



Potential impacts of climate change on Sub-Saharan African plant priority area selection

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ABSTRACT

The Global Strategy for Plant Conservation (GSPC) aims to protect 50% of the most important areas for plant diversity by 2010. This study selects sets of 1-degree grid cells for 37 sub-Saharan African countries on the basis of a large database of plant species distributions. We use two reserve selection algorithms that attempt to satisfy two of the criteria set by the GSPC. The grid cells selected as important plant cells (IPCs) are compared between algorithms and in terms of country and continental rankings between cells. The conservation value of the selected grid cells are then considered in relation to their future species complement given the predicted climate change in three future periods (2025, 2055, and 2085). This analysis uses predicted climate suitability for individual species from a previous modelling exercise.

We find that a country-by-country conservation approach is suitable for capturing most, but not all, continentally IPCs. The complementarity-based reserve selection algorithms suggest conservation of a similar set of grid cells, suggesting that areas of high plant diversity and rarity may be well protected by a single pattern of conservation activity.

Although climatic conditions are predicted to deteriorate for many species under predicted climate change, the cells selected by the algorithms are less affected by climate change predictions than non-selected cells. For the plant species that maintain areas of climatic suitability in the future, the selected set will include cells with climate that is highly suitable for the species in the future. The selected cells are also predicted to conserve a large proportion of the species richness remaining across the continent under climate change, despite the network of cells being less optimal in terms of future predicted distributions.

Limitations to the modelling are discussed in relation to the policy implications for those implementing the GSPC.

Keywords

Africa, Climate change, Global Strategy for Plant Conservation, important plant areas, persistence, reserve selection algorithms.

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INTRODUCTION

The Convention on Biological Diversity (CBD) requires ratifying states to implement the targets of the 2002 Global Strategy for Plant Conservation (GSPC). Among these targets is the goal for states to assure protection of 50% of the most important areas for plant diversity by 2010. An important plant area (IPA) 'is a natural or seminatural site exhibiting exceptional botanical richness and/or supporting an outstanding assemblage of rare, threatened and/or endemic plant species and/or vegetation of high botanic value' (Anderson, 2002). These sites should be identified according to three criteria: (1) the site contains significant populations of

threatened species; (2) it contains an exceptionally rich flora; and (3) a site contains a threatened habitat, or it is an outstanding example of a habitat type (Anderson, 2002). Establishing the location and priority of IPAs in a species-rich continent such as Africa is both urgent and problematic (Lovett, 2004).

The existing protected areas in Africa (Chape *et al.*, 2003) are of two main types: national parks, which have been established primarily for large mammals and for areas of outstanding natural habitat; and forest reserves, which aim to protect resource harvesting or water catchment areas (Burgess *et al.*, 2005). Data from vegetation mapping have been used regionally for conservation assessment (Cole *et al.*, 2000; Cowling & Hejnis, 2001;

Desmet *et al.*, 2002), but plant diversity has rarely been used as a criterion for area selection. There is a need for assessment that incorporates plant distribution data to aid in the prioritization and selection of areas important to plants. Some prior work has assessed biodiversity on a continental basis (Davis *et al.*, 1994; Myers *et al.*, 2000), but these studies are based on expert knowledge at a very coarse scale, rather than analysis of actual plant distribution data (Küper *et al.*, 2004). Regional assessments based on floristic data have been made (e.g. Lovett *et al.*, 2000; La Ferla *et al.*, 2002), but these only provide a very preliminary basis upon which to identify and compare IPAs at country level or continental scale.

A further problem faced when attempting the selection of IPAs is the need to ensure persistence of species in terms of ecological and evolutionary processes (Cowling, 1999; Cowling *et al.*, 1999; Margules & Pressey, 2000). One such long-term factor is climate change (Hannah *et al.*, 2002; Araújo *et al.*, 2004). Conservation using protected areas has always tacitly assumed that climate, environment, and species distributions will remain constant (Rutherford *et al.*, 1999; Midgley *et al.*, 2003). However, many studies have shown that climate change will over time eliminate, reduce, or shift the ranges of many species (Rutherford *et al.*, 1999; Midgley *et al.*, 2003; Araújo *et al.*, 2004; Thomas *et al.*, 2004; McClean *et al.*, 2005). What therefore might be the effects of changing climate on IPAs and the consequent implications for states attempting to meet the targets of the GSPC?

There are many ways in which to select IPAs using the criteria suggested by the CBD. Over recent years many efficient reserve selection algorithms have been developed and applied to species distribution data sets at a number of scales (Margules *et al.*, 1988; Williams *et al.*, 1996; Csuti *et al.*, 1997; Cabeza & Moilanen, 2001; Küper *et al.*, 2004). A reserve selection algorithm provides a set of rules designed to identify a set of nature reserves that fulfil a certain goal, such as containing the maximum number of species (Cabeza & Moilanen, 2001). Some widely used heuristic algorithms are based on the concept of complementarity, that is, selecting a set of areas that complement each other in species composition or other biodiversity value, rather than duplicate features (Pressey *et al.*, 1993; Williams, 2000). Methods based on complementarity principles have frequently used species richness or range-size rarity scores as the biodiversity values to structure the search for the desired selected set. Both of these complementarity approaches have potential to provide a systematic basis for the selection of IPAs. Richness-based complementarity algorithms provide results that could assist in IPA selection based on criterion 2 (exceptionally rich flora) and rarity-based complementarity algorithms, in particular range-size rarity, could be used to help select sites according to criterion 1 (populations of threatened species). Although a complementarity approach using range-size rarity does not specifically select for threatened species (threat is often driven by social and economic factors) it is biased towards species with narrow distributions, which by their very nature are vulnerable to extinction (Primack, 1998). Extent of occurrence and area of occupancy are both criteria used to categorize red list species in terms of their level of endangerment (IUCN, 2001). For example, species can be categorized as being endangered if

they have extent of occurrence less than 5000 km² or area of occupancy less than 500 km².

