (the Nile Valley, highland Ethiopia, and parts of South Africa), or have been rapidly degraded after colonisation in recent centuries (some small offshore islands) (Fig. 2a,b). Critically threatened and endangered ecoregions are often also found in mountain regions where moderate soils and reliable rainfall encourages agriculture within otherwise dry landscapes (see Fjeldså et al., 1997). Across the extensive and less degraded habitats of Africa – for example the miombo woodlands of eastern and southern Africa, the Congo basin, and the deserts – the current threats are much lower. Importantly, our assessment of future threat also points to the same areas as are threatened today, meaning that already threatened seem inevitably faced by even higher levels of threat. In biologically valuable and threatened areas conservationists will need to tackle the threats and their root causes if they are to succeed in their work.

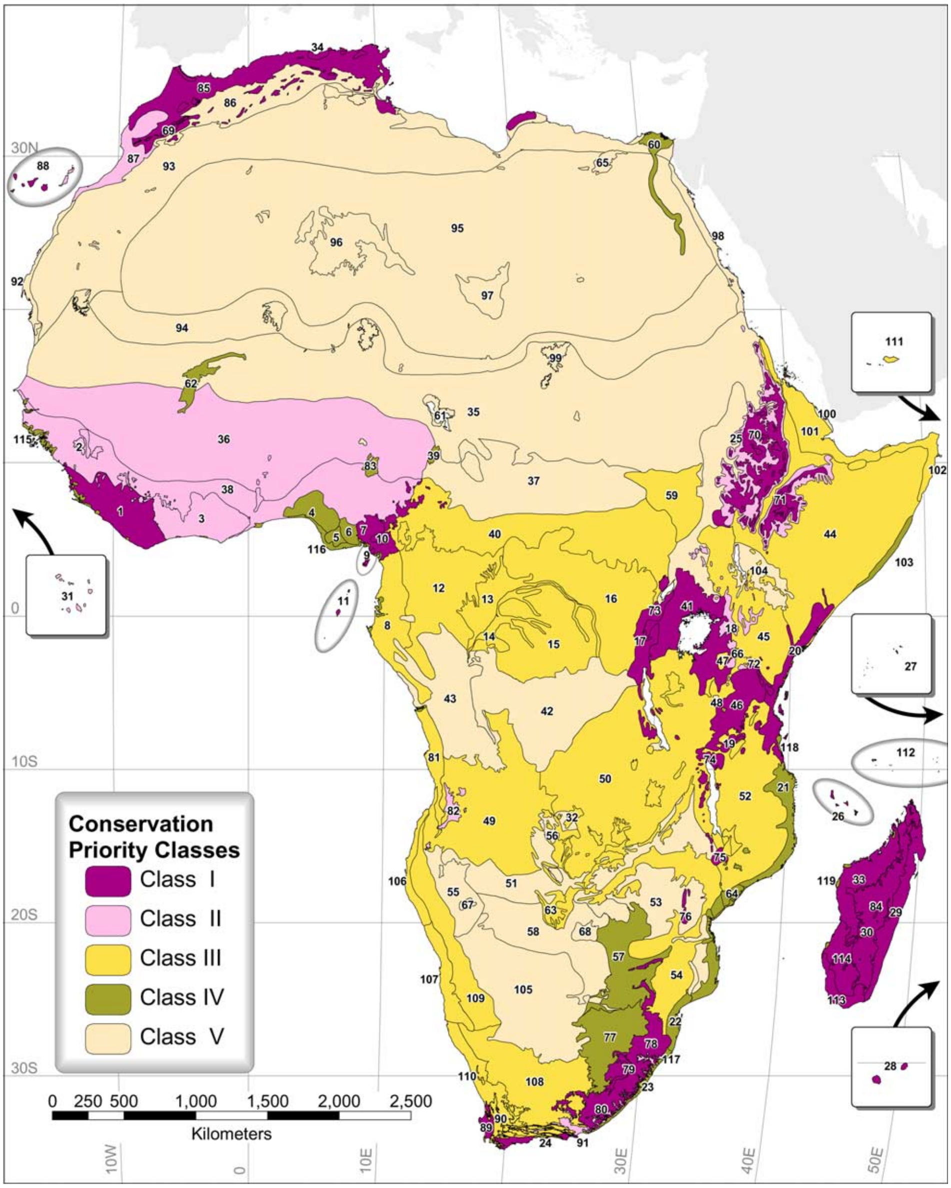

Fig. 3 – Priorities for conservation intervention in Africa, derived from the integration of threats and biological values. Class I, ecoregions with globally important biological values but highly threatened; Class II, ecoregions with regionally important biological values and highly threatened; Class III, ecoregions with globally important biological values and low to moderate levels of threat; Class IV, ecoregions with regionally important biological values and low to moderate levels of threat; Class V, ecoregions with locally important biological values.

