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AFRICA'S HOTSPOTS OF BIODIVERSITY REDEFINED[1]

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ABSTRACT

A key problem for conservation is the coincidence of regions of high biodiversity with regions of high human impact. Twenty-five of the most threatened centers of plant diversity were identified by Myers et al., and these "hotspots" play a crucial role in international conservation strategies. The primary goal of the hotspots is to cover the most threatened centers of plant diversity, but their efficacy has not yet been tested empirically. For sub-Saharan Africa, our study evaluates the hotspots postulated by Myers and compares them to a set of redefined hotspots proposed on the basis of mapped distribution data for 5985 plant species. The two sets of hotspots overlap by 48%. Our redefined hotspots include 80% of the species and 66% of the range-restricted species of the sub-Saharan flora in areas under high human

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impact, whereas these values are 15% and 11% lower for Myers's hotspots. Despite having equal size and a considerable spatial overlap with Myers's hotspots, our redefined hotspots include further highly threatened centers of plant diversity in the Maputaland Pondoland Region, in Katanga, the East African Afromontane region, the Lower Guinea Region, and the Albertine Rift. Many of these redefined hotspots are poorly protected centers of plant and animal diversity. Their conservation is essential for a comprehensive coverage of Africa's centers of biodiversity.

Key words: Africa, biodiversity, conservation, endemism, Global Strategy for Plant Conservation (GSPC), hotspots, important plant areas.

There are growing concerns about the coinciding spatial patterns of human population density and biodiversity (Cincotta et al., 2000; Myers et al., 2000; Balmford et al., 2001; Luck et al., 2004). In a pioneering study in 1988, Myers identified a global set of hotspots where exceptional concentrations of species with high levels of endemism face exceptional threats of destruction (Myers, 1988). Later updates (Myers, 1990; Myers et al., 2000) played a crucial role in the public perception of the threat to biodiversity and the development of large-scale concepts for setting spatial priorities for in situ conservation, as required by Article 8 of the Convention on Biological Diversity (UNCED, 1992).

Whereas centers of diversity are identified on the basis of biological richness and endemism, the hotspots concept of Myers et al. (2000) combined two criteria: plant diversity and the threats to that diversity. In practice, hotspots were defined as areas with less than 30% intact primary vegetation and with at least 0.5% of the global plant species being endemic to the area.

Myers et al. based their study on two types of information. In addition to expert advice, they used summary information on the number of endemic species occurring in the hotspots. This "inventory-based type" of information (Barthlott et al., 1999; Mutke et al., 2002) was the only available information on the biodiversity for many areas (Myers et al., 2000; Krupnik & Kress, 2003), though the application and the analysis of this data type is limited (Mutke & Barthlott, in press). Indeed, Myers et al. (2000; see also Brooks et al., 2001) mentioned several areas in sub-Saharan Africa for which the available data are insufficient to decide whether or not they represent a hotspot. They also stated that due to the heterogeneous data situation, they had to use the endemism criterion even though it was felt to be "minimalist" (Myers et al., 2000). In addition, information on biodiversity was, and often still is, only available for comparatively large areas delineated by political boundaries. This low spatial resolution limits the accuracy to which centers of diversity can be identified (Krupnik & Kress, 2003).

More than a decade after the first global set of hotspots was published, it has become possible to define hotspots more rigorously and accountably. Diversity can now be calculated from a "taxon-based type" of information (Barthlott et al., 1999; Mutke & Barthlott, in press), consisting of reliable data on the individual distribution areas of a large number of taxa (Williams, 1996; Burgess et al., 1998). New high-resolution socioeconomic data (CIESIN, 2000; Sanderson et al., 2002) have become available. Complex algorithms (Margules & Pressey, 2000) allow a more precise identification of centers of richness and endemism (Lovett et al., 2000; Linder et al., in press) and permit analyses of the degree of potential conflict between conservation and land-use interests (Balmford et al., 2001; Williams et al., 2003; Luck et al., 2004).

Consequently, taxon-based biodiversity information has been used to criticize the global hotspot areas as defined by Myers et al. (2000) for their conceptual background (Jepson & Canney, 2001), for their performance in comparison to other area networks selected on more complex parameters (Williams et al., 1996; Balmford et al., 2001), for their size (Brummit & Lughadha, 2003), and occasionally for their location (Burgess et al., 2002; Krupnik & Kress, 2003). However, to our knowledge, there is no study that assesses whether the hotspots do indeed cover the most threatened centers of plant diversity, even though this was the original intention of this prioritization scheme.

