JRC Scientific and Technical Reports

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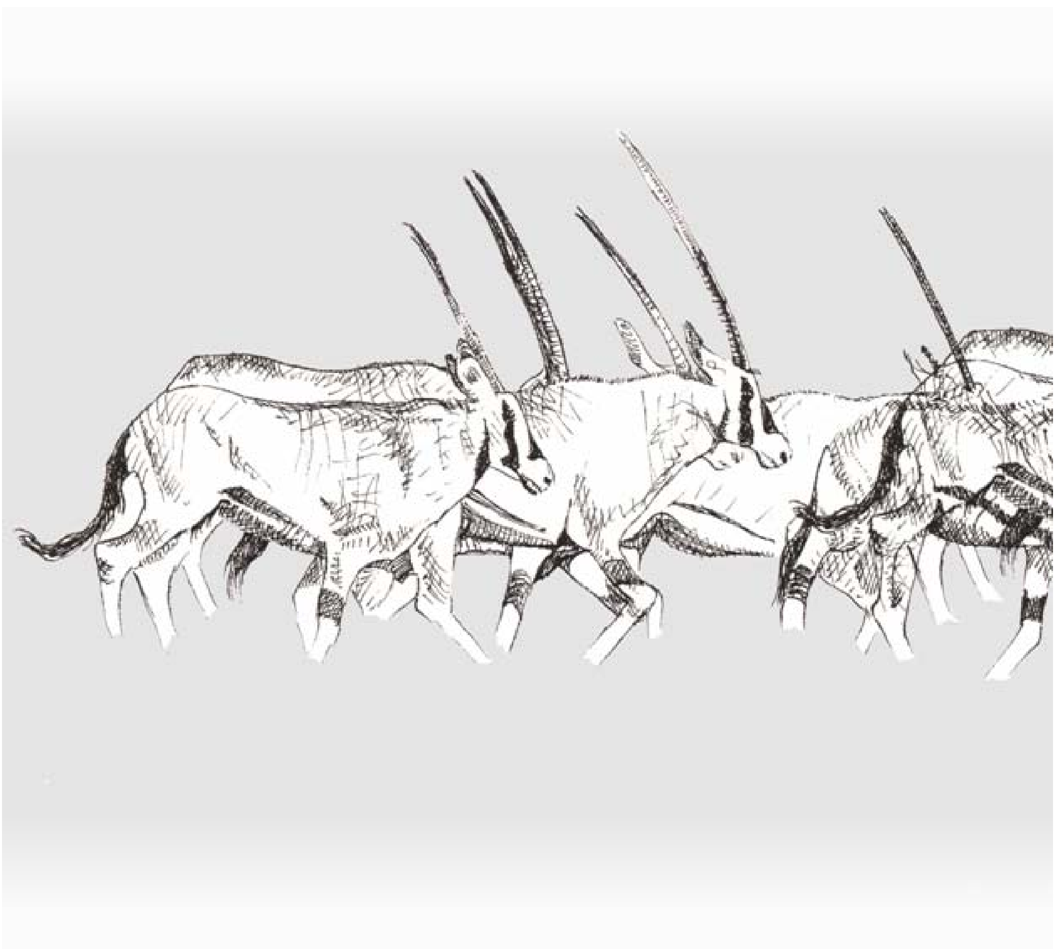

JRC
EUROPEAN COMMISSION

Institute for Environment and Sustainability

EUR 22780 EN - 2007

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JRC 7103

EUR 22780 EN
ISSN 1018-5593

Luxembourg: Office for Official Publications of the European Communities

Printed in Italy

Acknowledgments : The authors would like to thank the following for their input:
Graeme Buchanan (RSPB), Paolo Roggeri, and Enrico Pironio.

Front cover : Gemsbok (Oryx gazella), adaptation of a silk-screen print by Tim Chamberlain.
www.timchamberlain.net

Summary

This is the first consistent, continent-wide assessment of protected areas in Africa, based on (i) their value for conservation and (ii) anthropogenic pressures. It is based on the most up-to-date, scientifically accepted, and publicly available information on species, environment and socio-economics. Over 1,600 species across 741 protected areas in 50 countries have been studied. This report presents a scaleable information system, meaning that the user can assess a given protected area in the context of others in the continent as a whole, in the same Ecoregion, same country, or same locality. Consequently, a variety of users are foreseen, from European policy makers, to regional and country level planners, and even managers of individual protected areas. This information is available online in a series of reports for each protected area and each country. Furthermore, to assist future EC funding decisions, we analyse the relationship between protected areas that have recently received EC assistance and our measures of conservation value and pressure.

Key findings

General observations

- We have developed a method to classify protected areas on two key indices (i) Biodiversity Value and (ii) Anthropogenic Pressure. Reducing the data down to two important and easily interpreted indices provides a valuable tool for users at all levels.

- For the 741 protected areas that were studied - the classification of the 144 'critical' protected areas that have higher Value and higher Pressure agrees very well with other broad scale internationally recognised conservation priority assessments such as Conservation International's (CI) Biodiversity Hotspots, and the World Wildlife Fund's (WWF) Global 200 Ecoregions, with overlaps of 75% and 71% respectively. This demonstrates that our classification is in agreement with existing broad-scale conservation knowledge.

- The classification of 'critical' protected areas also agrees very well with assessments of conservation priorities that are based on a scale which makes them amenable to management such as BirdLife International's Important Bird Areas (IBAs), with an overlap of 75%. This demonstrates that our classification is in agreement with existing management-scale conservation knowledge.

- Protected areas in our 'critical' class that overlap with many conservation priority assessments have higher Value and higher Pressure than protected areas that overlap with few or no initiatives. This demonstrates a high degree of consonance between major conservation priority assessments and our two indices of Value and Pressure, although the relationship is stronger for Value than for Pressure. We considered seven initiatives in total, the three mentioned in the previous points, and Ramsar wetlands of international important, UNESCO World Heritage sites, UNESCO Biosphere Reserves and Alliance for Zero Extinction sites.

- Even though this analysis shows good general agreement with other conservation priority assessments, our approach goes further by providing more information, at a finer scale, on Value and Pressures at each protected area in the study.

Protected areas and EC biodiversity funding in Africa

- We have identified 96 protected areas that are receiving or have received EC funding. Of those protected areas, 68% have higher than average Biodiversity Value. Furthermore, 28% of EC funded protected areas have high Value & higher Pressure.