Our results also show a general correlation between the most threatened ecoregions and their importance for species richness, endemic species and the degree non-species biological values. This result confirms previous studies that have found that human population density (a strong correlate with the degree of threat) is highest in areas of greatest biological importance (Balmford et al., 2001a,b), with a similar relationship known between the diversity of languages and biological values (Moore et al., 2002). However, the relationship between non-species values and threat was previously unknown. These correlations were not particularly expected as it was envisaged that non-species values would be independent of our threat metrics. However, this is not the case and we found the non-species, as well as the species, attributes of Africa are positively correlated with threat and hence are imperilled more than would be expected by chance.

The integration of biological values and threats across the ecoregions of Africa identifies two sets of ecoregions of the highest importance for conservation attention. The first set (Class I ecoregions) contains those ecoregions with globally important biological values and high threats – here urgent conservation work needs to prevent extinction. The second set of ecoregions (Class III ecoregions) contains globally

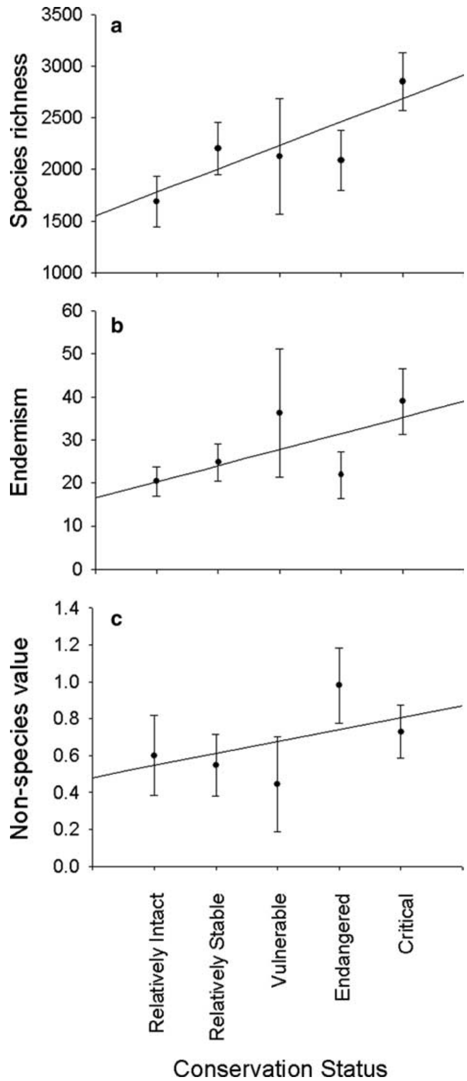

Fig. 4 – Mean species richness (vertebrates and plants), endemism (vertebrates) and non-species values across the categories of threat to African ecoregions. Error bars are also shown around each threat category point and regression analyses show the relationships between these attributes.

important biological values and lower threats – here conservation activities need to maintain large-scale ecological processes and habitats. This division into two clear sets of conservation priorities mirrors that outlined by Conservation International in their assessment of biodiversity Hotspots (Mittermeier et al., 1999, 2004) and tropical Wilderness Areas (Mittermeier et al., 2002); although we have taken the concept further by incorporating additional elements of biodiversity value and a more detailed assessment of threat.

4.3. *Conservation priorities*

Biomes with the highest proportion of their ecoregions in Class I include montane grasslands and forest mosaics (66% of 15 ecoregions), tropical lowland and montane forests (43% of 30 ecoregions) and Mediterranean habitats (28% of seven ecoregions). Of the 33 Class I ecoregions, most are on offshore islands (12) or on mainland montane islands (14) leaving only seven in the lowlands. This result confirms previous assessments that rank offshore islands and montane habitats as conservation priorities (e.g., Stattersfield et al., 1998). Most of the 27 Class III ecoregions are found in the lowland forests (20% of 30 forested ecoregions), in the savanna woodlands (35% of 23 ecoregions) and deserts (36% of 22 ecoregions). The majority of these Class III ecoregions are found on the African mainland.