We do not use red listed plants in this paper as few African plant species have been analysed according to the red list criteria to date. In this study, important plant cells (IPCs) are selected by richness- and rarity-based reserve selection algorithms using both continent and country approaches. The targets of the GSPC are germane at the national level, as parties to the CBD are expected to plan and report on national GSPC implementation activities, so selection should be made from this perspective. However, plant communities are not restricted to national boundaries, so a continental approach to IPC selection has been used to assess whether or not sites selected at country level capture those cells that might be important at the continental level.

We use the term important plant cells rather than important plant areas because the data available for the study are at 1 degree latitude by 1 degree longitude resolution. Complementing our continental-scale analyses with a regional-scale assessment will be necessary for identifying sites in the context of factors such as species turnover, threatening processes, and implementation opportunities and constraints (Driver *et al.*, 2003; Eken *et al.*, 2004). However, the importance of this study is to look at predicted species distributions for 2025, 2055, and 2085 to assess how resilient a country-level implementation of the GSPC may be to the pressures of climate change. The influences of climate change on plants will act supranationally, so an overview of likely impacts at the continental scale should be useful at the CBD level of decision making. Our analysis is limited to coarse resolution data when studying the continent because fine resolution data across the entire continent is simply unavailable. The species in our data set form a sample of the plants that should be protected by the GSPC, so individual countries will have to seek to preserve important areas that will at least consider these species. The cells we identify are therefore 1 degree spaces where regional assessment and conservation planning are likely to be required to ensure efficient conservation. Our main aim, however, is to find out whether or not these cells might remain important in terms of plant conservation as climate changes.

METHODS

This analysis was based on the predicted distributions of climate suitability for over 5000 species presented in McClean *et al.* (2005). These in turn were based on African plant distribution data from a large database currently hosted by the Nees Institute for Biodiversity of Plants in Bonn (see Küper *et al.*, 2004; Küper *et al.*, 2006). The resolution of the original data used to develop the models, and as a result the resolution of the models, was 1-degree square. The database, at the time of its use, had 6200 taxonomically revised species, including 330,000 distribution records from confirmed collection sites. The modelling approach was to use a Bayes-based genetic algorithm (McClean *et al.*, 2005; Termansen *et al.*, 2006) to estimate the probability of occurrence of each species in 1-degree grid cells on the basis of nine climate variables. A total of 5197 species were modelled. Species with only 1-grid cell record were not included. Models were developed

using climate variables for the recent 30-year period (centred on 1975) and for future 30-year periods centred on 2025, 2055, and 2085. Model predictions for future periods assume that species can occupy any cells that have climate deemed suitable by the model in the future; an assumption of full dispersal (Thomas *et al.*, 2004). The fits of the models developed for the recent period with the observed species distributions were, in general, very high, with only 61 species producing areas under their relative operating characteristics curves (Fielding & Bell, 1997) of less than 0.75. This means that on the basis of the probabilities of occurrence predicted for cells, our individual species level models discriminate well between cells where the species is recorded in comparison to other cells. The correlation between the observed species richness pattern for the taxa included and the modelled species richness pattern was 0.73 (Spearman's rank).

Thirty-seven countries entirely south of 27 degrees North, the maximum northerly margin of the ranges of the most northerly species used in the modelling process, were included in the analysis of potential IPCs; a total of 1998 cells in our representation. One-degree grid cells were allocated to countries on a majority area basis, that is, if a 1-degree grid cell straddled the border between two countries, the cell would be allocated to the country, making up the larger proportion of the cell's area. The distribution model for each species records the probability of occurrence of the species in a cell given the presence of the set of climatic characteristics for that cell. This gives a good indication of the likely spatial distribution of the plant species, but differing probability scores may be associated with true presence observations across different species. So that each species has the same weight in any reserve selection algorithm, the probabilities of occurrence for each species were placed on a 11-point scale, zero representing the lowest 10% of the range in probability of occurrence values for an individual species model and 10 representing probabilities from 0.9 to less than 1, while 11 would represent probabilities of occurrence of 1. When submitted to the reserve selection algorithms, cells falling in the bottom 10% were therefore deemed unsuitable for selection, whereas cells scoring 10 counted most (no models predicted probabilities of occurrence of 1). These scores are referred to as occurrence scores in the rest of the paper. A potential advantage of using probability of occurrence values in our analysis is that there is some evidence that they may reflect some of the potential of species to persist (Araújo *et al.*, 2002; Cabeza *et al.*, 2004).

