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Major gaps in the distribution of protected areas for threatened and narrow range Afrotropical plants

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Abstract. We investigated the major patterns of plant rarity in sub-Saharan Africa, and looked for the most significant gaps in the reserve network of the region in terms of representing the distribution of threatened and geographically rare plants. Comparisons of the species ranges captured by the network of reserves were made against the proportion of species captured by randomly generated sets of areas and against a theoretical near minimum set of areas that represent all species once. At this scale of analysis, the network of large IUCN-coded reserves (the official 'protected areas') performs poorly against random and systematic selection procedures. Significant gaps in the IUCN-coded protected areas are in coastal Gabon/Cameroon, in the various tropical montane forest areas (Cameroon Highlands, Eastern Arc Mountains, Ethiopian Mountains), in lowland coastal eastern Africa, and in the South African Cape. Some of these gaps, for example in the Eastern Arc and eastern African coastal regions, are covered on the ground by a network of Forest Reserves under the management of national Forestry Authorities. The networks of Forest Reserves in Ghana, Nigeria, Cameroon, Uganda, Kenya, Zimbabwe, Zambia and Sierra Leone also fill reservation gaps for rare African plants in these countries. Upgrading the conservation status of some key Forest Reserves, which has been gradually happening for some decades, is proposed as an efficient way to enhance the protected area network of the Afrotropical region for the conservation of rare African plant species.

Introduction

Reserves are regarded as one of the most important mechanisms available for the conservation of biological diversity (World Parks Congress 2003). Such reserves can be divided into two broad categories, those that are established primarily for conservation and those that have a greater role in resource utilisation. Those established for conservation purposes are coded according to a system proposed by IUCN and are termed 'protected areas' (IUCN 1993, 1998; UNEP-WCMC 2003). In Africa, wildlife conservation authorities mainly manage these kinds of reserves. Other reserves have been established as sites for controlled resource utilisation, primarily within forests and woodlands. This category of reserve includes various forms of government gazetted 'Forest Reserves', managed by Forestry Authorities. These reserves are not coded according to the IUCN system and hence cannot strictly be regarded as 'protected areas'.

Africa's first wildlife 'protected area' was the Albert National Park, declared in 1925, in what was then the Belgian Congo (Balmford et al. 1992). Large numbers of protected areas have been established since. Traditionally these protected areas were declared opportunistically (Siegfried 1989) on vast flat savannah regions, such as the Serengeti national park in Tanzania or the Kruger National Park in South Africa, which are famous for their large mammal assemblages. Many of the protected areas were declared during the colonial years to provide opportunities for big game hunting and some have been upgraded to non-hunting areas over the past century (Balmford et al. 1992). The network of protected areas covers large areas of savanna woodland habitats, but considerably smaller proportions of other habitats, such as the tropical moist forests and Mediterranean-climate habitats (Burgess et al. in press). These savanna-woodland protected areas also tend to be climatically unstable, often of low potential for livestock and agriculture, and many contain the vectors of diseases such as sleeping sickness carried by tsetse flies (Fjeldså et al. 1997; IUCN 1998).

The first 'Forest Reserves' were established in the late 1800s, for example in the East Usambara Mountains region of northeastern Tanzania (Hamilton and Bensted-Smith 1989; Lovett 2003). Countries under British and German colonial rule developed the most comprehensive systems of Forest Reserves, but similar areas were also created by other colonial powers. Traditionally these kinds of reserves were established in tropical forest habitats and aimed to provide areas for logging and other forms of resource harvesting, although in eastern and southern Africa this reserve category also covers montane forests that are placed under central government control because of their water catchment functions.

None of the different kinds of reserve networks in Africa south of the Sahara were originally established with the conservation of rare plants in mind. Only recently, for example within the detailed planning exercises undertaken in the Cape Floral Kingdom of South Africa – an area of global significance for endemic plants – have systematic assessments of ideal configuration of reserve networks been produced (see Cowling et al. 2003). As a consequence the existing reserve networks may be expected to perform poorly at covering the distributions of Africa's plant species.

This paper has two aims. The first is to explore the patterns of threatened and narrow range plant species in Africa, to illustrate the centres of extinction risk. The second is to assess the degree to which IUCN-coded protected areas and uncoded Forest Reserves across Africa potentially cover the distributions of those plant species assessed as threatened in the global 'Red List' (IUCN 2002), or which have narrow distributional ranges.