In this paper we evaluate the extent to which Myers's hotspots include a maximum number of rare plant species in those areas most threatened by human impact in Africa. This is important for four reasons: (i) as the foundation of food webs, plants are of essential importance for terrestrial biodiversity; (ii) plants might be the best available surrogate to represent invertebrate diversity (Myers, 1988); (iii) plant diversity is insufficiently covered by current networks of protected areas (Burgess et al., in press); and (iv) plants are the group from which hotspots were identified by Myers et al.

Which criteria should be used to evaluate and enhance the performance of the hotspots? A modification of the current hotspots would be desirable if they exclude areas in which more rare plant species are more threatened by human impact than in included areas. Here we test the efficacy of the hotspots using the most comprehensive available database of plant species distributions for sub-Saharan Africa.

METHODS

SPECIES DATABASE

Since 2003, an international group of research institutions has contributed data on Africa-wide plant distributions to the *Biogeographic Information System on African Plant Diversity* (*BISAP*), which is hosted and curated by the BIOMAPS Project within the BIOLOG BIOTA framework (www.biota-africa.org).

The database includes Africa-wide distribution records for 6269 species (status March 2004), all of which had been taxonomically revised. The database comprises about 330,000 distribution records from confirmed collection localities. The spatial precision of the data varies from exact localities (mainly from herbarium collections with geo-referenced localities) to one-degree resolution data from digitized maps. Data are organized in MS Access databases and have been plotted and analyzed using WORLDMAP software (Williams, 2002) and ArcView 3.2a GIS software (ESRI, 2000). In order to achieve maximum comparability with previous analyses on sub-Saharan zoodiversity (Balmford et al., 2001; Brooks et al., 2001; Burgess et al., 2002; Burgess et al., in press; Fjeldså et al., 2004; De Klerk et al., 2004), all plant distribution data were rescaled to a one-degree grid resolution within a base map of 1713 one-degree latitude-longitude grid cells covering mainland sub-Saharan Africa south of 17 degrees latitude. By restricting the geographic coverage to Africa south of the Sahara and excluding those species found only on offshore islands, a database with 5985 plant species remains for further analyses. This is between 10% and 15% of the species in the African flora (Lebrun & Stork, 1991–1997; Beentje et al., 1994). Additional information on the origin of this data set is documented in Burgess et al. (in press, see also footnote 1).

Our plant data are the most comprehensive ever assembled for the study area, but inevitably have limitations. There are certain areas in Ethiopia and Somalia, Sudan, the Central African Republic, the Republic of Congo, the Democratic Republic of Congo, and Angola where analysis of sampling intensity indicates that plant diversity is not adequately documented in our databases (W. Küper, unpublished data). The scientific exploration of these areas is an important challenge for the future. Inadequate availability of distribution data could have two effects on our analysis: First, in cases where we have inadequate data for areas included in the hotspots as delineated by Myers et al. (2000), testing the hotspots on the basis of our data might result in an underestimation of their performance in covering sub-Saharan plant diversity. However, in fact the most detailed, updated, and comprehensive distribution data in our database is for those areas covered by the Myers's hotspots (which may partly be a consequence of highlighting these areas since 1988): (i) Data for the upper Guinea (West Africa) hotspot stem from the National Herbarium of the Netherlands–Wageningen branch; (ii) data for the Western Cape are from the National Botanic Institute, Republic of South Africa, and contributed by T. Rebelo and N. Jürgens; and (iii) distribution data for East Africa stem from a compilation of restricted-range species for the area of the Flora of Tropical East Africa (H. Beentje, unpublished data, together with other sources). Even though the data for West Africa are comparatively comprehensive, the eastern part of the upper Guinea hotspot is potentially less well represented due to lower data availability. Second, it is possible that the selection of our alternative set of hotspots on the basis of our data misses areas that are richer in species than those included simply because the former ones are not adequately collected. This is certainly a key problem if areas are selected on the basis of species richness alone. But this problem is not as prominent when selecting hotspots, because their identification is also based on the intensity of human impact. Hotspots tend to be particularly well collected (i) due to their popularity with biologists (Reddy & Dávalos, 2003) and (ii) because their high human impact is associated with a comparatively good infrastructure providing access (Gibbs Russell et al., 1984).