Two heuristic algorithms that incorporate the principle of complementarity were used. These algorithms assign values to cells according to their richness or rarity. They then select cells on a step-by-step basis, recalculating at each step the values of other cells so that the following cells chosen complement the already selected cells in respect to their species content. The richness algorithm starts with the cell containing the most species and sequentially includes cells that add the most additional species. If there are any ties, the algorithm simply chooses the cell on a first-found basis. The rarity algorithm chooses cells in order of the rarity of the species they contain (Csuti *et al.*, 1997). This algorithm weights species by a form of range-size rarity. With presence/absence data, inverse range-size is defined as the inverse

number of cells in which a species occurs and the range-size rarity of a cell is the sum of these values across all species present at the cell. Our algorithm uses the sum of the occurrence scores, found across all grid cells in the study area, as the range size component in this calculation. Both algorithms finish when all species have been conserved in at least one selected cell at an occurrence score of one or above.

These two algorithms have been observed to select sites that are well correlated when using real species distribution data (Roberts *et al.*, 2002). However, these correlations cannot be attributed solely to the summation of inverse range sizes. Cells with a large number of species with large range sizes can have a smaller score than cells with a smaller number of species with small range sizes. Alternatives to inverse range-size rarity measures for selecting cells with high proportions of range-rare plants exist, but this approach has the advantage that it weights a species influence on the selection procedure in inverse proportion to its range size.

We ran these selection procedures at two scales. The entire data set was used to select a set of grid cells from the whole of sub-Saharan Africa that would contain all of the species at a score of one or above. We also ran the algorithms on subsets of the data contained in each of the 37 countries. For each country, the range-size calculations were performed as if the species were only found in that country. Each run of the richness algorithm produced a list of selected cells along with the species richness score at which they were selected, while each run of the rarity algorithm produced a list of selected cells along with the range-size rarity sum calculated for that cell. The cells selected in these ways were assumed to represent IPCs, our very rough approximation of IPAs. As the GSPC requires 50% of all IPAs to be conserved, the best 50% of the sets of cells selected by the different runs of the algorithms were also chosen. To do this, all cells above the median richness/range-size rarity score were selected. We refer to these cells as IPC50s. The need to select these IPC50s meant that we only included countries with three or more 1-degree grid cells.

In order to test whether modelled species distributions yield realistic selections of IPCs, we also ran the original presence/absence data through suitable versions of the algorithms. The levels of correlation between the richness values of cells selected using the observed distributions and the values of cells selected using the modelled distributions were calculated. This was also carried out for rarity scores. We compared the overlap in IPCs and IPC50s identified using the observed distribution data and modelled distribution using Cohen's kappa statistic (Cohen, 1960; Fielding & Bell, 1997).

An assessment of how well the IPCs selected at a country level captured priority areas at a transnational level was carried out by determining the overlap between the country-level and continent-level algorithm results.

We assessed the resilience of the cells selected by the algorithms in the face of climate change by calculating the number of species that have an occurrence score of above zero in future periods within the selected sets of cells. The maximum magnitude of these occurrence scores for each species across the selected cells

at different time periods was also assessed. Using Sørensen's index for selected cells, we also determined the extent to which the species composition might change within cells across time (Krebs, 1999).

The algorithms were also run using the species model distribution predictions for 2025, 2055, and 2085 as inputs. We used Jaccard's index to assess how much overlap exists between current and future selected sets. The positions of the IPCs that might be selected if the prioritization process was carried out in the different periods are compared with the selected set for the current period in terms of the distance between the different selected sets.

RESULTS

For the continent, the richness algorithm selected 434 of the total 1998 cells as IPCs when using the observed species distributions, and 422 cells using modelled species distributions. A few extra cells were also selected by the rarity algorithm when using observed distributions (425) in comparison to modelled distributions (416). For both algorithms, this general pattern was repeated at the country level with slightly more cells required to cover the observed species distributions than the modelled distributions. Similar results were found when considering the IPC50 cells selected by the algorithms.

For the IPC50 cells, correlation coefficients comparing the scores from the algorithms when run on observed distributions

with those from modelled distributions indicated good agreement in pattern. The lowest coefficient (Pearson's) was 0.74 between the richness algorithm scores for observed and modelled. A value of 0.98 was obtained for the comparison when using the rarity-based algorithm. The degree of overlap between cells selected using observed and modelled distributions ranged from a kappa value of 0.81 for the IPC50 cells selected using the richness-based algorithm to 0.88 for those selected using the rarity-based algorithm.

At both continental and country level, fewer cells were selected by the rarity-based algorithm compared to the richness-based algorithm. Agreement between selected cells using the two algorithms for modelled distributions was good, producing a correlation coefficient of 0.86 when comparing scores and a kappa value of 0.79 when comparing the overlap between the top 50% sets. The cells selected by one or both algorithms as IPC50s are mapped in Fig. 1.