Different conservation approaches are required in these two broad sets of priority ecoregions.

Firstly, within the Class I ecoregions, most of the ecoregions are found on offshore islands or continental habitat islands on mountains. Past studies have shown that there is a correlation between biological importance and human population density, language diversity, smaller reserve sizes, and extinction risks (Balmford et al., 2001a,b; Harcourt et al., 2001; Moore et al., 2002; Brooks et al., 2002). This is particularly important in the Class I ecoregions where habitat patches are small and narrow endemic species are often restricted to tiny areas. With a high and expanding agricultural population preferentially selecting the same areas, perhaps for the same combinations of climatic stability and soils (Fjeldså et al., 1997) conserving large areas of habitat will most likely be impossible in these ecoregions. Maintaining the current protected area networks, developing targeted new areas – often with the collaboration and management support of the local populations, is going to be the mainstay of conservation here. In addition, working to maintain the connectivity between fragmented patches of habitat is also an important strategy for reducing species extinction.

Secondly, within the Class III ecoregions, the conservation situation is quite different. Here the human populations are low, correlating with low rates of narrow endemism and species richness patterns that are distributed across huge tracts of land. Often, large-scale habitat mosaics and underlying ecosystem processes support the species richness and maintaining these at huge scales are important for maintaining the biological values. Most of the large protected areas of Africa are found in these ecoregions, be they savanna-woodland, desert, or lowland rainforest. Surrounding the protected areas, various forms of community-based natural resource use is often promoted as the most profitable method of land management, often involving large mammal hunting, or the harvesting of timber within large concessions. The conservation approaches that are appropriate in these areas are large scale, extensive, and not focused on smaller scale patterns of endemism. Single species work mainly focuses on those species threatened by human over-use, such as elephant, rhinoceros, etc. The methods for conservation in the Class III ecoregions are well established, but need continual implementation if they are to succeed.

4.4. *Future needs*

One part of the future needs for setting priorities within Africa is to continue the process of mapping biodiversity, through computerising species distribution maps according to distributional records published in the literature or found within Zoological Museums and Herbaria. Such a programme is already being undertaken through various initiatives in Europe and USA and results are being made available (see www.zmuc.ku.dk; biomaps, iucn).

Even though we have considered a number of different issues in our priority setting, there are additional factors that might be brought into future analyses. Some ecological processes have a large economic value to humans and hence can provide an economic justification for the conservation of different ecoregions and the habitats within them. One example is the issue of water supply from mountain cloud forests to large urban centres in the lowlands (Dudley and Stolton, 2003) and another is the carbon sequestration value of large areas of forest or woodland habitats, linked to the clean development mechanism. Mapping and quantifying ecosystem processes and determining their economic value to people living on the African continent has only just started with efforts already published for South Africa (Rouget et al., 2003; Pressey et al., 2003; Cowling and Pressey, 2001; Cowling et al., 2003).

Another issue of relevance when proposing areas for conservation investment is feasibility. This can have two components: the socio-economic reality of working in the area, and the costs of doing so. Some of the ecoregions we identify as priorities for investment are in countries (such as Somalia), which are almost impossible to work in due to extended wars and poor governance. Other priorities fall in countries that are more expensive (e.g., northern African nations, the Seychelles and South Africa) than others (e.g., Kenya and Tanzania), or have a greater (e.g., South Africa) or lesser (e.g., Gabon) human capacity for conservation. The total costs of conservation have been outlined in recent years (James et al., 1999, 2001; Balmford et al., 2002, 2003; Frazee et al., 2003), with these estimates becoming increasingly more sophisticated. More recent studies have attempted to integrate costs into the process of conservation prioritisation, showing that this approach makes a different to the set of conservation areas chosen, especially if the ability to invest in conservation is determined by available funds (Balmford et al., 2000; Moore et al., 2004). Finally, other recent studies have attempted to include socio-economic factors other than cost into conservation prioritisation exercises, including issues of development (O'Connor et al., 2003) and governance (Smith et al., 2003). Across the ecoregions of Africa incorporating such factors into the set of priority areas for investment has not yet been done systematically and represents a new frontier for scientific exploration.