DIGITIZING THE HOTSPOTS OF MYERS ET AL.

In order to compare the sub-Saharan hotspots of Myers et al. (2000) with our data arranged in one-degree cells, we first digitized Myers's hotspot polygons (delineations taken from Mittermeier et al., 1999) and overlaid them on our grid of cells. We then identified all cells that had a spatial overlap of more than 25% of their area with the hotspots polygons (see methods in Burgess et al., 2002). The decision to accept or omit cells with less than 25% overlap could affect the performance of the hotspots in covering Africa's most threatened centers of plant diversity compared to alternative hotspots de-

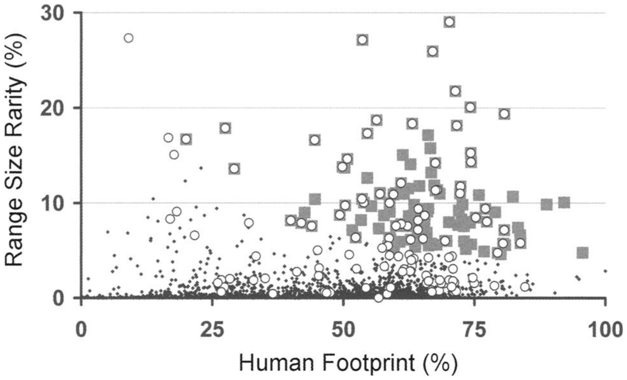

Figure 1. Scatterplot illustrating the values of range-size rarity and mean human footprint (rescaled from Sanderson et al., 2002) for each of the 1713 sub-Saharan one-degree cells (each represented by a black dot, partly concealed by other symbols). Both parameters are rescaled to percentages. For better visualization, the seven cells with a range-size rarity of more than 30% are not shown (X/Y-values for these cells: (63/100), (75/89), (99/68), (97/60), (38/42), (53/36), (42/35)—these are all in both Myers hotspots and redefined hotspots). Open circles: 125 cells covered by the Myers hotspots. Gray boxes: 125 cells with highest product of range-size rarity and human footprint, cited as "redefined hotspots" in the text.

lineated on the basis of our data. We therefore tested whether the inclusion of further cells (those with less than 25% overlap) would improve the performance of the hotspots in comparison to our redefined hotspots of equal area in each case. If this was the case, we accepted the cell as part of the hotspots. With this most conservative method in favor of the performance of the Myers et al. hotspots, 125 cells were identified as being part of these hotspots. From here on, they will be referred to as "Myers hotspots" (Fig. 2A).

CHOOSING DATA TO REPRESENT PLANT ENDEMISM AND ITS THREAT

The aim was to select data to best approximate the two criteria used for the delineation of the Myers hotspots, which were plant endemism and threat. Using our data we selected 125 cells in which plant diversity and threat are maximized (Fig. 1) on the basis of the following two measures. (i) We calculated range-size rarity for each cell (Fig. 2B). This combines the number and range sizes of species in each cell (Williams, 1996; Kier & Barthlott, 2001; Wieringa & Poorter, 2003). The more species that occur in a cell and the smaller their ranges are, the higher the value. We chose range-size rarity since it best approximates the endemism criterion applied by Myers et al. (2000). In contrast to their criterion, range-size rarity includes not only the species strictly endemic to the hotspots, but also every species whose range overlaps with them. Hence, two areas with the same number of strict endemics can still be differentiated according to their contribution in covering the ranges of other species. (ii) As a surrogate for threat, we calculated the mean human footprint for each cell, rescaling the data from Sanderson et al. (2002) to one-degree cells (following the methods used in Balmford et al., 2001; Luck et al., 2004). For coastal cells, the mean footprint was calculated on the basis of mainland values only. The human footprint index shows similar spatial patterns to parameters such as population density, which was used in previous studies (Balmford et al., 2001; Lesslie, 2002; Luck et al., 2004), but in addition takes into consideration a wider range of factors, such as infrastructure and land-cover. Thus, agricultural areas that do not necessarily have a high human population density are included as having a high human impact on biodiversity. We calculated mean values of human

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Figure 2. —A. Map of the set of redefined hotspots identified in the present study, contrasted with the hotspots as delineated by Myers et al. (2000). Solid black line within continent: *Myers hotspots.* Gray open squares: 125 one-degree grids covered by the Myers hotspots (see methods). Red squares: 125 cells covered by the *redefined hotspots* (cells with highest product of range-size rarity and mean human footprint per cell). Black dots represent 125 first cells (compare Table 1) of a near-minimum-cost area set (Williams, 2002, the entire near-minimum-cost set is illustrated in Fig. 2B). —B. Range-size rarity per one-degree grid cell. This measure combines the values for richness and the range sizes of the species occurring in each cell. It is calculated as the sum of the inverse range sizes per cell (Williams, 1996).