- The relationship between funding and our two indices varies from country to country, with countries like Ghana and Côte d'Ivoire having excellent targeting both in terms of Value and Pressure. In other countries such as Ethiopia targeting is closely related to Value but not Pressure, and finally several other countries where there is no discernable link between funding and either Value or Pressure.

- EC funded parks that overlap with several internationally recognised conservation priority assessments have higher Value and Pressure scores than those that do not.

Towards a shortlist of protected areas for future funding consideration

- We have identified a tentative shortlist of 106 ‘critical’ protected areas in ACP countries that have not received EC assistance, but which could be taken into consideration in future funding proposals. It should be noted that the EC is not the only donor, and many of these protected areas are funded by other aid agencies. Cross-referencing these ‘critical’ protected areas with those funded by other donors will reduce this list further.

- A very high percentage of these overlap with broad scale, internationally recognised, assessments of conservation priority: 79 protected areas (75%) are in CI hotspots and 75 (71%) are in the WWF global 200 ecoregions. This demonstrates that our methodology is identifying a plausible set of important protected areas based on broad scale criteria.

- A very high percentage of these overlap with park scale assessments of conservation priorities, 77 protected areas (73%) are also BirdLife IBAs. This demonstrates that our methodology is identifying a plausible set of important protected areas based on management scale criteria.

- Within these ‘critical’ protected areas, those that belong to more than one conservation priority assessment have higher Value and higher Pressure scores, which suggests that the method can also be used to rank or prioritise ‘critical’ protected areas.

- Identifying (EC) unfunded parks that belong to several conservation priority assessments may be a good indicator for successful cooperation with other international agencies and hence a greater likelihood of sustainability and higher impact. Alternatively, critical parks that belong to few such schemes can be considered 'gaps' in our collective knowledge which could also be targeted.

Limitations of the method and data

General observations

- We have developed a continent wide and consistent methodology for assessing the value and pressures on protected areas across Africa. The assessment is based on quantifiable and objective measures using the most up to date and accurate information for Africa. We realise that the species and protected area information is of variable quality and this variation will inevitably affect the results. This was one of the key reasons for reducing our detailed data down to two key indices (Value and Pressure). As new data and better information become available we will integrate them into future assessments.

- The species data that we have used is the best available, but is still incomplete. We have included three taxa and will include more if and when continental or global assessments become available. Future versions of the assessment will include plant data which will affect our final assessment.

- There is concern that the species maps are sometime not accurate enough to be used in conjunction with small protected areas. We have tried various combinations of the species maps and found that our ranking of parks based on irreplaceability is robust to changes in the species maps. We will continue to assess this sensitivity with a multiscale analysis of species irreplaceability from country down to protected area level. It will also contribute to the literature on potential gaps in the protected area network.

- To our knowledge, this is the first time that such a detailed assessment has been attempted on a continental scale. It is also the first time that an assessment of the pressures upon and value of protected areas have been linked to assistance. It would be extremely useful if we could include assistance from other major donors and agencies to produce a more complete picture of biodiversity related funding in Africa. This would probably reduce the shortlist of critical unfunded parks, and would be a valuable resource both for the international donor community and the European Commission.

- We were unable to locate any meaningful consistent information on the effectiveness of EC assistance to protected areas in Africa. Such information is difficult to acquire, subjective in nature, expensive and may not be factored into the project cycle. Furthermore, impact can often only be measured over a duration that is much longer than that of the funded project. This online resource, if maintained over a longer period, could be developed to assess the impact of conservation projects either on a park by park basis or from the impact assessments of regional initiatives (e.g. ECOFAC).

- This assessment measures *indicators* of biodiversity value and pressure on protected areas. We do not directly measure biodiversity or pressures such as hunting, or threats from invasive species. This is primarily because there is no consistent, continent wide method to do so. Nevertheless, we make the assumption that our general assessments of pressure do give an indication of other pressures. We note that some threats are not (and cannot) be taken into account, particularly those related to crisis situations, such as displacement of people by conflicts.

- The pressure scoring system, while robust in our estimation, remains uncalibrated. Assessments of recent land cover change within and around parks with different scores will enable fuller assessment of how well this index describes pressure on parks. We also recognise that the effectiveness of park management will be a big factor in determining the actual pressure on protected areas.

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1. Introduction

Natural ecosystems are in rapid decline. Major habitats are disappearing at a speed never observed before. The current rate of species extinction is several orders of magnitude higher than the background rate from the fossil record (Millenium Ecosystem Assessment 2005). At the global level, the Convention on Biological Diversity (CBD) to which the European Community and Member States are parties - adopted in 2002 the target to significantly reduce the rate of biodiversity loss by 2010. This target was subsequently endorsed by the world's Heads of State and Governments. The World Conservation Union (IUCN) Program on Protected Areas regards the network of protected areas within Africa as the principle safeguard for Africa's rich biodiversity. Protected areas are recognised as the most important core "units" for in situ conservation (Chape et al. 2005). The Convention on Biological Diversity defines a protected area as: "a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives". These objectives range from the preservation of endangered species or landscapes to the protection of natural ecosystems. Uneven distributions of species diversity and threats to their continuing survival, as well as limited financial resources, mean that in order to achieve this goal, conservation priorities must be set (Myers et al. 2000).

Realising the importance of the interdependency between poverty and ecosystems, the European Community (EC) has made significant commitments to halt the loss of biodiversity. European Union (EU) Heads of State and Governments agreed in 2001 to halt the loss of biodiversity in the EU by 2010 and to restore habitats and natural systems. The developed countries have committed themselves to assist developing countries in addressing the issue of the continued loss of biodiversity.

The EC recognizes the crucial role of Protected Areas (PAs) in biodiversity protection, conservation and the sustainable use of natural resources. From the late eighties the EC commitment in supporting PAs and conservation policies at national and regional level has regularly increased and the EC is now an essential donor and stakeholder for biodiversity issues in most of the African countries. Most of the biggest and most successful programmes to support conservation and PA management - i.e. ECOFAC in Central Africa (more than € 150M in 20 years) and ECOPAS in Western Africa (€27M in 7 years), among others - have been funded by the EC. However, due to the limited amount of funds available, there is the need to provide a global picture in order to support decision making. The EC would greatly benefit from concrete support in the identification of priority areas for intervention in order to continue playing an active role in reducing biodiversity loss in Africa.

Why evaluate Protected Areas?