Methods

Area of analysis

This paper analyses plant distributions from Africa south of the Sahara. Previous work has recognised two major plant zones within this region, the Afrotropical region from the southern margins of the Sahara down to southern South Africa, and the Cape Floristic Region confined to the area of southwestern South Africa (e.g., Cowling and Richardson 1995). Detailed studies of the distribution of plant species, detailed gap analyses, and assessments of threat have already been completed for the Cape Floristic Kingdom (Rebelo 1994; Cowling et al. 2003) and we concentrate the discussion of our paper at the broader scale of the entire sub-Saharan area of Africa.

Species databases

Since 1997 several datasets on Africa-wide plant distributions have been established in order to map and analyse patterns of African phytodiversity. Significant work has been done by Linder (1998, 2001), at the Centre of Ecology, Law and Policy, University of York (Lovett et al. 2000; CELP 2001; La Ferla et al. 2002; Taplin and Lovett 2003), within the Botanical Museum, University of Copenhagen (Bürger 2001), and by the BIOMAPS Working Group at the Nees Institute for the Biodiversity of Plants (Küper et al., in preparation).

Since 2003, all these datasets have been fused with others into a *Biogeographic Information System on African Plant Diversity*, which is hosted and continuously updated by the BIOMAPS project within the BIOTA Africa framework programme (www.biota-africa.de). Since then, further collaborative analyses have been conducted (Linder et al. in press; Lovett et al. in press). The geographic coverage of the entire database extends to 27°N (the lower border of Morocco) and a database on plant distributions for Mediterranean Africa is in preparation. Data include Africa-wide distribution records for more than 6100 taxonomically revised species (status October 2003). This is about 10–15% of the African Flora. All species maps within this database present data as confirmed collection localities, with no extrapolation of potential ranges between these collection points.

Data were compiled from three main types of sources: one source of the data are digitised distribution maps, for example taken from publications like the AETFAT series 'Distributiones Plantarum Africanarum' ('DPA', Jardin Botanique National de Belgique ed., 1969-), for example 'Crotalaria in Africa and Madagascar' (Polhill 1982), 'Studies in Begoniaceae' (Sosef 1994), or the 'Loganiaceae of Africa XVIII' (Leeuwenberg 1977). We also digitised and georeferenced specimen information from various taxonomic revisions (see www.nees.uni-bonn.de/biomaps/biota/metadata.html). The third source is information taken directly from herbarium specimen labels. They have been either digitised by the authors or were contributed by co-operating institutions, for example, by the Wageningen Herbarium (including revised parts of the ECOSYN database), the PROTEA ATLAS PROJECT (http://protea.worldonline.co.za/default.htm), by H. Beentje (Kew), from the SIG Ivoire project (see Chatelain et al. 2001), the National Herbarium in Burkina Faso, and the Senckenberg Herbarium in Frankfurt. Additional data for southern Africa were contributed by P. Linder (especially on South African Orchidaceae and Restionaceae) and for arid areas by N. Jürgens, University of Hamburg complemented by data from Craven (2002). Data for the Saharan and the Sudano-Sahelien region were contributed by P. Frankenberg in Stuttgart (see Frankenberg and Klaus 1980).

The degree of spatial precision of the distribution data varies between exact localities, often from collections that were georeferenced *in situ* with GPS facilities, to 1° resolution data from digitised maps (e.g., the DPA series). Data are organised in MS Access databases and have been plotted and analysed using WORLDMAP software (Williams 1998, 2002) and ArcView 3.2a GIS software (ESRI 2000).

In order to achieve maximum comparability with previous analyses on sub-Saharan zoodiversity (Burgess et al. 2002; De Klerk et al. 2004; Fjeldså et al. 2004), all plant distribution data were rescaled to a 1° grid resolution within a base map of 1962 one-degree latitude–longitude grid cells, covering mainland sub-Saharan Africa. By restricting the geographical coverage to Africa south of the Sahara, and excluding those plants only found on offshore islands, we remain with a database containing 5958 plant species for further analysis.