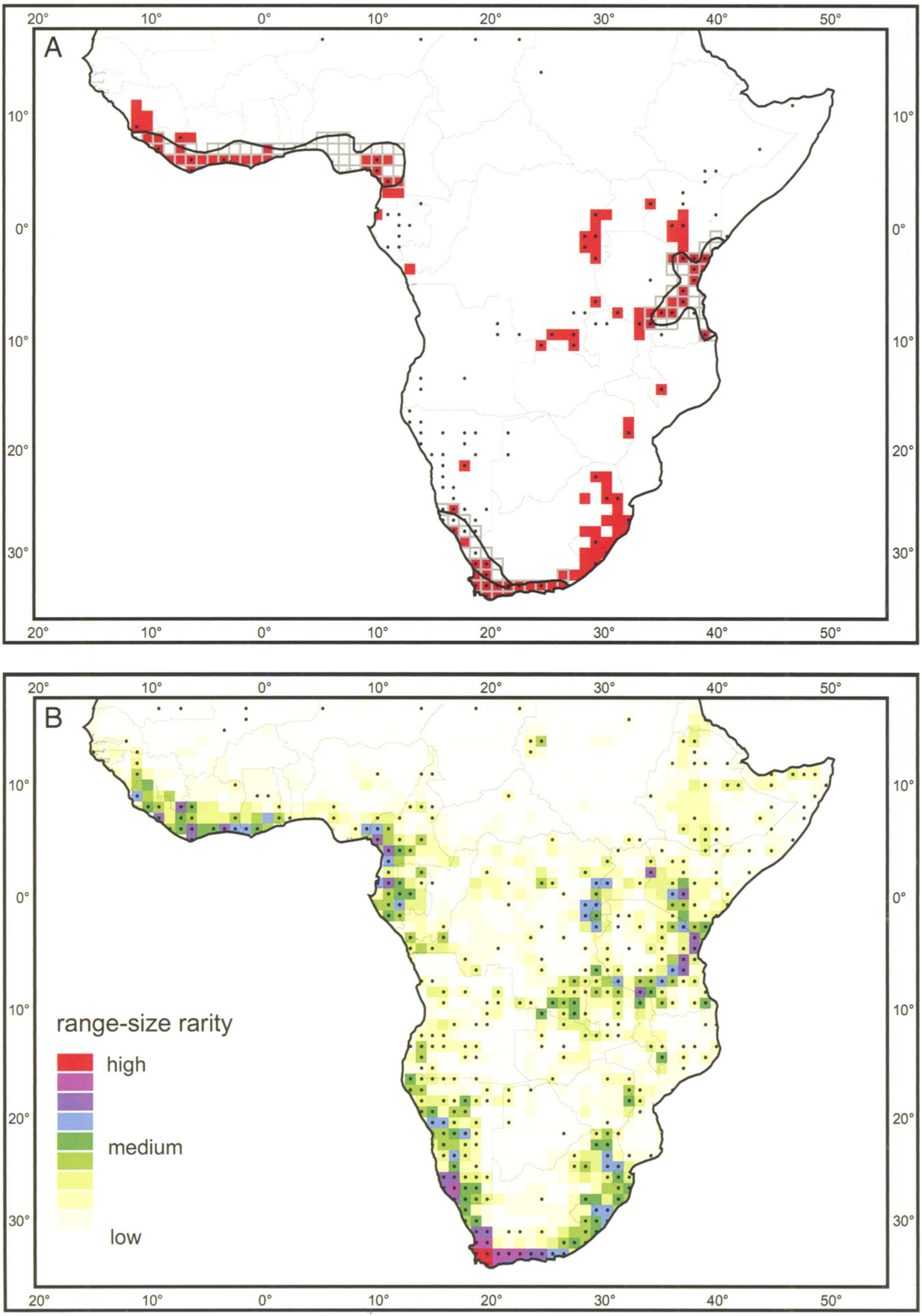

Figure 2. —B. (Continued) Note that many species of medium range size may result in a similar cell value as one with fewer species of very small range size. Black dots mark 422 cells that form the near-minimum-cost area set for sub-Saharan plant diversity in the data set (Williams, 2002). These cells represent all 5985 plant species in a set with near-minimum total human footprint. The figure shows Africa south of 17ºN latitude with grey background lines indicating national boundaries.