Existing systematic assessments of global or continental scale conservation priorities tend to focus on large scale, homogenous biogeographical units, which may contain numerous protected areas. While this information is useful to characterise the ecosystem over a large geographical area, it has less relevance at other scales, especially that of an individual protected area. Therefore the question remains, why is it necessary to focus on such potentially small planning units?

The answer is because protected areas represent an efficient means for protecting our planet's rich biodiversity (Balmford et al. 2002; Bruner et al. 2001), meaning that conservation actions on PAs potentially have a higher impact on reducing the rate of biodiversity loss. Despite the fact that the African Protected Area network forms an extensive set of sites that are of high conservation and economic importance (Balmford et al. 2002), there are currently no continent-wide systematic assessments of the relative conservation value and threats to African PAs. As such they should clearly be a core focus of conservation action and priority setting at a continental scale.

This is a first attempt at a continent-wide assessment of protected areas using the most up-to-date, objective, and consistent datasets and methodologies as opposed to case studies on individual parks (Tchouto et al. 2006) or global assessments (Chape et al. 2005; Myers et al. 2000). The strength of using this approach is that the results are relevant at many different scales, and can be used to look at protected areas in different contexts. Results can be used to assess the importance of a protected area in comparison to others in the same country or ecoregion, and furthermore the continental, or even global, importance of the site can be assessed. An equally important by-product of this approach is that all of the information used in the analysis is readily available to resource managers for every protected area in the assessment.

In short, this assessment is a first step towards an automatic system for generating local, country, and continental level information for the African protected area network. The system includes information on:

- EC funded projects
- World Development Indicators from The World Bank
- Millennium Development Goal assessments
- FAOSTAT
- Environmental Sustainability Indicators from CIESIN/Yale
- Earth Trends from the World Resources Institute
- Other databases (UNEP, UNSTAT etc)

This report describes the methodology for systematically identifying protected areas for conservation priority setting. These are identified based on the quantification, for each protected area, of six indicators of species irreplaceability, habitat irreplaceability, and the level of perceived threat to a protected area's habitat and species from agriculture and population. These indicators are then simplified into two key factors; biodiversity value (Value) and anthropological pressure (Pressure) and are compared to existing coarse scale assessments of biodiversity and pressure. We also look at the patterns of EC funding for protected areas in Africa compared to our measures of Value and Pressure.

By having access to all of this information in one place, the conservation planner will be better informed on how a protected area performs in the context of the country, and how a country performs in the context of internationally recognised indicators for sustainable development. These country level indicators will not only consider biodiversity conservation, but will also include sectors such poverty alleviation, environmental stewardship, gender equality, economic growth and many more.

Who can use this information?

This report is intended to aid policy and decision makers in the allocation of development funds for sustainable management of natural resources. In identifying the protected areas with the greatest need for attention, and the countries with the greatest need to meet internationally agreed development goals, our aim is to encourage the more effective allocation of conservation related development assistance.

Currently, we envisage that this information will be of most use to the following user groups:

European Commission

The Development Directorate-General (DEV) is responsible for the policy formulation and programming of environmental and forestry actions in all developing countries. DG DEV can benefit from the analysis as basic indicators at national level during the negotiation of the EDF indicative programs.

The EuropeAid Co-operation Office's (AIDCO) mission is to contribute directly or in support to the EC Delegations to the design and the implementation of the EC development policies, programs and projects. With the tool we have developed, AIDCO can better identify the priority areas where a strong effort should be put for preserving biodiversity because of a high value or a serious threat on resources.

The Environment Directorate-General (ENV) officially represents the European Commission at conventions related to environmental topics, such as the conventions related to biodiversity, climate change, and desertification The current work can drastically improve the monitoring of protected areas as well as reporting activities in the framework of the CBD, and in particular the 2010 target.

The Joint Research Centre (JRC) has set up an ACP Observatory for Sustainable Development whose mission is to provide scientific and technical support to EC policies, programs and projects for the sustainable management of natural resources. The current work will be further developed and integrated with other natural resource monitoring (land, forest, coastal…).

The EC Delegations in African countries are in charge of the day-to-day management of EC policies, programs and projects since the devolution process, which aims to bring decision making and implementation closer to the beneficiaries. This tool can provide valuable information both for programming at the national and regional level and for implementing programs and projects at the local level.

EU Member states

EU Member States have their own projects of biodiversity conservation in African countries and can put in perspective their interventions with other protected areas. These projects can also contribute to the richness of the information system developed in the frame of this work.

African nations and Regional Economic Communities (RECs)

National services and Regional bodies in charge of protected area management can easily access important information on biodiversity value and threats in a systematic way and prioritise their interventions in the same way as EC services.

UN organisations and Multilateral Environmental Agreements

The United Nations Environment Program develops monitoring programs and indicators on various environmental issues. This database can contribute to the Global Environmental Outlook. It can also provide consistent information for the verification of the target 2010 of the CBD.

Non Governmental Organisations

Many NGOs have developed "hot spots" of biodiversity (based on value and threats) at broad scale (e.g. Conservation International with an important analysis by Myers et al., 2000). For the first time, this analysis is done at the level of individual protected areas. The efforts of the conservation NGOs can be better spatially focused with this approach.

Civil society

There is an increasing request of scientific information on biodiversity by the wider public. Giving access to robust and consistent information on the biodiversity value of and the threats on protected areas can augment the interest of the civil society to the conservation issues.

2. Aims and Objectives

Objectives

The **overall objectives** of this work are twofold:

1) To contribute to a systematic identification of the protected areas which have the greatest value, in terms of biological resources, and of those which are the most threatened by human development.

2) To contribute to the definition of a decision support system for assessing the relative threats and pressures on protected areas in Africa through a pressure – state – response system, where threats are "pressures", biodiversity value and habitat irreplaceability are "state" and decision is "response".

The **purpose** of the work is to provide to decision makers a regularly updated tool to assess the state of Africa PAs and to prioritize them according to biodiversity values and threats so as to support decision making and fund allocation processes.

Expected results

The specific aims within this overall objective are:

1) To develop a framework that combines biodiversity, environmental and socioeconomic information from a range of sources, in order to create 'status' reports for each protected area.

2) To present the information about a protected area, with respect to other protected areas in the same country, and with respect to other protected areas in the same Ecoregion.

3) To ensure that the process is repeatable such that new information (i.e. new species data or measures of environmental or anthropological threats) can be incorporated into the system to improve or update the assessments.