There is substantial overlap between the cells selected at a continental-level and those selected on a country-by-country basis (Fig. 1). When considering all of the cells selected by the richness algorithm, 96.2% of continent level IPCs are also identified as IPCs at a country level. The corresponding figure for the rarity-based algorithm is 96.6%. However, these figures translate into 16 and 14 cells, respectively, which are identified as important at a continental level, but not on a country-by-country basis. When the top 50% of IPCs selected are considered, there is substantially

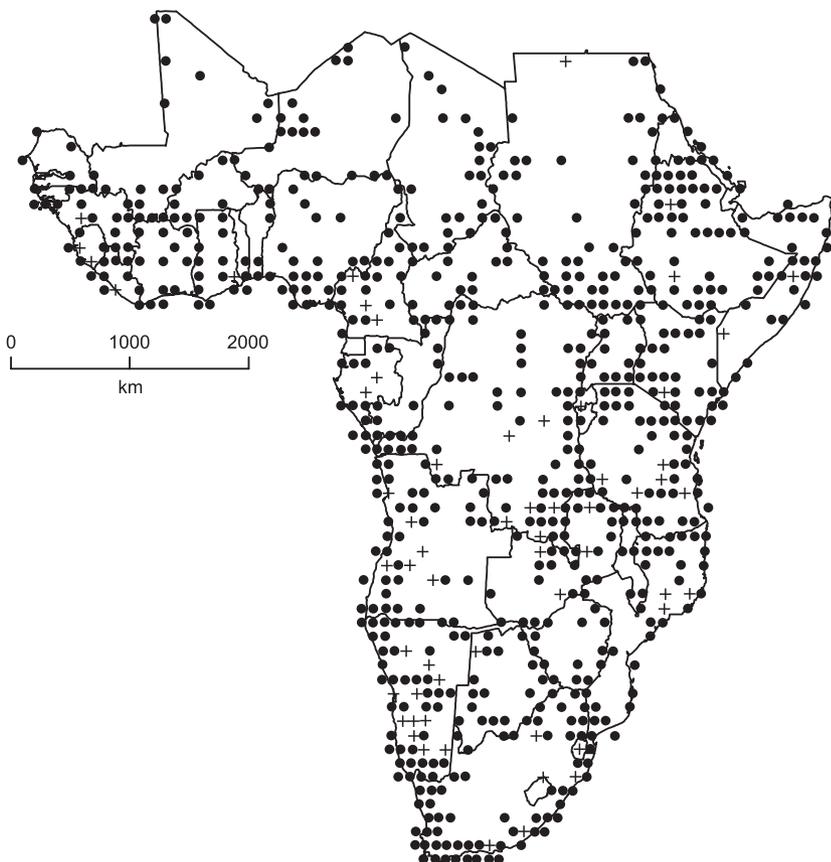


Figure 1 Agreement between country level and continental level IPC50s for both selection algorithms. Circles represent where either or both algorithms select an IPC50 cell when run at the country level. Crosses show continent level IPC50s that do not coincide with country level IPC50s. (Projection: Mollweide).

Table 1 Country-by-country results, showing the percentage of species richness protected by IPC50s for cells selected by each algorithm and for the current and 2085 periods. Also shown is the average increase or decrease in mean maximum probability of occurrence score (1–10 scale) between current period and 2085 period

Country (no. of grid cells)	% of species richness protected by IPC50s:				Change in mean probability of occurrence scores by 2085:	
	Richness algorithm	Rarity algorithm	Richness algorithm 2085	Rarity algorithm 2085	Richness algorithm	Rarity algorithm
South Africa (129)	97	95	92	92	-0.58	-0.58
Nigeria (79)	97	96	87	87	0.41	0.41
Ghana (24)	97	96	73	74	-2.15	-2.15
Congo (31)	97	97	95	96	0.15	0.15
Chad (105)	97	96	101	100	0.64	0.65
Zimbabwe (32)	97	94	90	90	-0.90	-0.94
Burkina Faso (21)	97	97	94	94	1.01	1.01
Tanzania (81)	96	95	85	86	-1.73	-1.73
Zaire (188)	96	94	85	85	-1.45	-1.44
Kenya (49)	96	95	64	64	-3.25	-3.25
Sudan (213)	96	95	57	54	-1.23	-1.23
Cameroon (39)	96	96	104	104	-0.17	-0.17
Ivory Coast (30)	96	96	94	93	-0.93	-0.93
C.A.R. (51)	96	96	91	92	-0.40	-0.40
Uganda (19)	96	95	86	86	-0.62	-0.62
Gabon (26)	96	94	97	97	-0.38	-0.38
Botswana (52)	96	95	75	75	-0.83	-0.83
Zambia (64)	96	96	86	86	-1.92	-1.92
Mali (111)	96	95	92	94	-0.17	-0.18
Namibia (84)	95	94	82	81	-1.00	-1.01
Angola (112)	95	94	91	92	-0.19	-0.17
Ethiopia (91)	95	95	96	97	0.37	0.36
Mozambique (76)	95	95	87	84	-0.43	-0.42
Somalia (66)	95	95	74	74	-1.13	-1.13
Liberia (11)	95	93	89	89	-0.88	-0.88
Niger (100)	95	95	84	84	-0.03	-0.03
Guinea (24)	94	94	81	82	-0.90	-0.90
Malawi (10)	94	94	89	90	-0.36	-0.36
Senegal (21)	94	94	96	95	-0.08	-0.08
Sierra Leone (8)	91	91	49	49	-2.60	-2.60
Benin (10)	91	91	95	95	0.08	0.08
Eritrea (15)	90	92	82	81	-0.64	-0.64
Rwanda (3)	88	88	80	80	-1.48	-1.48
Burundi (3)	87	87	84	84	-0.83	-0.82
Guinea-Bissau (3)	84	84	73	75	-2.51	-2.51
Togo (6)	81	79	112	108	0.50	0.50
Djibouti (4)	74	74	61	61	-0.11	-0.11

more disagreement between the two levels of analysis. The country-level IPC50s from the richness-based algorithm account for 73% of the continental IPC50 cells. Using the rarity-based algorithm, the figure falls to 52%.