In conclusion, by compiling data on species, non-species and threats data we can start to look in detail at where conservation priorities are located and how they vary as different sets of data are brought into the analysis. Moving down to the field level to implement the priorities is the next major challenge and is one that WWF and other conservation agencies have already started. For example field level conservation planning and implementation is being undertaken in the Congo Basin forests, the miombo woodlands, the eastern African coastal forests, the cape fynbos and the Albertine rift mountains (see www.worldwildlife.org/ecoregions for more information). These and other large-scale conservation efforts have the overall aim of conserving the biological diversity of Africa for present and future generations.

Acknowledgements

We thank the hundreds of people who have assisted us to compile the data used in this paper. They are listed in full in Burgess et al. (2004). Here, we also acknowledge the input of our colleagues in other NGOs in the USA, UK and Africa, and our colleagues working to make conservation happen in some of the special African ecoregions outlined in this paper. Jörn Scharlemann and Andrew Balmford of Cambridge University in the UK provided analytical advice.

Appendix A. Quantifying the non-species values of ecoregions

A.1. *Evolutionary or ecological phenomena*

Evolutionary phenomena

Extraordinary adaptive radiations of species

Criteria:

An ecoregion scored 1 for adaptive radiations if:

(a) It contains 20 or more species within a clear adaptive radiation in one or more genera in the same family.
(b) It contains extensive adaptive radiations (10 or more species displaying clear adaptive radiation to different resource niches) in genera from at least two different families.

Unusual ecological phenomena

Intact large vertebrate assemblages

Criteria:

An ecoregion scored 1 for this feature if:

(a) It contains all of the largest carnivores, herbivores, and frugivores and other feeding guilds in that ecosystem, and these species still fluctuate within natural ranges and play an important ecological role in the system.

Note. No more than three ecoregions were selected as globally outstanding for this feature per biome if the large carnivores, herbivores, and frugivores had widespread distributions throughout the biome.

Migrations or congregations of large vertebrates

Criteria:

An ecoregion scored 1 for this feature if:

(a) A migration of large terrestrial vertebrates occurs which exceeds 100 km in length and includes more than several thousand individuals and is accompanied by the full complement of native large predators.

(b) Enormous aggregations (millions) of breeding or migratory birds occur.

Regionally important migrations were also recognized, and these scored 0.5.

A.2. *Global rarity of habitat types*

Criteria:
An ecoregion scored 1 for this feature if:

(a) It is one of the globally rare habitat types recognised by WWF, which in Africa are tropical dry forests (59 ecoregions worldwide), montane moorlands (8 ecoregions worldwide in 3 widely separated regions) and Mediterranean forests, woodlands and scrub (39 ecoregions worldwide found in 5 distinct regions).

A.3. *Higher taxonomic uniqueness*

Criteria:
An ecoregion scored 1 for this feature if:

(a) The ecoregion contains one endemic family of plants or vertebrates.
(b) More than 30% of the genera of vascular plants or animals are estimated as endemic to the ecoregion.

An ecoregion was considered of *regional* importance (scoring 0.5) if there are more than five endemic genera, especially if these genera indicate a link back to groups more common millions of years in the past.

A.4. *Ecoregions harboring examples of large relatively intact ecosystems*

Criteria:
An ecoregion scored 1 for this feature if it is a core part of a wilderness area defined by Conservation International (Mittermeier et al., 2002). These are areas at least 10,000 km^2 in size, greater than or equal to 70% intact and with less than or equal to 5 people/km^2 once cities/towns have been excluded. We refined this assessment of wilderness areas to fit as closely as possible to our ecoregional framework, also using the results of Sanderson et al. (2002) for this purpose.

Appendix B. Thresholds used for assigning point values to habitat blocks in different biomes

Note. The value '>500' means "the unit contains at least one habitat block greater than 500 km^2." The value '90%' means "the unit contains at least one habitat block that is 90% the size of the largest original unit". For a unit of any given size, the table should be read from top to bottom until a statement is reached that is true of the unit.