A brief overview of the method

This report contains extensive information on data sources and data processing. Figure 1 shows how these data sources are linked and combined to create the final assessment of protected areas and how this is placed in context with external country level data such as (i) EC projects and funding, (ii) environmental sustainability, (iii) progress towards the Millennium Development Goals and (iv) social and economic indicators.

The next section reviews existing literature on biodiversity assessment and conservation planning and prioritisation. This is followed by a description of the datasets and the methods for generating the indices for assessing a protected areas status. The results of the assessment are presented and compared to existing coarse scale conservation priorities to determine the degree of agreement between the two. We then present the relationship between our assessment and EC funding in protected areas in Africa to highlight successful targeting and also areas where targeting could be benefit from the type of information contained within this assessment.

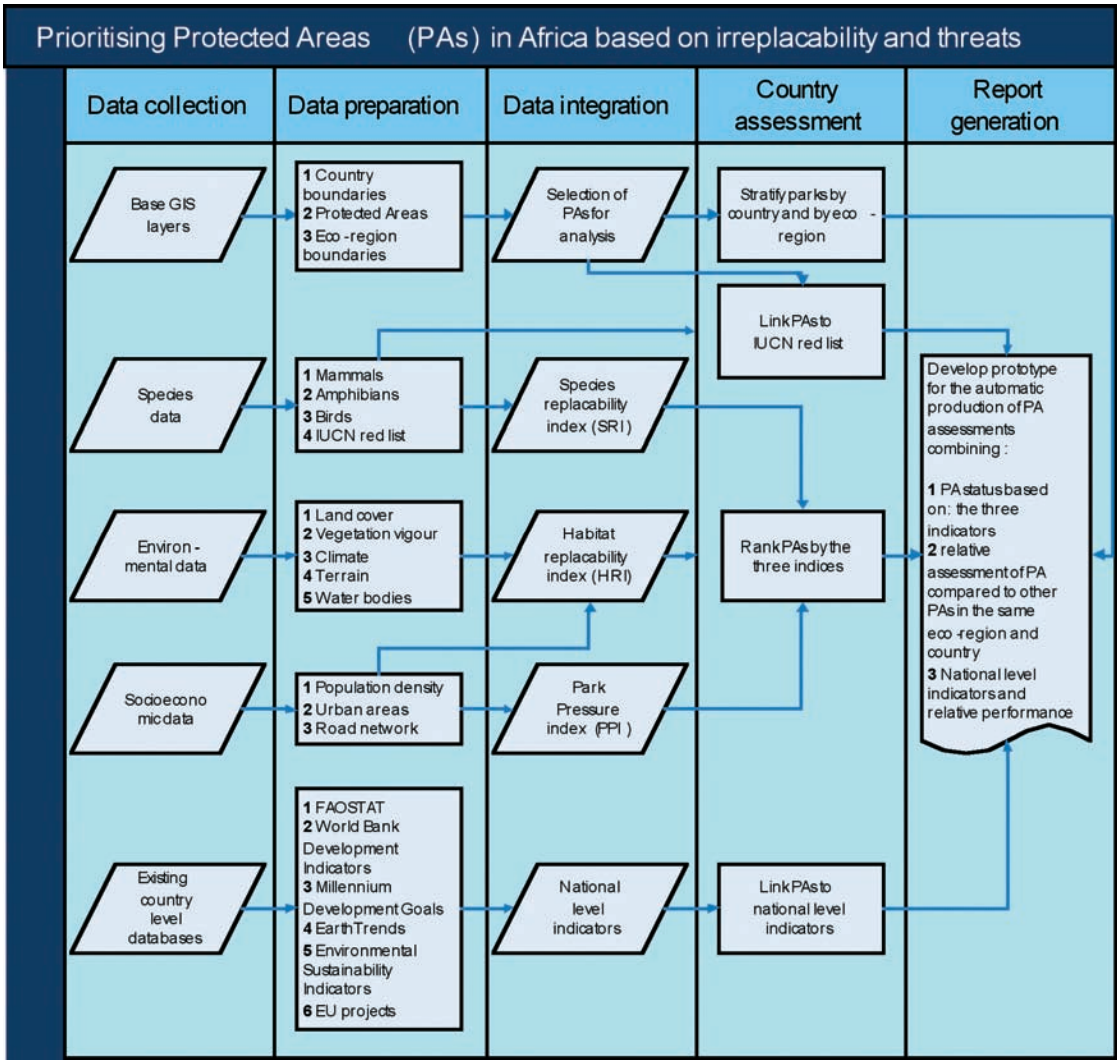

Figure 1. *Flow chart of the overall methodology.*

3. Background

Existing assessments for conservation priorities tend to focus on larger biogeographical units, in an effort to attract geographically flexible funding (Brooks et al. 2006). Despite the reported success of this approach in attracting funds, there still remains the question of how and where to spend this money within these large biogeographical units, especially if one is to assume that biodiversity and threat are not evenly distributed throughout a given spatial unit. The system of protected areas can go a long way to answering this question, by providing focus for conservation efforts, while at the same time engaging local communities and generating opportunities for poverty reduction (5th IUCN world parks conference).

Since Protected Areas are designated by a country's government, their aereal extent, and biodiversity values vary. While attempts have been made to standardise Protected Area selection across Africa (Csuti et al. 1997; Kirkpatrick 1983; Moore et al. 2003), there is still no standard assessment of biodiversity value or threats. Assessment of the effectiveness of the protected areas network, in terms of representing species diversity, has been helped by the massive effort of conservation organisations to collect geographical distributions and threat status information for an array of vertebrate taxa (Global Amphibian Assessment, (IUCN 2004); African Mammals Databank, (Boitani et al. 1999); BirdLife Endemic birds, (Stattersfield et al. 1998)). However, gap analyses have highlighted the fact that the network of protected areas is not representative of all biodiversity, which is especially so for species with smaller ranges, such as amphibians, or threatened species in general (Rodrigues et al. 2004). It has been estimated that, using amphibians and mammals as umbrella taxa, the area protected in Africa may need to be expanded by 45 – 70% (Rondinini & Boitani 2006). Considering that this is based on a small sample of overall diversity, Rondinini and Boitani accept that it is likely to be an underestimate. Similarly, only 57 % of the most important sites for the long term maintenance of bird species in Africa overlap (partially or wholly) with Protected Areas (Fishpool & Evans 2001). Estimates vary on the exact extent of the protected surface area needed to maintain species diversity, but the higher end estimates, such as the 50% estimate of the land surface (Soule & Sanjayan 1998) are politically unfeasible (Musters et al. 2000).