footprint per cell so that roads or populated places close to relatively intact areas do not dominate the values for these cells. From here on, mean footprint per cell is referred to as "human footprint."

IDENTIFYING HOTSPOTS ON THE BASIS OF OUR DATA

(i) Range-size rarity and human footprint were normalized to a percentage of their maximum value, so that they are both equally scaled.

(ii) To represent a measure that best approximates the "heat" of the Myers hotspots, we then calculated the product of the value of footprint and range-size rarity. This index, which combines biodiversity and human impact, does not fully reproduce the methods of Myers et al. and is too simplistic to derive any detailed conclusions on conservation priorities. However, it is suitable for representing the degree of potential conflict between the conservation of diversity and pressure on land use resulting from existing human activities (Fig. 1, compare methods used by Balmford et al., 2001; Luck et al., 2004). Using the product ensures that both range-size rarity and human footprint must have comparatively high values to obtain a high combined index value.

(iii) The 1713 sub-Saharan cells were then ranked on the basis of the square-root values of the combined index for each cell.

(iv) The top 125 cells with the highest values were selected. We chose only 125 cells so that their total area approximates to the total area of the Myers hotspots. From here on, the 125 cells selected on the basis of our data will be referred to as "redefined hotspots" (Fig. 2A).

COMPARING THE PERFORMANCE OF THE TWO ALTERNATIVE SETS OF HOTSPOTS

Although the redefined hotspots cover the 125 cells with the highest product of range-size rarity and human footprint, this does not necessarily mean that they must include more rare species in total, or indeed a larger proportion of the species' ranges than do the Myers hotspots. To compare both sets of hotspots, we applied three tests: (i) How many species are included? (ii) How many species belonging to the quartile of species with most-restricted ranges (see Gaston, 1994) are included? (iii) Which proportion of the ranges of the sub-Saharan plant species is covered? The latter measure is calculated by summarizing the values of range-size rarity for all cells included in each set (analogous to the C-value of Kier & Barthlott, 2001). From here on this measure is referred to as "cumulative range-size rarity." The parameters tested were considered to be the best measure of any set of areas to fulfill the original aims of the Myers hotspots.

HOTSPOTS AS CONSERVATION PRIORITIES?

The Myers hotspots are promoted as a network of areas suitable to "protect the most species per dollar invested" (Myers et al., 2000). This resembles the goal of recently applied heuristic selection algorithms for seeking near-minimum-cost area sets (Gaston, 1994). The latter type of area sets represents each species at least once, but tends to minimize the hypothetical "costs" of potential conservation actions by choosing cells with, for example, least human impact (Balmford et al., 2001; Williams et al., 2003), or at least cost (Moore et al., 2004). The approach aims to alleviate conservation conflicts where there is scope for this (Luck et al., 2004). Technically, the algorithm for near-minimum-cost area set counts the number of rare species in each cell (after taking floristic complementarity with previously chosen cells into account) and then divides the diversity score for each cell by the human footprint value of the respective cell. Such a near-minimum-cost area set was calculated on the basis of the same parameters used for the hotspots analyses. We then selected the 125 cells having the highest benefit-to-cost ratio and contrasted them with the Myers hotspots and the redefined hotspots (Table 1, Fig. 2A, B).

RESULTS

There is a substantial spatial overlap (Figs. 1, 2) between the Myers hotspots and the redefined hotspots identified on the basis of our data. The top 17 redefined hotspot cells are included in the Myers hotspots as well. A total of 60 out of the 125 cells covered by the Myers hotspots are also identified as redefined hotspots.