The percentage of species richness that is captured by the IPC50s in each country is given in Table 1. A high proportion of total species richness is captured by the IPC50s when using both algorithms. Unsurprisingly, the richness-based algorithm captures more of the richness than the rarity-based algorithm in most cases.

Comparison between present and future climates

There is a general pattern of slow decline in the level of species richness provided by the selected cells when the ratio of species richness in the future periods to the species richness in the current period is considered, although the median values shown in the box plots in Fig. 2(a) never fall below 0.86. However, there is wide variation from country to country as shown in Fig. 2 and Table 1. For example, the number of species actually rises in predictions for Cameroon for 2085, while a

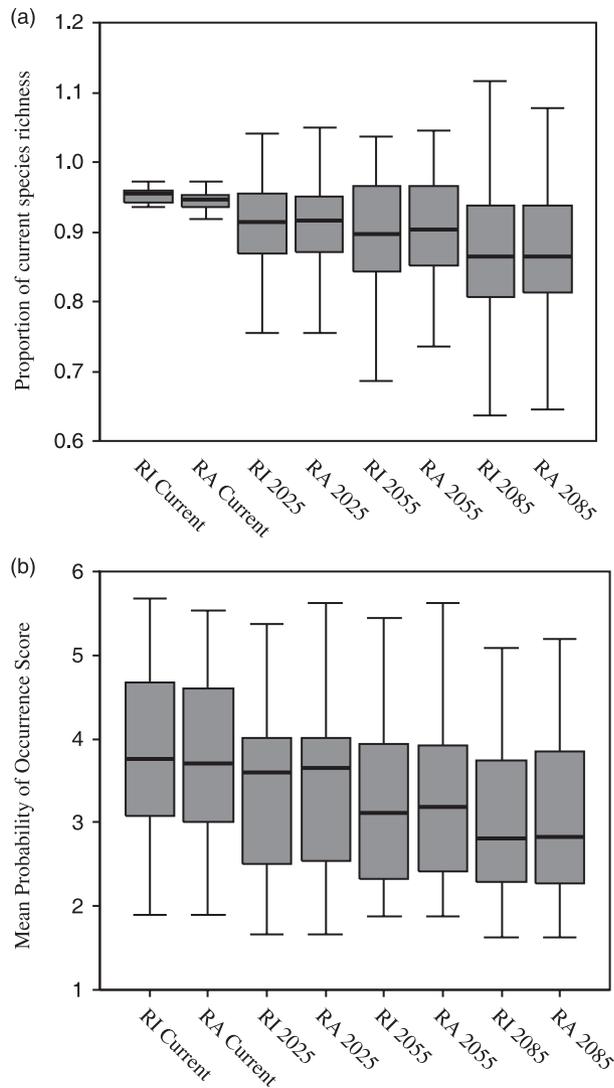


Figure 2 Boxplots of a) proportion of current species richness maintained by countries in current and future periods and b) mean maximum occurrence scores for species making up species richness of countries in current and future periods. RI — richness-based algorithm results, RA — range-size rarity-based results.

substantial fall in species numbers is predicted for Sierra Leone.

There is a similar slow, downward trend across time when considering the mean maximum probability of occurrence scores at which species are protected by the selected cells at a country-by-country level (Fig. 2b). At a country level, the average maximum occurrence scores are quite low, with three quarters of the countries having mean scores below 5 on the 10-point scale, even for the current period. However, if the maximum scores at which species are protected are considered across all countries, the mean for all species is above 9.4 for both algorithms (Fig. 3). This drops off across the predictions for future periods for both algorithms to around 8.7. If the distributions of the occurrence scores for species found in an equivalent number of randomly selected cells from across the continent are compared with those