Prioritisation approaches

In the past decade, there have been nine different approaches that have identified biogeographical regions for conservation priority. In a recent review of approaches for biodiversity conservation priority setting, Brooks et al (2006) described these approaches within the conceptual framework of irreplaceability and vulnerability. Most methods prioritise high irreplaceability, measured by either plant (Bryant et al. 1997; WWF & IUCN 1994-1997), or bird endemism (Stattersfield et al. 1998), or overall terrestrial vertebrate endemism (Myers et al. 2000; Olson & Dinerstein 2002). Furthermore, 5 out of the 9 prioritisations include the concept of vulnerability, either to habitats or to species, some prioritizing low vulnerability (Last of the wild (Sanderson et al. 2002), high biodiversity wilderness areas (Mittermeier et al. 2003), frontier forests (Bryant et al. 1997) and some high vulnerability (Biodiversity hotspots (Myers et al. 2000), crisis ecoregions (Hoekstra et al. 2005)). Lastly, Brooks et al observed that the different approaches to conservation priority assessment were focused on differing predefined biogeographical units, usually identified by regional experts. In the case of the G200 Ecoregions these are defined as "relatively large units of land containing a characteristic set of natural communities that share a large majority of their species, dynamics and environmental conditions" (Olson & Dinerstein 1998).

Currently, to the best of our knowledge, there has been no prioritisation for the conservation of biological resources based on an existing legally recognised infrastructure of planning units. Here, we propose a method of prioritisation of protected areas (henceforth PAs), based on the irreplaceability of habitat, and irreplaceability of amphibian, mammal and endemic bird species, relative to a general measure of the vulnerability of these habitats and species. We define irreplaceability to be a measure of the "uniqueness" of a PA's biological resources, with respect to those resources found in other PA's. We define vulnerability as the extent to which a PA's biological resources are threatened to the point of extinction. The aim of this study, as described in the conceptual framework of Brooks et al, is reactive: to prioritize protected areas which are highly irreplaceable in terms of biological diversity, which are also highly vulnerable to extinctions.

4. Data

Unless otherwise stated, all vector data has a nominal scale of 1:1,000,000 and all raster data has a pixel size of 30 arc-seconds or approximately 1km. All data are in Geographic projection.

4.1. Base layers

4.1.1. Country boundaries

Vector data for international borders were extracted from the 1:100,000 Vector Smart Map Level 0 (VMap0) data library (2005).

4.1.2. Protected areas

We used the World Database on Protected Areas (UNEP-WCMC, 2005), as the basis for our analysis. All IUCN PAs between categories I-IV were included in the study, as well as International PAs (World heritage sites, and Ramsar sites), and those national PAs which were known to us to have previously received conservation or development aid (effectively PAs which have been, or still are, funded by the European Commission). By focusing on PAs which are recognised internationally, and therefore more likely to have a management plan in place, we hope to avoid the inclusion of so-called "paper parks", and focus on PAs with an existing infrastructure that could benefit quickly from an increase in revenue. We removed PAs from the analysis with an area smaller than 2000 ha, because the datasets available to us with continental coverage are mapped to scales of 1:1million, or 1km pixel resolution. Finally, we excluded from the analysis PAs with a large offshore water component, due to their incompatibility with our land based data. In total, we included 741 African PAs in the analysis (Figure 2).

4.1.3. Eco-regions

We used White's Vegetation Map of Africa (White 1983) which is essentially a vegetation classification and map for continental Africa, consisting of 17 major vegetation types which we will refer to as eco-regions. This map was used to assign an eco-region to each PA (figure 3).

4.2. Species data

There are several sources for species data, all of which refer to the extent of occurrence (EOO) of a recorded species. The EOO is defined by the IUCN as the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy (see Figure 4).

4.2.1. Mammals

Geographical ranges of 280 mammals were downloaded from the African Mammals Databank (Boitani et al. 1999). The AMD is a European Commission funded (project no. B7-6200-94-15/VIII/ENV/1994/67) assessment of the global distribution patterns of 280 medium and large scale mammals across continental Africa, produced by the Institute of Applied Ecology, Rome. The assessment is based on published literature from approximately 1989 to 1999, as well as expert knowledge, in collaboration with the IUCN Species Survival Committee (IUCN/SSC). The published distribution maps were scanned from the literature, georeferenced and vectorised,