Reserve data

Reserve data come from version 6.0 of the UNEP-World Conservation Monitoring Centre protected area database, from August 2003, developed by a consortium of agencies for the 2003 World Parks Congress (UNEP-WCMC 2003). Two major categories of reserve are recognised across Africa, and were used to create two separate databases for further analysis. The first database included all 'wildlife' reserves, which were here taken as all IUCN I-VI reserves and any of the following that had not been attributed an IUCN reserve code: national park, game reserve, wildlife management area, faunal reserve, faunal sanctuary, hunting reserve, partial faunal reserve and wildlife reserve. The second database included all 'forest' reserves, none of which have been coded into IUCN protected area categories and which included all the following reserves from the UNDP-WCMC database: forest reserve, botanical reserve, classified forest, national forest, nature reserve, state forest and state forest reserve 2 and non-hunting forest reserve. H. De Klerk of Western Cape Nature Conservation in South Africa used these data to calculate the percentage of each one-degree grid cell covered by these two categories of reserve (De Klerk et al. 2004). This was done by overlaying a 1×1 degree grid onto the reserve polygons projected using Lambert Azimuthal Equal Area projection (meridian = 20 E; latitude = 0), and making the percentage area calculation using ArcView 3.2a GIS software (ESRI 2000). These reserve data are the same as that used in studies of reservation gaps for threatened birds and mammals (De Klerk et al. 2004; Fjeldså et al. 2004).

To assess the likelihood that the existing reserve network covers plant species, we developed cut-off levels for different amounts of protection and used these to assign grids as either 'protected' or 'unprotected' (*sensu* Williams et al. 1996). We used four arbitrary 'protected' thresholds – at least 10% of the area of a grid cell is covered by reserves, at least 25% covered, at least 33% covered, and finally at least 50% covered.

Threatened plants database

Two threatened plant databases were developed, as follows.

The first database is derived from the IUCN 2002 Red List (IUCN 2002; www.redlist.org). This identifies 1028 species of plants as threatened in sub-Saharan Africa. We selected all species that fall into the categories critically endangered (CR), endangered (EN) or vulnerable (VU). Extracting these species from our original database of 5958 species gave us 121 threatened plant species in 326 grid cells for further analysis. This is our 'Red List' database.

A second database was produced using geographical range as the measure of extinction risk. This was done because the Red-listing process for plants has not been completed for Africa, with only trees being classified to a reasonable extent (Oldfield et al. 1998; Walter and Gillett 1998; Farjon and Page 1999; IUCN 2002). One of the IUCN Red List criteria states that a species is classified as threatened if 'a species with severely fragmented populations existing at no more than 10 locations with an area of occupancy not exceeding 20,000 km^2'. A 1° grid cell is equivalent to an area of approximately 100 by 120 km (12,000 km^2). Because many plants have highly restricted distributions, they may only inhabit a small proportion of a grid cell. To further explore range rarity within our plant databases, we developed databases of plant species that have distributions of one, two, three and four grid cells. The one, two, three and four grid cell rarity databases contain between 863 and 2466 species in 318 to 762 grid cells. We selected the two grid cell plant database, containing 1551 species with a total distribution of less than 24,000 km^2 as our 'range-rarity' database.

Analyses

WORLDMAP software (Williams 1998, 2002) was used to perform the analyses undertaken in this paper. This programme has been designed for exploring aspects of spatial pattern in large biological data sets, particularly the analysis of biodiversity, rarity and conservation priorities. Using this software we completed three analyses.

Patterns of extinction risk across Africa. Extinction risk was mapped as the species richness of plant species in our 'Red List' and 'range rarity' databases.

Effectiveness of protected areas at covering threatened plant distributions. We defined effectiveness as the number of plant species captured within sets of grids defined as 'protected'. Calculations were performed separately for the 'Red List' and 'range rarity' databases against the set of grids defined as protected at the >10%, >25%, >33% and >50% thresholds, for both IUCN-coded wildlife reserves and wildlife plus Forest Reserves.

Efficiency of protected areas at covering threatened plant distributions. Efficiency is defined here as the degree to which a network of 'protected' grid cells performs better or worse than other ways of selecting grid cells to cover the distribution of 'Red List' and 'range rarity' plants in sub-Saharan Africa. Firstly, we calculated the percentage of threatened species present in sets of cells 'protected' by IUCN-coded protected areas and uncoded Forest Reserves at the different thresholds. Secondly, we performed a similar calculation against randomly selected grids. The randomisation procedure we used calculated the median representation of species across 1000 sets of each size, and generated confidence limits 2.5% above and 2.5% below the random line (Williams 1998). Thirdly, we used the greedy complementarity algorithm according to range size rarity (Margules et al. 1988, 2002; Williams 1998) to define near minimum sets that cover all plant species from the 'Red List' and 'range rarity' databases in at least one grid.