The 125 cells in the Myers hotspots include 3841 of the 5985 sub-Saharan plant species represented in our database (Table 1). Fifty-two percent of the species belonging to the quartile of species with most restricted ranges are included. Cumulative range-size rarity for all cells is very high, with 39% of the maximum cumulative value for all 1713 sub-Saharan cells. The average human footprint among the 125 cells is 24.32; similar values are measured in cells covering cities such as Kigali, Kisangani, or Bloemfontein. Values higher than 30 are characteristic of metropolitan areas such as Durban, Cape Town, Dar es Salaam, Abidjan, and Douala.

Table 1. Comparative performances of three area sets of equal size to cover the sub-Saharan centers of plant diversity. The following sets are compared: the hotspots as defined by Myers et al. (2000), a redefined set of hotspots identified on the basis of distribution data for 5985 plant species, and a near-minimum-cost area set on the basis of the same data. In order to compare the sets, all have been rescaled to a one-degree based grid of 1713 cells covering Africa south of 17°N latitude. The comparison is based on four criteria: (i) overall number of species covered; (ii) number of restricted range species covered; (iii) cumulative range-size rarity for the included cells; and (iv) human footprint (sum and average for the included cells). Percentages indicate the proportion of the respective total values for sub-Saharan Africa. The plant data stem from the Biogeographic Information System on African Plant Diversity (BISAP) representing 10%–15% of the species of the sub-Saharan African flora. Note that the aim of hotspot sets is to cover the most threatened centers of plant diversity (represented by high values for both plant diversity and human footprint), whereas the near-minimum-cost area set seeks to cover all species in cells with a human footprint as low as possible.

	Sub-Saharan Africa	Myers Hotspots		Redefined Hotspots		Near-minimum-cost set	
	Total	Total	%	Total	%	Total	%
One-degree cells	1,713	125	7.3	125	7.3	125	7.3
All species	5,985	3,841	64.2	4,759	79.5	5,196	86.8
Restricted-range species	1,540	802	52.1	1,011	65.6	1,155	75
Range-size rarity (sum)	5,985	2,354	39.3	2,955	49.4	2,603	43.5
Human footprint (sum)	33,965	3,040	—	3,420	—	2,215	—
Human footprint (average)	19.8	24.3	—	27.4	—	17.7	—

However, the Myers hotspots exclude some of the cells with very high range-size rarity and human footprint, and conversely include other cells with comparatively low values for range-size rarity and human footprint (Figs. 1, 2). In total, 65 cells of the redefined hotspots do not coincide with the Myers hotspots (see below).

In an area of approximately the same size as the Myers hotspots, the redefined hotspots include 15% more of all species and 11% more of the rare species occurring in our databases for sub-Saharan Africa (Table 1); in total, that is about 80% of the species included in our databases. Moreover, they cover a 25.5% higher cumulative range-size rarity than the Myers hotspots—and they do so in areas that are characterized by a 12.5% higher total human footprint.

The redefined hotspots overlap with regional centers of plant diversity not covered by the Myers hotspots (Fig. 2A, B). In southern Africa these are mainly cells in Maputaland, Pondoland, Barberton, Sekhukhuneland, and Soutpansberg. In Katanga, the Zambezi Source Area, Kundelungu and Upemba National Park are important. In eastern Africa, the Chimanimani Centre, Mt. Mulanje, a large block of cells in the Albertine Rift including the Kivu area, the Ruwenzori and Virunga Volcanoes, Bwindi forest, Mt. Elgon, Mt. Kenya, as well as other areas with Afromontane or Afroalpine vegetation mainly in Kenya are among the redefined hotspots (Fig. 2). The same is true for cells in the lower Guinea forest block, including parts of southeastern Cameroon and the area between Crystal Mts. and the coast in Gabon, the Mayombe center of plant diversity. These areas have been identified as centers of plant diversity before (for example, in Brenan, 1978; Beentje et al., 1994; Olson & Dinerstein, 1998; van Wyk & Smith, 2001).

The 125 cells selected for the near-minimum-cost area set for sub-Saharan plant diversity have an overlap of 58 cells with the redefined hotspots (Fig. 2). The overlap is high because all regional clusters of redefined hotspots contain cells with one-cell endemics. Although the algorithm seeks to avoid hotspots and instead chose alternative cells with a low human impact, this is not possible for many cells because they are irreplaceable for representation of their endemic species. Even though the redefined hotspots have been delineated on the basis of simplistic criteria and methods, the irreplaceability of a considerable part of their area implies that they will play an important role in more complex and more adequate prioritizing schemes—there are simply no alternatives in many cases.