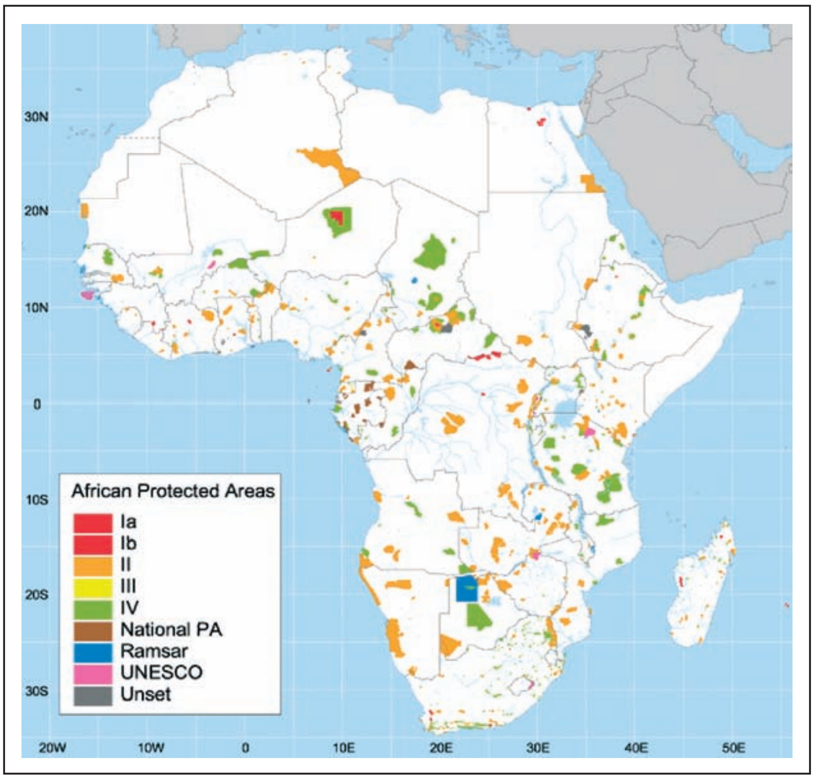

Figure 2. *Protected areas in Africa from the WCMC database.*

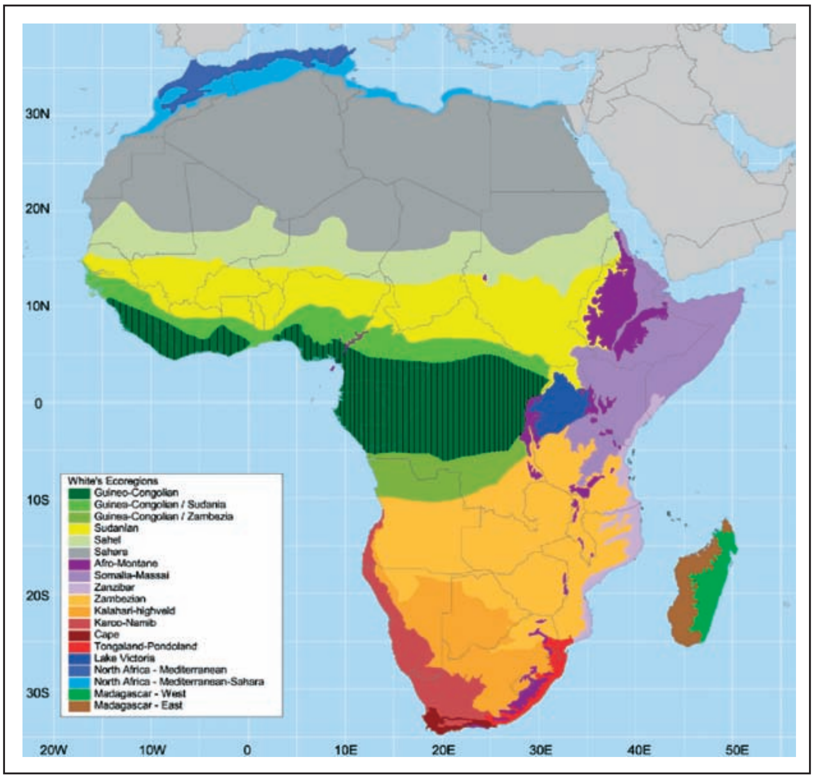

Figure 3. *White's Vegetation Map of Africa.*

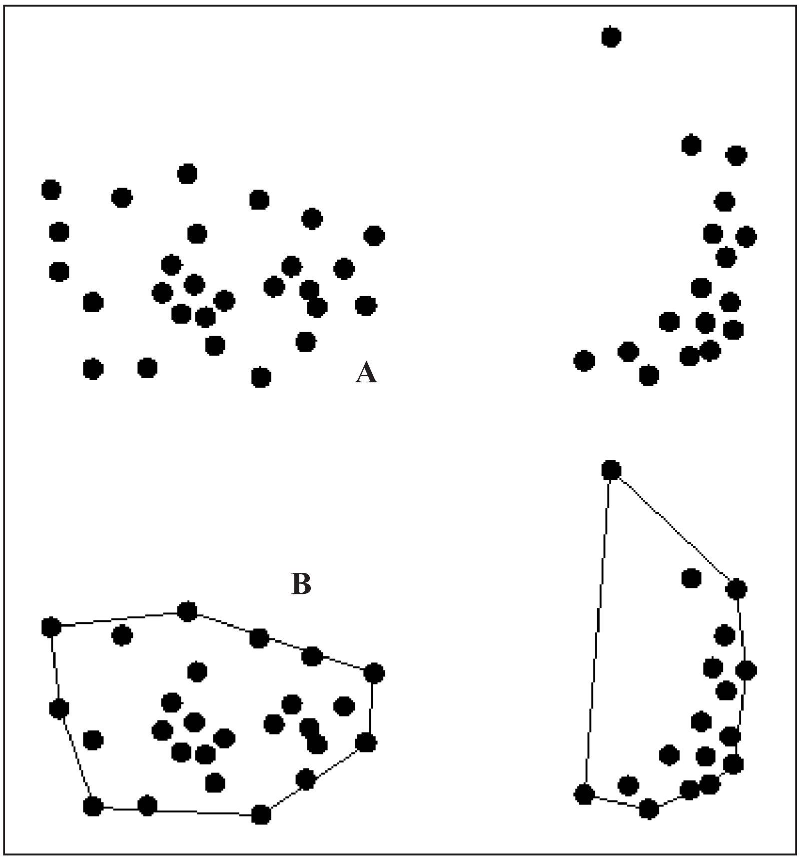

Figure 4. *The following two examples explain the extent of occurrence. (A) shows the spatial distribution of known, inferred or projected sites of present occurrence. (B) shows the boundary of the extent of occurrence. Note how there is uneven spatial distribution of points within both of the boundaries.*

then checked by a regional expert via the IUCN/SSC. Furthermore, species habitat preferences (in relation to land cover, water availability, and altitude) were recorded when possible, and used to create area of occupancy (AO) maps for each species, by identifying suitable areas for a given species within its extent of occurrence. The databank in its downloaded form includes vector data on the geographical extent of occurrence, and two different models of suitability. The categorical-discrete distribution model (suitable and non-suitable areas) was used in this study.

4.2.2. Amphibians

Information for amphibian diversity was downloaded from the IUCN Global Amphibian Assessment (IUCN et al. 2006). The GAA is the first global assessment of all 5918 known amphibian species in the world. Geographical ranges for almost all of the assessed species were scanned from the published literature, georeferenced and vectorised, and then checked with a group of regional experts. Furthermore, the characteristics and occurrence of each species were assessed against the IUCN Red List Categories and Criteria (http://www.redlist.org/), resulting in an assessment of the threat status for each species. Data were downloaded (from http://www.natureserve.org last accessed, July 2005), and all 930 amphibian species found on the African continent were extracted.