Tropical and subtropical moist broadleaf forests biome (biome 1) and tropical and subtropical dry and monsoon broadleaf forests biome (biome 2)

Point value	Ecoregion size >10,000 km^2	Continuous habitat <10,000 km^2	Discontinuous habitat <10,000 km^2
0	>5000 or ⩾3 blocks > 2000	>3000 or ⩾3 blocks > 1000	⩾2 blocks > 500
6	>3000 or ⩾3 blocks > 1000	>1000	⩾2 blocks > 300
12	>2000	>500	⩾2 blocks > 200
18	>1000	>250	100
25	None >1000	None >250	None >100

Temperate conifer forests biome (biome 5)

Point value	Ecoregion size >10,000 km^2	Ecoregion size <10,000 km^2
0	>4000 or ⩾3 blocks > 1500	>2500 or ⩾3 blocks > 800
6	>3000 or ⩾3 blocks > 1000	>800
12	>2000	⩾3 blocks > 250
18	>1000	>250
25	None>1000	None > 250

Tropical and subtropical grassland, savannas, shrublands and woodlands biomes (biomes 7,9,10)

Point value	Ecoregion size >10,000 km^2	Ecoregion size <10,000 km^2
0	>2000 or ⩾3 blocks > 800	>1000 or ⩾3 blocks > 500
6	>1000	>500
12	>500	>250
18	>250	>100
25	None > 250	None > 100

Mediterranean-climate shrublands and woodlands biome (biome 12) and deserts and xeric shrublands biome (biome 13)

Point value	Ecoregion size >10,000 km^2	Ecoregion size >10,000 km^2
0	⩾2 blocks > 750 or ⩾3 blocks > 500	⩾2 blocks > 500 ⩾3 blocks > 300
6	>750	>500
12	>500	>250
18	>250	>100
25	None >250	None >100

Mangroves biome (biome 14)			
Point value	Ecoregion size >3000 km^2	Ecoregion size 1000–3000 km^2	Ecoregion size <1000 km^2
0	>1000 or ⩾3 blocks >500	>750 or ⩾3 blocks > 500	90–100%
6	>500	>500	70–90%
12	>250	⩾3 blocks > 200	40–70%
18	>100	>75	10–40%
25	None >100	None >75	<10 blocks

REFERENCES

Balmford, A., Gaston, K.J., Rodrigues, A.S.L., James, A., 2000. Integrating costs of conservation into international priority setting. Conservation Biology 14, 597–605.

Balmford, A., Moore, J.L., Brooks, T., Burgess, N.D., Hansen, L.A., Williams, P., Rahbek, C., 2001a. Conservation conflicts across Africa. Science 291, 2616–2619.

Balmford, A., Moore, J.L., Brooks, T., Burgess, N.D., Hansen, L.A., Lovett, J.C., Tokumine, S., Williams, P., Rahbek, C., 2001b. People and biodiversity in Africa. Science 293, 1591–1592.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Turner, R., Kerry, P., 2002. Economic reasons for conserving wild nature. Science 297, 950–953.

Balmford, A., Gaston, K.J., Blyth, S., James, A., Kapos, V., 2003. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. Proceedings of the National Academy of Sciences USA 100, 1046–1050.

Barthlott, W., Lauer, W., Placke, A., 1996. Global distribution of species diversity in vascular plants: towards a world map of phytodiversity. Erdkunde 50, 317–327.

Barthlott, W., Biedinger, N., Braun, G., Feig, F., Kier, G., Mutke, J., 1999. Terminological and methodological aspects of the mapping and analysis of global biodiversity. Acta Botanica Fennica 162, 103–110.

BirdLife International, 2000. Threatened Birds of the World. Lynx Editions and BirdLife International. Barcelona and Cambridge, UK.

Brooks, T., Balmford, A., Burgess, N.D., Fjeldså, J., Hansen, L.A., Moore, J., Rahbek, C., Williams, P., 2001. Towards a blueprint for conservation in Africa. BioScience 51, 613–624.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., Hilton-Taylor, C., 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16, 909–923.

Burgess, N.D., de Klerk, H., Fjeldså, J., Crowe, T., Rahbek, C., 2000. A preliminary assessment of congruence between biodiversity patterns in Afrotropical forest birds and forest mammals. Ostrich 71, 286–290.

Burgess, N.D., Rahbek, C., Wugt Larsen, F., Williams, P., Balmford, A., 2002. How much of the vertebrate diversity of sub-Saharan Africa is catered for by recent conservation proposals. Biological Conservation 107, 327–339.