Results

Patterns of extinction risk across Africa

For the 'Red List' database, the most distinct centres of threatened species richness occur in the Eastern Arc Mountains of Tanzania, the eastern African coastal forests of Kenya and Tanzania, the Cameroon highlands, the Cameroon to Gabon lowland coastal forests, and the Western African equatorial forests (Figure 1(b)). The one, two-grid cell rarity databases show additional centres of rare species richness in the Cape Floristic Region, the Albertine Rift Mountains, Kenya Highlands, around the Zambezi-Congo watershed region, in southern Namibia and along the Drakensberg Mountains, and the southeastern coastal forests of South Africa (Figure 1(c and d)). Similar patterns are also seen in the three- and four-grid cell databases (Figure 1(e,f)). To a large degree these patterns track those of overall species richness in the 5958 plants in the database (Figure 1(a)), although rare species are more confined to the tropical mountains.

Effectiveness of protected areas at covering threatened plant distributions

Our analysis indicates that the network of large IUCN-coded protected areas does not adequately represent the distributions of plant species in our 'Red List' and 'range rarity' databases (Table 1).

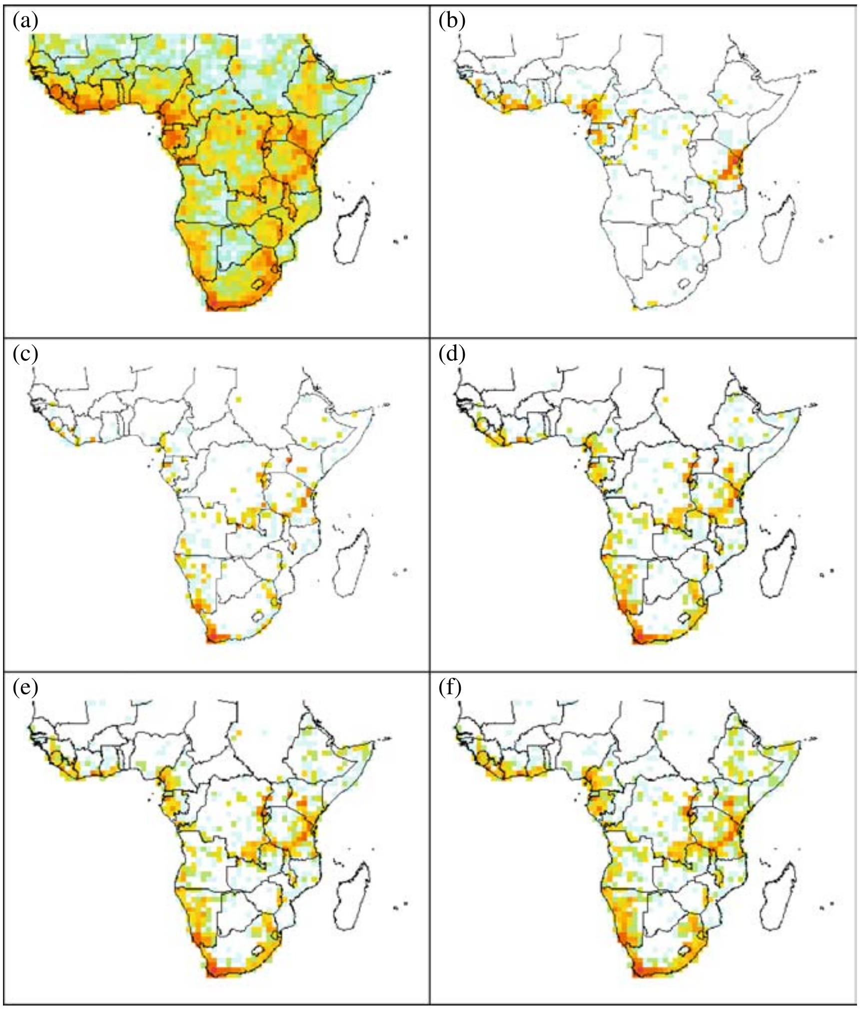

Figure 1. Plant species richness patterns across Africa. (a) Patterns of richness of collection records for 5958 plant species across sub-Saharan Africa at one-degree grid cell resolution. (b) Richness of records for 121 Red listed threatened plant species. (c) Richness of records for 871 one-grid cell range rare species. (d) Richness of records for 1571 two-grid cell range rare species. (e) Richness of records for 2074 three-grid cell range rare species. (f) Richness of records for 2496 four-grid cell range rare species. Species richness ranges from blue (low), through yellow and orange to red (high). White means no records of relevant plant species are known for that grid cell.