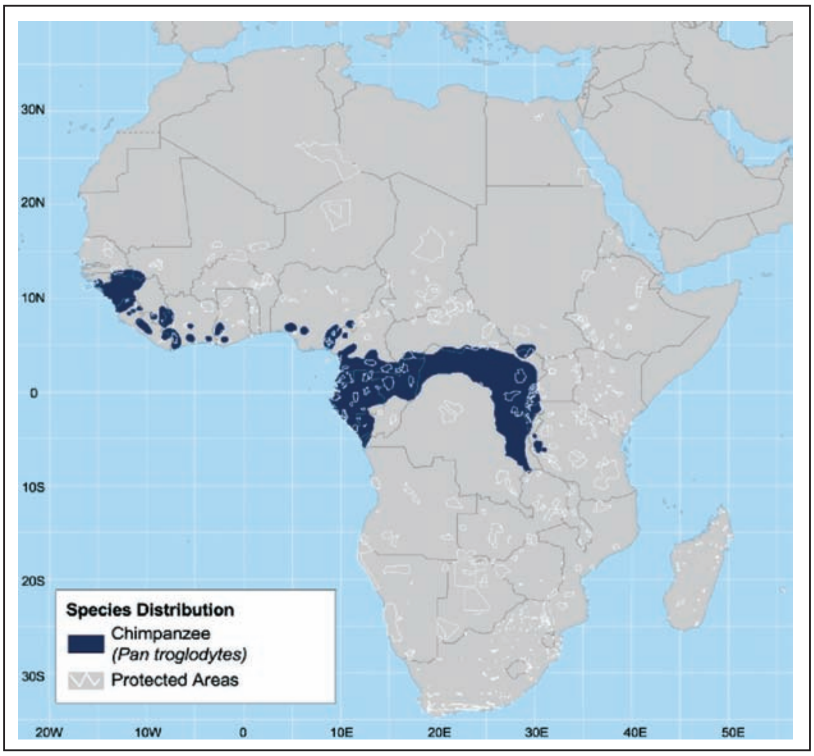

Figure 5. *Sample dataset from the African Mammals Databank. The known extent of occurrence of the species Pan troglodytes (Chimpanzee).*

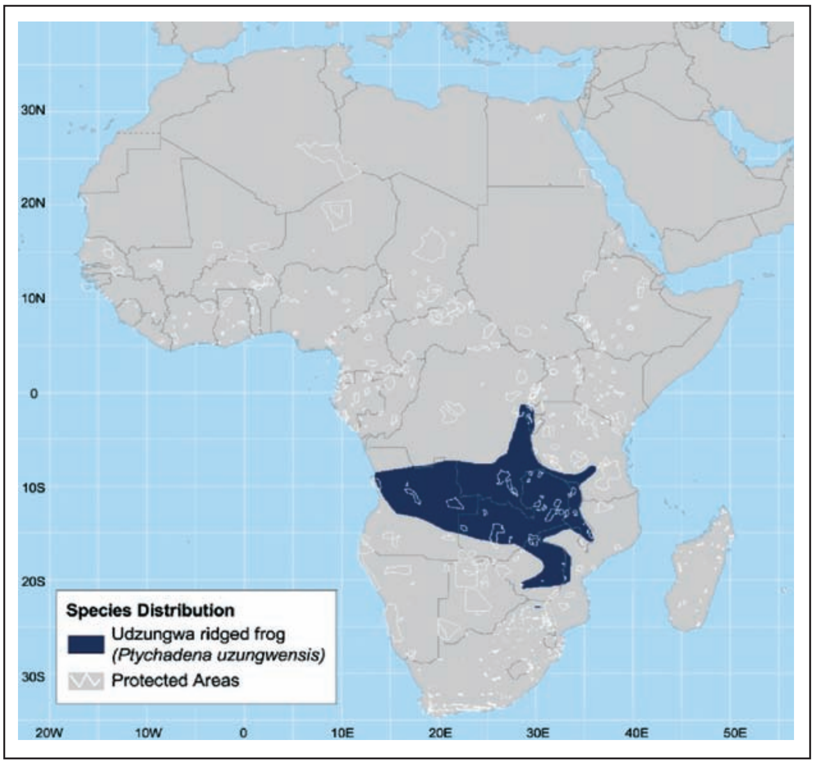

Figure 6. *Sample dataset from the IUCN Global Amphibian Assessment. The known extent of occurrence of the species Ptychadena uzungwensis (Udzungwa ridged frog).*

4.2.3. Birds

BirdLife International's Important Bird Areas (IBAs) are sites of high conservation priority for the protection of globally threatened birds. They are chosen based on one or more of the following three criteria:

- The site holds significant numbers of one or more globally threatened bird species
- Is one of a set of sites that together hold a suite of restricted-range species or biome-restricted species
- Has exceptionally large numbers of migratory or congregatory species

The identification of IBAs was done using standard, objective, quantitative, and scientifically defensible criteria. The network of IBAs, while not exclusively comprised of sites with a formal protection plan in place, overlaps considerably with the protected area network (399 out of 741 protected areas in this study). Since the IBA site selection was designed to include all globally threatened bird species, it can be assume that protected areas which do not overlap with an IBA site do not contain a globally threatened bird species. Therefore, lists of globally threatened bird species for each IBA (obtained from BirdLife International via personal communication) could be used to indicate conservation value of African protected areas with respect to threatened bird species. Bird lists for each IBA were compiled by regular, consistent in-situ measurements by BirdLife International's African Partnership.

4.2.4. IUCN red list

Each of the 1591 species assessed in this study were checked with the 2006 IUCN Red List of Threatened Species, (http://www.iucnredlist.org/search/search-expert.php, last accessed July 2006). This provided the most up to date assessment of the current state of each species.

4.3. Environmental data

4.3.1. Land cover - GLC2000

The regional land cover map for Africa (Mayaux et al. 2004), from the Global Land Cover 2000 project was produced mainly from daily observations throughout the year 2000 from the Vegetation instrument onboard the SPOT-4 satellite. Land cover classes were assigned based on the spectral response and temporal signature of the vegetation cover. It includes a total of 27 land cover categories, and represents the most spatially and thematically detailed land cover map available for the whole continent.