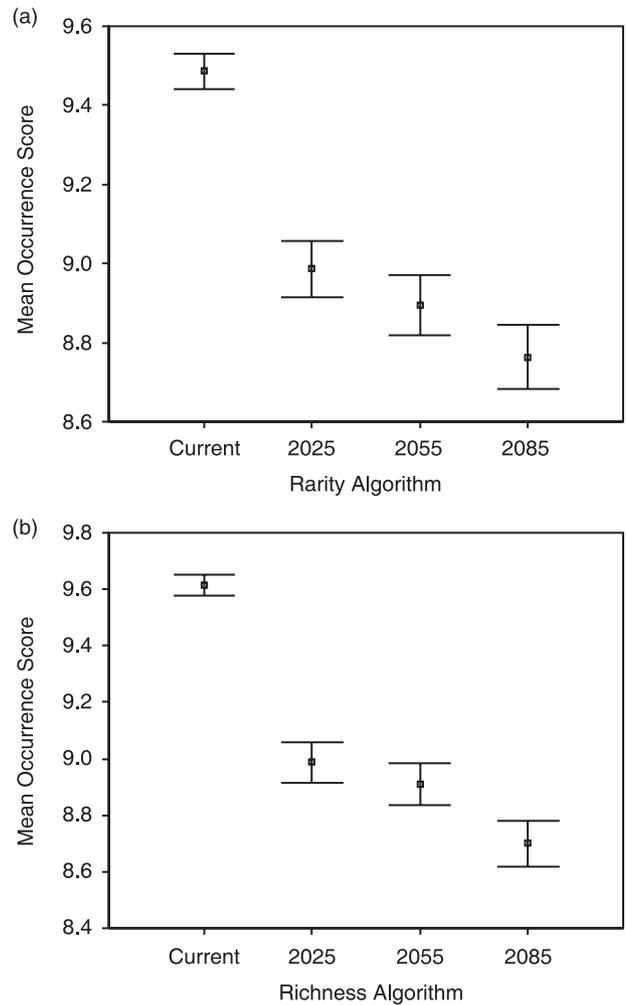


Figure 3 The mean, across all species, maximum occurrence scores for species protected by selected cells using a) the rarity-based algorithm and b) the richness-based algorithm. The maximum value for each species has been found across all IPCs for the continent, selected by the country level analysis, carried out on current modelled distribution data. The mean maximum values for the same sets of cells are reported for species that would be protected by these cells in each of the future periods. Error bars show 95% confidence intervals for the mean values.

found in the cells selected by the algorithms, significant differences are found between random and algorithm selections for each time period (Mann–Witney U, $P < 0.001$ for all tests). However, the differences between algorithm-selected sets and randomly selected sets decrease over time. The average change in suitability for countries estimated for 2085 is given in Table 1, which once again shows wide variation. Figures for the continental-level analysis are always lower than the mean maximum scores for the country-level analysis (Table 2).

On a cell-by-cell basis, the species richness scores and rarity scores at which cells would be selected, if running the algorithms on the predicted future species distributions, are shown in Fig. 4. The pattern of cells that increase and decrease in their status as

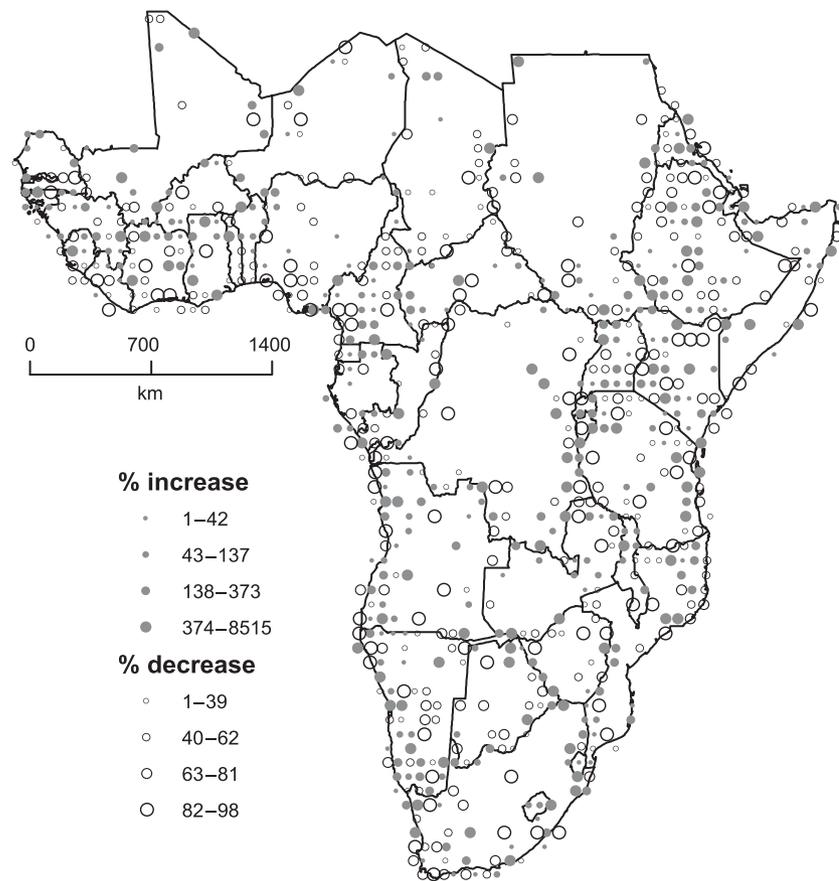


Figure 4 Percentage increase and decrease in rarity score at which cells selected on the basis of current modelled distributions could be selected on the basis of 2085 predicted distributions from country level analysis. (Projection: Mollweide).

Table 2 The mean, across all species, maximum occurrence scores at which species are conserved over time in the selected important plant cells (IPCs) for the current period using different algorithms and distance from current selected IPC50 sets to IPC50 sets selected on the basis of predicted future species distributions (expressed as number of cell units)

Country results	Mean species occurrence scores		Mean distance to future IPC50 cells		Max. distance to future IPC50 cells	
	Rarity algorithm	Richness algorithm	Rarity algorithm	Richness algorithm	Rarity algorithm	Richness algorithm
Current	9.49	9.61				
2025	8.99	8.99	0.54	0.57	6.0	3.0
2055	8.90	8.91	0.56	0.59	5.0	3.1
2085	8.76	8.70	0.56	0.57	5.0	3.1
Continent results						
Current	9.17	9.16				
2025	8.15	8.13	1.20	1.16	6.3	5.3
2055	8.12	8.01	1.25	1.36	5.8	6.0
2085	7.98	7.84	1.21	1.34	6.3	7.0

IPCs is complex, with many cells with large increases in score having neighbours with large decreases in score.