For the ‘Red List’ database, the IUCN coded protected areas, at the >25% threshold, cover 53 of the 121 species (43.8%), with major protection gaps in the eastern African Coastal Forest and the Eastern Arc Mountains of Kenya and Tanzania (Figure 2(a)). Other areas rich in ‘Red List’ plants that are not covered adequately by IUCN-coded protected areas are the Upper Guinea forests of West Africa,

Table 1. Number and percentage (in parentheses) of Red listed (IUCN 2002) and range restricted (1, 2, 3 or 4 grid cells) plant species captured within grid cells protected by 10%, 25%, 33% or 50% coverage of IUCN coded protected areas (categories I–VI) managed by wildlife conservation authorities, or by IUCN-coded plus unlisted Forest Reserves (FR) managed by forestry management authorities.

Species rarity		Percentage of protection of grid cells							
		10% IUCN 403 grids	10% IUCN&FR 522 grids	25% IUCN 218 grids	25% IUCN&FR 274 grids	33% IUCN 172 grids	33% IUCN&FR 214 grids	50% IUCN 99 grids	50% IUCN&FR 117 grids
IUCN Red list	121 species	89(73.5)	95(78.5)	53(43.8)	78(64.5)	46(38.0)	56(46.3)	38(31.4)	42(34.7)
1-Cell range rarity	871 species	291(33.5)	354(40.7)	96(11.1)	119(13.7)	74(8.5)	88(10.2)	53(6.1)	55(6.4)
2-Cell range rarity	1571 species	651(41.5)	769(49.0)	222(14.2)	299(19.1)	157(10.0)	208(13.3)	97(6.2)	107(6.8)
3-Cell range rarity	2074 species	952(46.0)	1123(54.2)	329(16.0)	445(21.5)	231(11.2)	303(14.6)	135(6.5)	151(7.3)
4-Cell range rarity	2496 species	1264(50.7)	1467(58.8)	458(18.7)	623(25.0)	325(13.1)	432(17.3)	175(7.1)	210(8.4)
All taxa in database	5958 species	4382(73.5)	4734(79.4)	2586(43.4)	3132(52.6)	2224(37.3)	2756(46.3)	1344(22.5)	1687(28.3)