However, the top 125 cells of the near-minimum-cost area set include more species and more restricted-range species than the Myers hotspots and the redefined hotspots, even though they include a set of cells with a much smaller total and average human footprint. Bearing in mind the limited comparability and simplified assumptions of the algorithm, this result indicates that, instead of prioritizing all hotspots as "conservation areas," there is potential to alleviate conservation conflicts in sub-Saharan Africa by prioritizing areas with less human impact for conservation, such as, for example, a rainforest block in central Gabon (see Fig. 2).

DISCUSSION

A REDEFINED SET OF SUB-SAHARAN HOTSPOTS

The Myers hotspots cover 64% of all plant species and more than half of the restricted-range plant species included in our database for sub-Saharan Africa.

Although this is an impressive performance for only 125 cells (7.3% of the total area), the redefined hotspots have an even higher representation of the threatened sub-Saharan flora (Table 1). This is mainly due to the fact that some important centers of plant diversity under high human impact are not included in the Myers hotspots.

Several of these areas have been mentioned by Myers et al. (2000), but their inclusion in the Myers hotspots was uncertain due to poor data availability. These data are now available and strongly support inclusion (see also Brooks et al., 2002). Moreover, some of the sites have been identified as major gaps in the network of protected areas (IUCN categories I–VI plus forest reserves) for threatened and restricted-range Afrotropical plants (Burgess et al., in press). This emphasizes the urgency to consider them in large-scale conservation assessments.

In the Myers hotspots analysis zoological diversity served as "backup support" (Myers et al., 2000). Patterns of plant and zoological diversity are not necessarily congruent. There are, for example, obvious differences in the importance of the Western Cape or Kaokoveld in the diversity of restricted-range plants compared to birds or mammals. Nonetheless, the majority of cells now included in the redefined hotspots are centers of species richness and endemism for animals as well. This is true for the Albertine Rift (Plumptre et al., 2003) including the Kivu area, the southwestern connection of the Eastern Arc to the Mbeya Range, nearly all of the Afromontane areas mentioned above, including Mt. Elgon, Mt. Kenya, and the Chimanimani Mts., some of the areas in northeastern Southern Africa and also Katanga (Burgess et al., 2004; Cotterill, in press). Range-size rarity patterns for mammals, snakes, and amphibians (Brooks et al., 2001) are very similar. In analyses that are currently most comprehensive for sub-Saharan zoological diversity, many of these areas have been classified as irreplaceable in the context of biodiversity conservation (Balmford et al., 2001) but are inadequately protected (De Klerk et al., 2004; Fjeldså et al., 2004; Burgess et al., in press; Rodrigues et al., 2004). If we want to base hotspots on this list of taxa, many of the newly redefined hotspots would certainly have an equal priority in comparison to the areas currently included in the Myers hotspots.

The most obvious difference between the Myers hotspots and the redefined hotspots is their spatial resolution, in particular for the Afrotropical region. The distribution of the species within the Myers hotspots was not known, but in our study it was possible to optimize the performance of the redefined hotspots on a spatial scale of one degree. Hence, several cells within the hotspots have been replaced by others previously not considered.

The low resolution of inventory-based data limits not only the spatial precision of the identification of centers of diversity, but also their comparability. The Myers hotspots by definition have to include at least 1500 endemic species per hotspot. This does not take into account the fact that some areas with high regional concentrations of restricted-range species, such as the Albertine Rift, cannot match this threshold because they are too small (Plumptre et al., 2003). Since the distribution of the endemics within the Myers hotspots was not known in many cases, priority of hotspots was determined by ranking the average number of endemics per standard area. In contrast, taxon-based distribution data can be used to compare any of the 1713 sub-Saharan one-degree cells enabling comparison of areas such as the central part of the Albertine Rift or the Maputaland Center of plant endemism with parts (not the average) of the hotspots in West Africa. In addition, instead of only considering the number of endemics and the threat per area, taxon-based data can provide a variety of additional parameters, such as diversity at higher taxonomic level or even phylogenetic diversity, enabling creation of a hierarchy of priorities.