For the country-level analysis, there is very low overlap in cells if they are selected on the basis of the modelled distributions for each of the different periods. Jaccard's index calculated between cells selected in the current period and the future periods is always below 0.18 for both IPCs and IPC50s. This contrasts with the high overlap

between sets of cells selected by different algorithms in the present period; Jaccard's index is 0.61 for IPC50s and 0.89 for IPCs.

The shortest distances, measured in numbers of cells, that separate cells selected by the algorithms when run on the current modelled species distributions and the future modelled species distributions are also summarized in Table 2. The average distance that must be traversed between the current set of

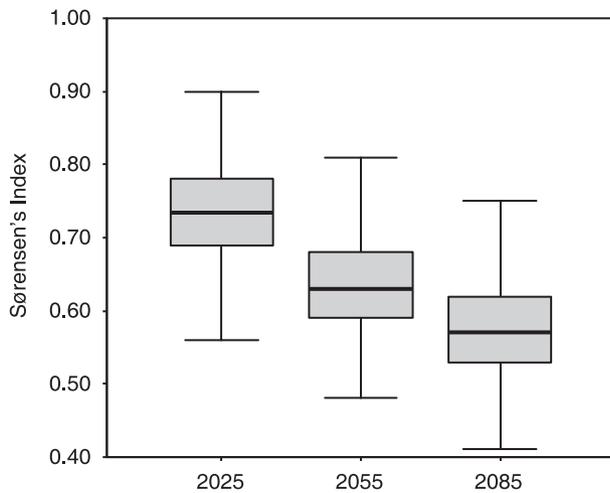


Figure 5 Sørensen's index for the cells selected by the rarity algorithm measuring species turnover from the current period to 2025, 2055, and 2085. A value of one indicates that there has been no change in the complement of species recorded to have suitable climate in that cell between the current period and the future period. A value of zero indicates that the species recorded to have suitable climate in that cell are all different in the future period compared to the current period. The set of cells analysed are those identified as IPCs using the current period data. Sørensen's index captures the loss in species range that will occur for many species across these cells.

selected cells and those that might be selected in 2085 is just over half a cell, although the maximum distances are 3.1 and 5.0 cells for the richness-based algorithm results and the rarity-based algorithm results, respectively.

The mean turnover in species composition by 2025 in cells selected by the rarity algorithms, indicated by Sørensen's index, is 0.73, dropping to 0.56 by 2085 (Fig. 5). This pattern is similar to that shown by the richness algorithm. Although the mean values for algorithm-selected cells become increasingly larger than those for randomly selected cells over the time periods, there are no significant differences between the mean value of the index for cells selected by the algorithm and cells selected at random.

DISCUSSION

This modelling exercise captures the broad patterns of country and continental priorities in the face of predicted climate change. Comparisons of the algorithm results for observed and modelled distributions indicate that the use of the modelled probability of occurrence data produce similar patterns of IPCs to those using the original presence/absence data. This gives us some confidence that our assessment of the influence that future climate may have on IPCs selected at the present time is robust, within the constraints of the assumptions made when predicting future ranges of individual species as stated in McClean *et al.* (2005).

Although the GSPC, by its very nature, must be delivered at a country-by-country level, the continental extent of the data set and modelling exercise that we employ allow us to assess whether IPAs at a continental scale can be adequately captured when

implementation of the convention occurs at a country-by-country level. On the whole, our results suggest that most IPAs could be protected if countries adhere adequately to the convention. However, cross-border cooperation would be necessary to ensure that all areas of continental importance are protected, particularly if only 50% of the important areas are selected by countries as planned. An important role for supranational NGOs may be to seek such necessary collaboration. Conservation areas that straddle national borders could often provide efficient ways for all countries involved to meet their targets.

The country-by-country level results of this study reveal that the burden of the GSPC agreement will not fall evenly across states; rather, some countries are likely to have to conserve much larger areas because of the diversity that lies within their borders. Once again, supranational support might usefully help to address this issue. Fortunately, the target set by the GSPC, the selection of 50% of important areas, if that percentage constitutes the 'best' 50%, can protect much more than 50% of the diversity. For most countries, over 90% of species might be protected by selecting the top 50% of areas (Table 1). There is also good agreement between the cells selected by the richness and rarity-based algorithms. This suggests that both GSPC criterion 1, sites contain significant populations of threatened species, and 2, sites contain exceptionally rich flora, might be satisfied by using a similar set of sites. However, our assessment takes no account of various aspects of persistence, though we come to climate change issues soon.