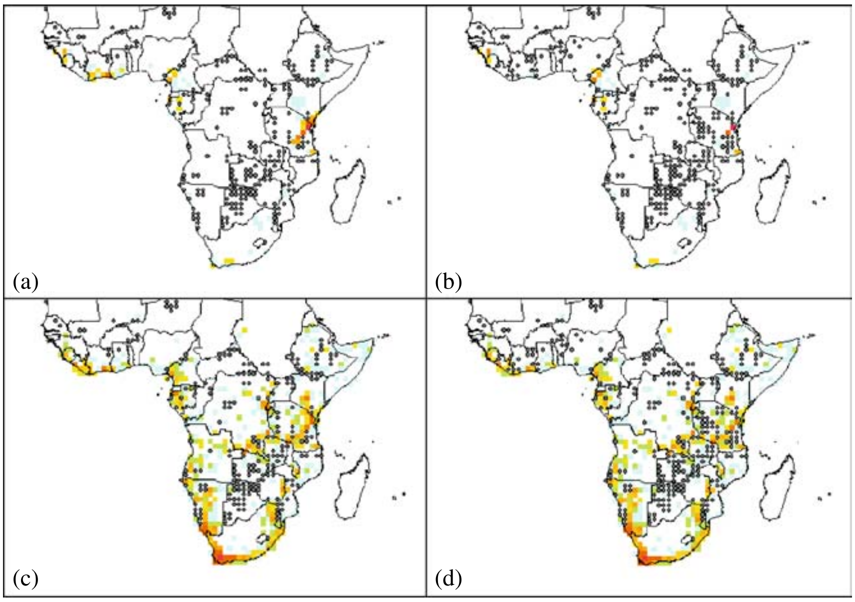

Figure 2. Major gaps in the Afrotropical protected area network for threatened plants. (a) Gaps in the Red List database at the >25% 'protected' threshold for IUCN-coded wildlife reserves (218 grid cells), (b) Gaps in the Red List database at the >25% 'protected' threshold for IUCN-coded wildlife reserves, plus Forest Reserves (274 grid cells), (c) Gaps in the two-grid cell 'range rarity' database at the >25% 'protected' threshold for wildlife reserves, (d) Gaps in the two-grid cell 'range rarity' database at the >25% 'protected' threshold for wildlife reserves, plus Forest Reserves. Dark grey spots mark grids covered by protected areas at the 25% threshold. Remaining (not covered) species richness ranges from blue (low), through yellow and orange to red (high). White means no records of relevant plant species are known for that grid cell.

the Cameroon Highlands, and lowland Gabon (Figure 2(a)). The proportion of 'Red List' species covered rises to 73.5% in the set of grid cells 'protected' at the 10% cut-off, and falls to 38% and 31.4% at the 33% and 50% protected thresholds, respectively. When Forest Reserves are added, the number and percentage of Red listed species rises at every protected threshold (Table 1), with the greatest level of coverage of plants (78.5%) achieved at the 10% reserve threshold. Forest Reserves cover some of the Red List species of the Eastern Arc and coastal forests of Tanzania and Kenya and those in the Upper Guinea forests of West Africa (Figure 2(b)). However, this category does not close the protection gaps in the Cameroon Highlands.

The reserve networks cover fewer of the species in the various 'range rarity' databases we have constructed (Table 1). The IUCN-coded protected areas at the 25% threshold cover 222 of the 1571 species (14.2%) in the two-cell range rarity plant database (Figure 2(c)). Apparent protected area gaps are seen in the Cape area of South Africa, in coastal Cameroon, Equatorial Guinea and Gabon, in the Albertine Rift, in the Eastern Arc and coastal forests of Tanzania, West African

Table 2. Comparison between percentage of Red listed and range restricted (2 grid cells) plant species captured within grid cells protected by 10%, 25%, 33% or 50% coverage of IUCN-coded protected areas (categories I–VI), or IUCN-coded reserves plus uncoded Forest Reserves (FR), in comparison with selecting the same number of grid cells randomly (with 5% confidence limits spread either side of the random line), or using complementarity (greedy algorithm – range size rarity).

Protected area coverage	Number of grids	Red List species covered by reserves (%)	Red List random (%)	Lower 2.5% (%)	Upper 2.5% (%)	Complementarity (%)	2-Cell range rarity species covered by reserves (%)	Range rarity random (%)	Lower 2.5% (%)	Upper 2.5% (%)	Complementarity (%)
10% IUCN	403	73.5	100	100	100	100	41.4	87.0	79.3	91.3	100
25% IUCN	218	43.8	90.9	77.7	96.7	100	14.2	53.9	43.1	62.9	89.9
33% IUCN	172	38.0	83.5	66.1	93.4	100	10.0	43.8	32.9	53.9	85.6
50% IUCN	99	31.4	65.3	43.0	81.0	100	6.2	25.9	17.8	36.7	74.1
10% IUCN&FR	522	78.5	100	100	100	100	49.0	100	100	100	100
25% IUCN&FR	274	64.5	96.7	88.4	100	100	19.1	65.4	54.6	73.1	93.5
33% IUCN&FR	214	46.3	90.1	76.9	96.7	100	13.3	53.1	42.4	62.3	89.7
50% IUCN&FR	117	34.7	71.1	49.6	85.1	100	6.8	30.7	21.8	41.3	77.9

forests, and around the headwaters of the Zambezi in northern Zambia and south-eastern DRC. At the 10% protected threshold, the percentage of plants 'protected' increases to 41.5% and at the 33% and 50% protected thresholds, it falls to 10.0% and 6.2% of the two-grid cell plant species, respectively. The proportion of the two-grid cell range rare species is slightly higher when the Forest Reserves are added to the IUCN-coded protected areas (Table 1), and some of the gaps (especially in the Eastern Arc and coastal forests of Tanzania and the West African forests) are closed by the addition of these reserves (Figure 2(d)).