Burgess, N.D., D' Amico Hales, J.A., Underwood, E., Dinerstein, E., Olson, D., Schipper, J., Ricketts, T., Itoua, I., Newman, K., 2004. Terrestrial Ecoregions of Africa and its Islands: A Conservation Assessment. Island Press, Washington DC, USA.

Burgess, N.D., Küper, W., Mutke, J., Westaway, S., Brown, J., Turpie, S., Meshack, C., Taplin, J., McClean, C., Lovett, J., 2005. Major gaps in the distribution of protected areas for threatened and narrow range Afrotropical plants. Biodiversity and Conservation 14, 1877–1894.

CIESIN, Columbia University, IFPRI, and WRI. 2000. Gridded Population of the World (GPW), Version 2. Retrieved 2001, from the World Wide Web. Available from: <http://sedac.ciesin.columbia.edu/plue/gpw>.

Cowling, R., Pressey, R., 2001. Rapid plant diversification: planning for an evolutionary future. PNAS 98, 5452–5457.

Cowling, R.M., Pressey, R.L., Rouget, M., Lombard, A., 2003. A conservation plan for a global biodiversity hotspot – the Cape Floristic Region, South Africa. Biological Conservation 112, 191–216.

Crowe, T.M., Crowe, A.A., 1982. Patterns of distribution, diversity and endemism in Afrotropical birds. Journal of Zoology, London 198, 417–442.

de Klerk, H., Crowe, T., Fjeldså, J., Burgess, N.D., 2002. Patterns in the distribution of Afrotropical birds. Journal of Zoology, London 256, 327–342.

Dinerstein, E., Olson, D., Graham, D., Webster, A., Pimm, S., Bookbinder, M., Ledec, G., 1995. A Conservation Assessment of the Terrestrial Ecoregions of Latin America and the Caribbean. World Bank, Washington DC.

Dobson, J.E., Bright, E.A., Coleman, P.R., Durfee, R.C., Worley, B.A., 2000. LandScan: a global population database for estimating populations at risk. Photogrammetric Engineering and Remote Sensing 66, 849–857.

Dudley, N., Stolton, S. (Eds.), 2003. Running Pure: The Importance of Forest Protected Areas to Drinking Water. World Bank/WWF Alliance for Forest Conservation and Sustainable Use, Gland, Switzerland.

Fishpool, L.D.C., Evans, M.I. (Eds.), 2001. Important Bird Areas in Africa and Associated Islands: Priority Sites for Conservation (BirdLife Conservation Series No. 11). Pisces Publications and BirdLife International, Newbury and Cambridge, UK.

Fjeldså, J., Ehrlich, D., Lambin, E., Prins, E., 1997. Are biodiversity 'hotspots' correlated with current ecoclimatic stability. A pilot study using the NOAA-AVHRR remote sensing data. Biodiversity and Conservation 6, 401–422.

Frazee, R.R., Cowling, R.M., Pressey, R.L., Turpie, J.K., Lindenberg, N., 2003. Estimating the costs of conserving a biodiversity hotspot: a case-study of the Cape Floristic Region, South Africa. Biological Conservation 112, 275–290.

GEO3, 2002. Global Environmental Outlook 3: Past, Present and Future Perspectives. UNEP and Earthscan, London, UK.

Groombridge, B., Jenkins, M.D., compilers. 2000. Global Biodiversity: Earth's Living Resources in the 21st Century. World Conservation Press, Cambridge, UK.

Hansen, M.C., Reed, B., 2000. A comparison of the IGBP Discover and University of Maryland 1 km global land cover products. International Journal of Remote Sensing 21, 1365–1373.

Hansen, M., DeFries, R., Thownsend, J.R.G., Sohlberg, M., 2000. Global land cover classification at 1 km resolution using a decision tree classifier. International Journal of Remote Sensing 21, 1331–1365.

Harcourt, A.H., Parks, S.A., Woodroffe, R., 2001. Human density as an influence on species/area relationships: double jeopardy for small African reserves? Biodiversity and Conservation 10, 1011–1026.

Hilton-Taylor, C., 2000. 2000 IUCN Red List of Threatened Species. IUCN, Gland, Switzerland and Cambridge, UK.