Unfortunately, these figures assume that all other conditions favourable for each species persist under future climate. Estimates of the number of species that might lose all or some of their range have been produced (Thomas *et al.*, 2004; McClean *et al.*, 2005). The study on which our results are based (McClean *et al.*, 2005) shows that 81% of species might lose areas of climatic suitability, with 25% potentially losing all area of climatic suitability. These predictions of increasing threat to species are consistent with regional-scale predictions of increasing threat for areas such as the Cape Floristic Region (Bomhard *et al.*, 2005). Our results do not incorporate species that are recorded in single 1-degree grid cells in Africa and these species are likely to be the most susceptible to climate change. Given such changes, can cells selected on the basis of current plant distributions conserve what is left of species diversity in the future? Our results suggest that the cells selected on the basis of current modelled distributions will often still be important areas in the future, even though they may not be the optimal locations for conservation in the future. Both selection algorithms choose sets of cells, for three-quarters of the countries studied, that still manage to capture over 80% of the predicted available richness in 2085. However, the cells in the current selected sets, if not in the top 50% optimal set for the future time periods, will on average have a neighbouring cell that would be in the optimal set in the future. Furthermore, the cells selected conserve at least some areas of a plant's distribution that can be considered to be in the top 20% of that species area of climatic suitability. On average this amounts to a drop of less than 10% in suitability.

Despite the observation that a country-by-country selection of the best 50% of important plant cells may be relatively robust in

capturing plant diversity in the future, certainly more robust than a random selection of areas, the threat to these areas under climate change remains. Such a random selection may be more akin to the *ad hoc* network of plant conservation that currently exists (Burgess *et al.*, 2005) and could therefore be quite susceptible to climate change. However, even with a designed network of conservation, the species composition of selected cells is predicted to change substantially by 2085 under the assumptions used in the modelling effort of McClean *et al.* (2005). Typically, less than 60% of species for which a cell was predicted to have suitable climate in the current period are expected to have suitable climate in that cell by 2085. The cells may remain good at capturing diversity because the cells become climatically suitable for species that could disperse into them. There is an underlying assumption in the results presented here, that species have unlimited dispersal abilities, if a cell becomes climatically suitable for a species in a future period it is assumed that the species can reach that area. This assumption of full dispersal is likely to be responsible for the complex patterns of cells which seem to benefit and suffer in terms of rarity scores in the future (Fig. 4). Suitable climate for species maybe found in neighbouring cells under future conditions. However, whether or not species can track changing climate conditions fast enough to survive remains an unanswered question (Thomas *et al.*, 2004). Furthermore, suitable spatial connectivity in habitat is assumed to exist to allow for such a rapid dispersal assumption. While this assumption may accentuate our measure of species turnover, it makes our results conservative as far as potential species loss is concerned; species are allowed to escape into IPCs and IPC50s under future predictions.

The need to shift knowledge obtained by modelling exercises such as this into operationally feasible conservation planning has been made clear over recent years (Whitten *et al.*, 2001; Knight *et al.*, 2006). The models used in this study are developed for species distributions with a spatial resolution of 1 degree. It is therefore only appropriate to apply our conclusions at such a supranational scale. Our findings support the ongoing efforts of the CBD in achieving the GSPC; protecting as much as possible on a country-by-country basis is likely to mitigate against the effects of climate change more than identifying IPAs at a continental scale. We therefore hope that these results encourage those implementing the GSPC at the country level. However, it must be noted that the data we analysed makes up only a sample of the full African flora and there is a need to increase this sample to be sure that gaps in representation are plugged (Küper *et al.*, 2006) and that all IPAs are identified.

Local- and regional-scale conservation planning to deliver the GSPC will have to be achieved within individual countries, and our results only illustrate the broad areas where such detailed planning will be necessary. Good examples of regional-scale planning exist for Africa within the Cape Floristic Region (Cowling & Pressey, 2002). These include efforts to consider persistence beyond the potential effects of climate change; incorporating information on threats from human-induced land use changes and the need to capture long-term ecological and evolutionary processes (Cowling *et al.*, 1999). Methods have been proposed to aid in the development of priority areas in this

region that identify minimum-dispersal corridors that might allow plant species to escape advancing changes in climate (Williams *et al.*, 2005). Regional-level planning will not preserve entire 1-degree grid cells, and much of the area within these grid cells will not be of conservation interest, but the species in the database used in this study are likely to be included in these more local conservation plans. Unfortunately, the higher resolution data that have enabled the work in the CFR are not as readily available for all IPAs in Africa, but such data are required if conservation planning is to be effective.

In conclusion, selection of important plant cells on the basis of current plant distribution data seems to be justified, despite potential species loss due to changing climate. This study shows that current important plant cells may remain important plant cells in the future. It must be hoped that sites selected using local- or regional-scale data that are of greater utility for implementation of on-the-ground conservation action might exhibit some of the same resilience indicated at the 1 degree level. Although models can be built to predict species distributions under future climate scenarios, the uncertainty in spatial predictions, due both to uncertainty in the predictions of climate models (IPCC, 2001) and to the effects of climate change that cannot be predicted by models such as we use here (Davis *et al.*, 1998), makes basing priority areas for conservation on potential, future species distributions impractical. However, the surest method of maintaining plant diversity in the future given the current knowledge is to protect as many IPAs as possible — today.

ACKNOWLEDGEMENTS

We thank Conservation International, the German Federal Ministry of Education and Research (BIOLOG BIOTA programme www.biota-africa.org), and the Akademie der Wissenschaften und der Literatur, Mainz, for financial support for both database development and analysis. We thank numerous contributors to the Biogeographical Information System on African Plant Diversity used in this paper.

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