Efficiency of protected areas at covering threatened and rare plant distributions

There is a great variation in area between the IUCN-coded protected area network and the Forest Reserve networks at given protection thresholds (Table 1). Hence differences in the coverage of plant species are partly due to differences in area. Looking at the coverage of species against area, and in comparison with random and theoretical 'best' solutions to covering the same sets of plant species, provides a metric to compare these results more equally. Results show that the random selection of grids covers a higher percentage of Red List or range rarity species than do any of the sets of grid cells developed using different percentage thresholds of protection (Table 2). Table 2 also shows that the theoretical minimum set of areas required to cover all the Red List or range rarity species is much more efficient at covering these species once than either the networks of reserves, or the set of randomly selected grids. For the Red List database the greedy area complementarity algorithm (Williams 1998) only requires 32 grid cells to cover all 121 species at least once, and for the range rarity database this method requires 370 grid cells to achieve the same for 1571 plant species.

Discussion

Our analysis of the patterns of threatened species across Africa builds upon the analyses of patterns of Afrotropical plant species richness and endemism presented elsewhere (Linder 1998, 2001; Lovett et al. 2000; Mutke et al. 2001; La Ferla et al. 2002). By mapping the species of smallest distributional ranges, and those regarded as threatened by extinction, we have highlighted those areas of particular importance for the conservation of Afrotropical plant biodiversity. In general the most important areas are located on tropical mountains, in the tropical forests of the western Congo Basin and West Africa and the Mediterranean-climate habitats of South Africa.

This paper also shows that, in general terms, there appear to be significant gaps in the reserve networks of Africa in terms of their coverage of plant species regarded as threatened with extinction and those with small ranges that are not on 'Red Lists'. These gaps are concentrated in some of the montane regions of tropical

Africa, and in the Cape Region of South Africa, both places of exceptional plant endemism and numerous threats to plants. The paper has also indicated that Forest Reserves have value for the conservation of threatened plant species, and might be important conservation targets in some regions. In particular, the forested habitats of the eastern African coastal forests and the Eastern Arc Mountains of Tanzania and Kenya (our largest protected area gap) are almost entirely located within Forest Reserves (Lovett and Pócs 1993; Rodgers 1993; Burgess et al. 1998, 2002; Burgess and Clarke 2000; Newmark 2002). Using a more detailed analytical approach, Nature Kenya and WCST (2003) showed that the majority of the Red Listed plants from the same region are found within Forest Reserves. Other African countries with biologically important and relatively well-managed Forest Reserves are Ghana (Hawthorne and Abu-Juam 1995; Hawthorne 2001), Uganda (Howard 1991), Kenya (Wass 1995), Zimbabwe (Müller 1999) and Sierra Leone (e.g., Harcourt et al. 1992). These forms of reserves also have some conservation functions in Liberia, Ivory Coast, Nigeria and Cameroon, although many are used heavily for logging and may be severely degraded. It seems likely that the Forest Reserve network of many African countries has considerable value for the conservation of threatened plants, which should be further explored at the national and regional levels.

Not featured at all within the protected area database of UNEP-WCMC are the community level protected areas, such as sacred forests. These are already known to have a significant role in the conservation of threatened and range-restricted plant species, for example in the fragmented forests of Ghana and coastal Kenya (Robertson and Luke 1993; Hawthorne and Abu-Juam 2001). Community conservation in the form of village wildlife areas, and village Forest Reserves is being promoted in Africa as an alternative to, or complementary with, the traditional establishment of government reserves (e.g., Hackel 1999; Hulme and Murphree 1999; Miller and Hobbs 2002). Although most community protected areas are small, they may be effective conservation areas for relatively small and immobile species, such as many rare species of plants.