ICBP, 1992. Putting Biodiversity on the Map. Priority Areas for Global Conservation. International Council for Bird Preservation, Cambridge, UK.

IUCN, 1998. 1997 United Nations list of protected areas. WCMC/IUCN, Cambridge, UK and Gland, Switzerland.

James, A.N., Gaston, K.J., Balmford, A., 1999. Balancing the Earth's accounts. Nature 401, 323–324.

James, A., Gaston, K.J., Balmford, A., 2001. Can we afford to conserve biodiversity? Bioscience 5, 43–52.

Kier, G., Mutke, J., Dinerstein, E., Ricketts, T.H., Küper, W., Kreft, H., Barthlott, W., 2005. Global patterns of plant diversity and floristic knowledge. Journal of Biogeography 32, 1107–1116.

Küper, W., Sommer, J.H., Lovett, J.C., Mutke, J., Linder, H.P., Beentje, H.J., van Rompaey, R., Chatelain, C., Sosef, M., Barthlott, W., 2004. Africa's hotspots of biodiversity redefined. Annals of the Missouri Botanical Garden 91, 525–535.

La Ferla, B., Taplin, J., Ockwell, D., Lovett, J.C., 2002. Continental scale patterns of biodiversity: can higher taxa accurately predict African plant distributions. Botanical Journal of the Linnean Society 138, 225–235.

Lebrun, J., 1960. Sur la richesse de la flore de divers territoires africains. Bulletin des séances de l'Académie Royale des Sciences d'Outre-Mer 6, 669–690.

Lovett, J.C., Rudd, S., Taplin, J., Frimodt-Møller, C., 2000. Patterns of plant diversity in Africa south of the Sahara and their implications for conservation management. Biodiversity and Conservation 9, 33–42.

Mace, G.M., Lande, R., 1991. Assessing extinction threats: towards a reassessment of IUCN endangered species categories. Conservation Biology 5, 148–157.

Mace, G.M., Balmford, A., Boitani, L., Cowlishaw, G., Dobson, A.P., Faith, D.P., Gaston, K.J., Humphries, C.J., Lawton, J.H., Margules, C.R., May, R.M., Nicholls, A.O., Possingham, H.P., Rahbek, C., van Jaarsveld, A.S., Vane-Wright, R.I., Williams, P.H., 2000. It's time to work together and stop duplicating conservation efforts. Nature 405, 393.

Malyshev, L.I., 1975. The quantitative analysis of flora: spatial diversity, level of specific richness, and representativity of sampling areas. Botanicheskiy Zhurnal 60, 1537–1550 (in Russian).

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–353.

Mittermeier, R.A., Myers, N., Thompsen, J.B., da Fonseca, G.A.B., Olivieri, S., 1998. Biodiversity hotspots and major tropical wilderness areas: approaches to setting conservation priorities. Conservation Biology 12, 516–520.

Mittermeier, R.A., Myers, N., Gil, P.R., Mittermeier, C.G., 1999. Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. CEMEX, Mexico City.

Mittermeier, R.A., Mittermeier, C.G., Gil, P.R., Pilgrim, J., Fonseca, G.A.B., Konstant, W.R., Brooks, T. (Eds.), 2002. Wilderness: Earth's Last Wild Places. CEMEX, Mexico City, Mexico.

Mittermeier, R.A., Robles Gil, P., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C.G., Lamoreux, J., da Fonseca, G.A.B., 2004. Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. CEMEX, Mexico City.

Moore, J.L., Manne, L., Brooks, T., Burgess, N.D., Davies, R., Rahbek, C., Williams, P., Balmford, A., 2002. The distribution of cultural and biological diversity in Africa. Proceedings of the Royal Society Biological Sciences Series B 269, 1645–1653.

Moore, J.L., Balmford, A., Brooks, T., Burgess, N.D., Hansen, L.A., Rahbek, C., Williams, P.H., 2003. Performance of sub-Saharan vertebrates as indicator groups for identifying priority areas for conservation. Conservation Biology 17, 207–218.

Moore, J., Balmford, A., Allnut, T., Burgess, N.D., 2004. Integrating costs into conservation planning across Africa. Biological Conservation 117, 343–350.