TOWARD A NETWORK OF PRIORITY AREAS FOR CONSERVATION

The Myers hotspots had a very important impact as a pioneering study demarcating areas where ongoing "mass extinctions" (Myers, 1990) make it most urgent to conserve biodiversity. In parallel, they have been promoted also as a network of areas suitable to "protect the most species per dollar invested" (Myers et al., 2000). At first glance this seems to be contradictory since the most problematic areas for conservation are unlikely to be those where conservation is most cost-effective. However, our results indicate that there are indeed often no alternatives to protection of narrowly endemic species within centers of human settlement and intensive land use. The 125 cells identified as redefined hotspots are inhabited by more than 80 million people (population data according to [RWPE], 2002) and the vast majority of the areas of high plant endemism in sub-Saharan Africa are characterized by a very high human footprint (Fig. 1). Despite their vicinity to metropolitan areas such as Cape Town, Abidjan, Douala, and Dar es Salaam, and despite being often completely surrounded by converted land, many sites of "remaining primary vegetation" (Myers et al., 2000) within hotspots (such as, for example, Taï and Banco National Park of Côte D'Ivoire, Table Mountain National Park of the Republic of South Africa, and the Coastal Forests of eastern Africa) are irreplaceable due to the many restricted range species they contain. Due to this irreplaceability, a large proportion of the areas delineated in the Myers hotspots cannot be substituted for other areas, even if the latter had an even higher plant species richness. In our study, the redefined hotspots were constrained by being the same spatial size as the Myers hotspots. Consequently, the inclusion of new areas formerly not considered in Myers hotspots resulted in omitting others previously included. Moreover, a range of additional areas could not be included despite having considerable numbers of restricted-range species and despite being highly threatened. For effective conservation, inclusion of all areas containing clusters of strict endemics is a minimum requirement. For example, the Namib desert and arid woodlands of northeastern Somalia are also key areas for plant conservation. Moreover, in order to translate the hotspots concept to conservation in the field, floristic checklists of areas with comparatively intact vegetation and, in particular, checklists of existing protected areas are needed in order to quantify how many restricted-range taxa are already protected so that conservation gaps can be determined. This will help African countries comply with international agreements such as the Global Strategy for Plant Conservation (GSPC), which requires signatories of the Convention on Biological Diversity to assure protection of 50% of the most important plant areas by the year 2010 (Lovett, in press).

Although many irreplaceable parts of sub-Saharan hotspots are in sites of high pressure for alternative land uses, there are also areas with high range-size rarity and a comparatively low human impact (Fig. 1). These areas could contribute to optimizing conservation efficiency and alleviating conservation conflicts. However, the data on which the Myers hotspots and the extremely broadly defined "high biodiversity wilderness" (Mittermeier et al., 2003) areas are based do not account for complementarity and hence cannot be used to generate priorities on the basis of cost-effectiveness. To meet targets of initiatives such as the GSPC, taxon-based data are the key information. This includes information on species distributions in areas that have so far remained comparatively untransformed because of difficult access—and that tend to be undercollected for the same reason. For example, how many species in the heavily transformed hotspot around Monrovia could be efficiently protected in the largely underexplored Krahn Bassa National Forest or Sapo National Park in southeastern Liberia? Similarly, we do not yet know the potential of the undercollected border triangle of Cameroon, the Republic of Congo, and the Central African Republic for the conservation of the lower Guinea rain forest and its ecotones.

PRIORITIES FOR A GLOBAL CONSERVATION STRATEGY

We see three priorities for the future application of taxon-based data in the context of biodiversity conservation. The first priority must be to acquire these data at a finer spatial resolution. If the current progress of data acquisition continues, it is likely that before 2010 reliable distribution data for plants will be available at a quarter-degree resolution for the majority of the globally most biodiverse ecoregions, a scale which approaches that at which actual conservation actions are implemented. In particular, in addition to further exploration of the hotspots, we urgently need better information on the biodiversity of remote areas with intact vegetation and of existing protected areas. A second priority is to combine botanical and zoological information to obtain a clear picture of overall biodiversity. There is some preliminary evidence of concordant centers of endemism among many different taxa particularly in geodiverse areas such as Afrotropical mountains, and these areas should have a high priority for conservation action. Third, the high resolution biological data need to be compared with socioeconomic information and remote sensing data on habitat status. Inevitably, biodiversity in large parts of the redefined hotspots has already been drastically reduced. The combination of remote sensing and taxon-based biodiversity data, therefore, seems to be a promising avenue leading to identification of those sites where we can protect biodiversity in an efficient and sustainable way.

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