There are several possible limitations to the results presented here. Firstly, the analysis does not cater for reserve networks that cover less than 10% of the area of a grid cell. Smaller reserves are typically found in areas of higher population density (Harcourt et al. 2001) and these include some of the centres of plant rarity (tropical mountains and Cape Fynbos) outlined here. For example, more than 70% of South Africa's 582 protected areas are relatively small (<5000 ha) and spatially isolated and hence do not fulfil our criteria. Other assessments from the region indicate that South African reserves cover 74% of the 20,300 indigenous vascular plants of the region (Siegfried 1989). Although the existing reserve network may do a better job at conserving rare African plants than is indicated here, protected area gaps for rare plants in the Cape Region are also demonstrated in studies working at finer scales (Rebelo 1994; Cowling et al. 2003). Secondly, our total plant database represents around 15% of the estimated number of plant species in sub-Saharan Africa and hence a further 85% are not yet included in the database, a high proportion of which are probably not yet mapped. Amongst these are several hundreds of species that are featured in the current plant Red List or which have tiny ranges and which might feature in future Red Lists. Such species are also still being discovered all the time, for example in the Eastern Arc Mountains of Tanzania (Cheek 2004). Thirdly, sampling intensity is not spread evenly among the continent. As a consequence, using databases such as the one presented here, the absences of species in some areas could be merely due to incomplete sampling rather than real absences. We have some evidence that, especially in Sudan, Ethiopia, Republic of the Congo, and Democratic Republic of the Congo, species distributions in several areas are so poorly documented that at present their absence cannot be confirmed (Küper et al., in preparation). Potential effects are an overestimation of their range restrictedness and consequently the threat imposed on them, as well as an under-representation of inadequately sampled areas in terms of their biodiversity. This problem becomes particularly important if costs and consequences caused by conservation are taken into consideration, for example, to maximise the effectiveness of protected area networks not by area size but by cost efficiency (Balmford et al. 2001). If less accessible areas (wilderness, *sensu* Mittermeier et al. 1998) tend to be less well sampled in comparison to areas with a pronounced human infrastructure, the potential of these wilderness areas to alleviate conservation conflicts (Luck et al. 2004) might be underestimated so far. However, for the comparison of the performance of various area networks, we are confident that the bias does not distort the relevant result since it is likely to influence each area network equally.

Despite the mentioned limitations, we predict that our results do show some of the broad patterns of threat and protected area gaps across the continent. Spatial patterns retrieved in our analysis are well in accordance with regional studies based on very comprehensive and detailed data, as for the upper Guinea region (Wieringa and Poorter 2003) and the area of the Flora of Tropical East Africa (personal communication, Henk Beentje, Kew). Moreover, the reservation gaps we outline here are basically the same as those indicated in analyses of threatened birds and mammals (De Klerk et al. 2004; Fjeldså et al. 2004), although the Cape region of South Africa is of much higher importance for plants. When compared across all three taxa, the existing reserve network is most effective at covering the distributions of threatened mammals, but becomes increasingly less optimal for the effective conservation of threatened birds and plants. For the majority of the protected area network, this is not surprising, since on the whole, these reserves were established for the protection of large mammals, mostly without consideration of the distribution of other taxon groups including plant species. In other cases the location of reserves has been based more on political, economic and social factors than on conservation requirements, for example many reserves are located in areas of semi-arid variable climate and traditionally utilised by pastoralists (Balmford et al. 1992).

Other studies provide additional clues on the challenges to the effective conservation of threatened and narrow ranging plants within reserves. Recent studies show that species richness of plants and animals across Africa is correlated with rainfall (Balmford et al. 2001; Mutke et al. 2001; Taplin and Lovett 2003). Other studies have hypothesised that centres of narrow-range endemism are often found in regions that have experienced long-term ecoclimatic stability (Lovett and Friis 1996; Fjeldså and Lovett 1997; Fjeldså et al. 1997; Lovett et al. 2000). The same wetter and climatically stable regions contain the highest human population densities and human cultural diversity (Balmford et al. 2001; Moore et al. 2002), and typically support smaller and more threatened reserves (Harcourt et al. 2001). The gaps we have identified in the reserve network for the conservation of threatened and narrow-ranging plants tend to be located in regions of high human population density, which have at least moderately fertile and profitable land, and where settled human habitation has occurred over hundreds of thousands of years. The development of additional large government protected reserves in such areas will be difficult. The creation of targeted smaller reserves, at the national, local authority or, community levels, may be the only way to prevent threatened plant species from becoming extinct within an increasingly transformed landscape.

In conclusion, it seems reasonable to suggest that the network of IUCN-coded protected areas in sub-Saharan Africa leaves numerous Red-listed threatened plant species, or species with small geographical ranges, vulnerable to extinction. Moreover, it seems that the largest gaps in the network of IUCN I-VI-coded reserves are within the tropical mountain ranges, coastal eastern Africa and in parts of the Cape of South Africa. In some regions Forest Reserves managed by forestry authorities fill some of the protected area gaps, and in other cases there are also traditional sacred patches that conserve plants that require small patches of habitat to survive. Recognising some of the important contributions to plant conservation made by Forestry Departments and local populations, and supporting these, may significantly assist the conservation of rare African plants, but the targeted creation of additional IUCN-coded protected areas is also regarded as essential to prevent species loss in the region.

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