Mutke, J., Kier, G., Braun, G., Schulz, C., Barthlott, W., 2001. Patterns of African vascular plant diversity - a GIS based analysis. Systematics and Geography of Plants 71, 1125–1136.

Myers, N., 1988. Threatened biotas: "hot spots" in tropical forests. The Environmentalist 8, 187–208.

Myers, N., 1990. The biological challenge: extended hot-spots analysis. The Environmentalist 10, 243–256.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

O'Connor, C., Marvier, M., Kareiva, P., 2003. Biological vs. social, economic and political priority setting in conservation. Ecology Letters 6, 706–711.

Olson, D.M., Dinerstein, E., 1998. The Global 200: a representation approach to conserving the earth's most biologically valuable ecoregions. Conservation Biology 12, 502–515.

Olson, D.M., Dinerstein, E., 2002. The Global 200: priority ecoregions for global conservation. Annals of the Missouri Botanical Garden 89, 199–224.

Olson, D.C., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E., D'Amico, J.A., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Lamoreux, J.F., Ricketts, T.H., Itoua, I., Wettengel, W.W., Kura, Y., 2001. A new map of the world. BioScience 51, 933–938.

Pimm, S.L., Ayers, M., Balmford, A., Branch, G., Brandon, K., Brooks, T., Bustamante, R., Costanza, R., Cowling, R., Curran, L.M., Dobson, A., Farber, S., da Fonseca, G.A.B., Gascon, C., Kitching, R., McNeely, J., Lovejoy, T., Mittermeier, R.A., Myers, N., Patz, J.A., Raffle, B., Rapport, D., Raven, P., Roberts, C., Rodrigues, J.P., Rylands, A.B., Tucker, C., Safina, C., Samper, C., Stiassny, M.L., Supriatna, J., Wall, D.H., Wilcove, D., 2002. Can we defy nature's end? Science 293, 2207–2208.

Pressey, R.L., Cowling, R.M., Rouget, M., 2003. Formulation of conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation 112, 99–127.

Ricketts, T.H., Dinerstein, E., Olson, D.M., Loucks, C., 1999a. Who's where in North America. Patterns of species richness and the utility of indicator taxa for conservation. Bioscience 49, 369–381.

Ricketts, T.H., Dinerstein, E., Olson, D., Loucks, C.J., Eichbaum, W., DellaSala, D., Kavanagh, K., Hedao, P., Hurley, P.T., Carney, K.M., Abell, R., Walters, S., 1999b. Terrestrial Ecoregions of North America: A Conservation Assessment. Island Press, Washington DC.

Rosenzweig, M.L., 1995. Species Diversity in Space and Time. Cambridge University Press, Cambridge, UK.

Rouget, M., Cowling, R.M., Pressey, R.L., Richardson, D.M., 2003. Identifying spatial components of the ecological and evolutionary processes for regional conservation planning in the Cape Floristic Region, South Africa. Diversity and Distributions 9, 191–210.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., Woolmer, G., 2002. The human footprint and the last of the wild. Bioscience 52, 891–904.

Smith, R.J., Muir, R.D.J., Walpole, M.J., Balmford, A., Leader-Williams, N., 2003. Governance and the loss of biodiversity. Nature 426, 67–70.

Stattersfield, A.J., Crosby, M.J., Long, A.J., Wege, D.C., 1998. Endemic Bird Areas of the World: Priorities for Biodiversity Conservation. BirdLife Conservation Series No.7, Cambridge, UK.

UNDP, 1999. World Population Prospects: The 1998 revision, vol. 1, United Nations, New York, USA.

UNEP-WCMC, 2002. Protected areas database, version 5.0. UNEP-WCMC, Cambridge, UK.
White, F., 1983. The vegetation of Africa, a descriptive memoir to accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa (3 Plates, Northwestern Africa, Northeastern Africa, and Southern Africa, 1:5,000,000). United Nations Educational, Scientific and Cultural Organization, Paris, France.
Wikramanayake, E., Dinerstein, E., Loucks, C., Olson, D., Morrison, J., Lamoreux, J., McKnight, M., Hedao, P., 2002. Terestrial Ecoregions of the Indo-Pacific. Island Press, Washington DC, USA.
WWF and IUCN, 1994. Centres of Plant Diversity: A Guide and Strategy for their Conservation, vol. 1 Africa. Oxford, WWF and IUCN.