[1] http://www-gem.jrc.it/glc2000

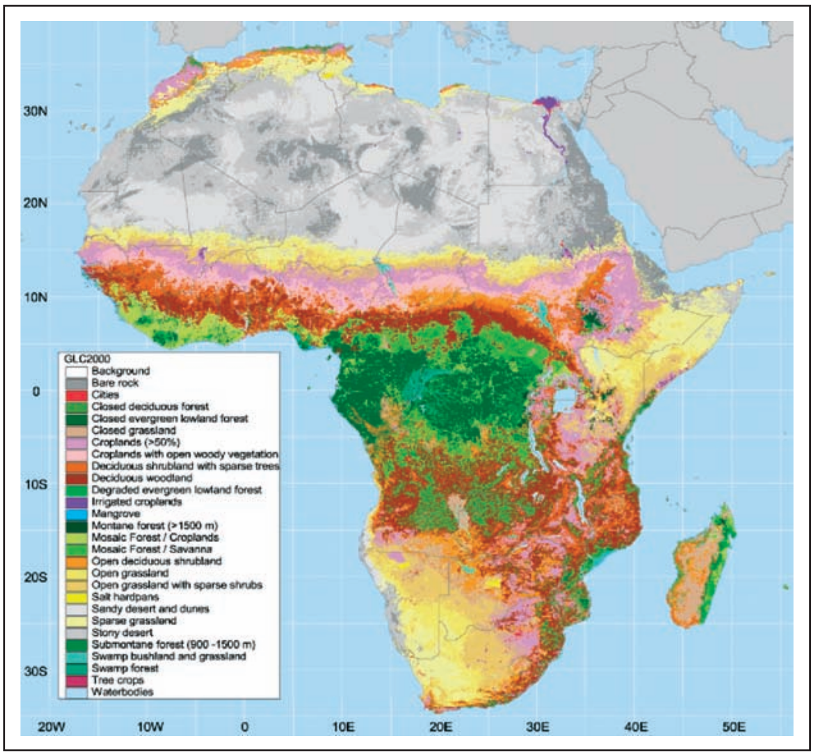

Figure 7. *Global land cover for the year 2000.*

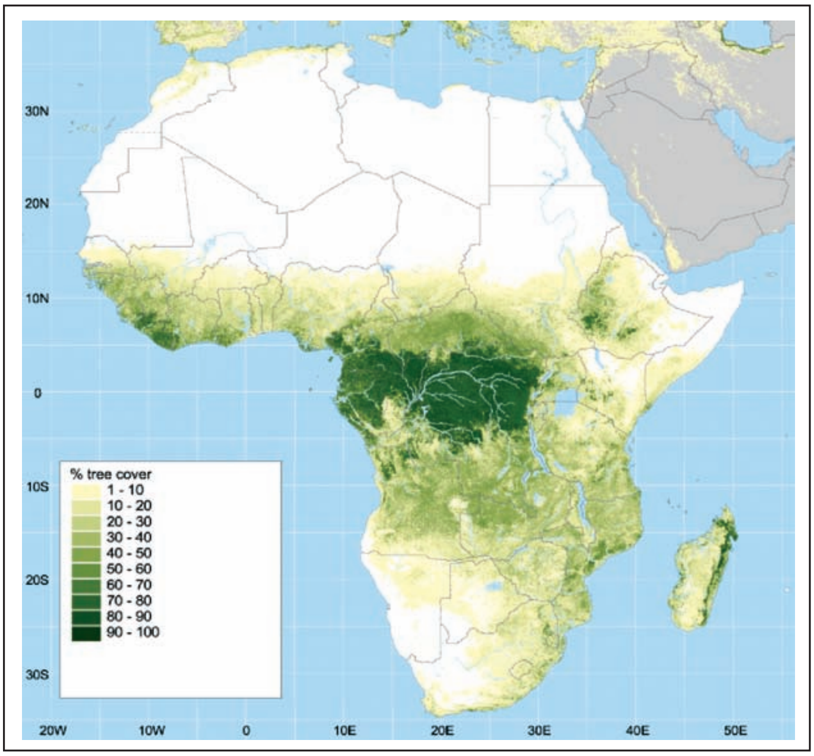

Figure 8. *Woody vegetation continuous fields data for Africa.*

4.3.2. Vegetation cover

The Vegetation Continuous Fields[2] collection contains proportional estimates for vegetative cover types: (i) woody vegetation, (ii) herbaceous vegetation, and (iii) bare ground. The product is derived from all seven bands of the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor onboard NASA's Terra satellite. The continuous classification scheme of the VCF product may depict areas of heterogeneous land cover better than traditional discrete classification schemes. While traditional classification schemes indicate where land cover types are concentrated, this VCF product is ideal for showing how much of a land cover such as "forest" or "grassland" exists anywhere on a land surface (Hansen et al. 2003).

4.3.3. Terrain

The SRTM30 map is one of a series of land surface products emerging from the Shuttle Radar Topography Mission (SRTM[3]). The SRTM data for Africa is available at approximately 90m resolution, which is too detailed for this study. However the SRTM30 product is a resampling of this data to approximately 1km resolution. Two terrain indices were extracted from this data, (i) elevation in meters and (ii) slope in degrees.

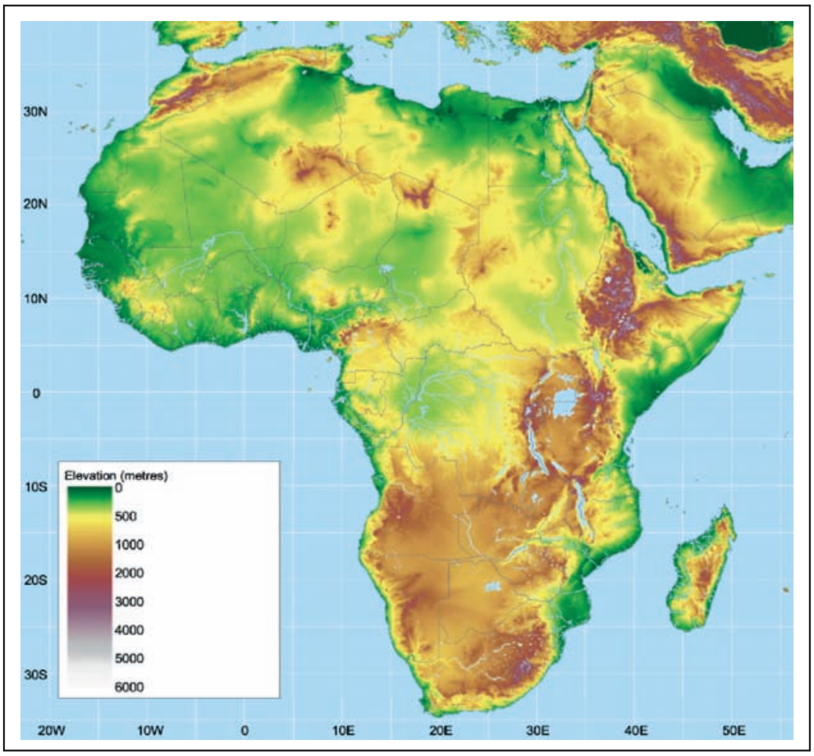

Figure 9. *Elevation data for Africa.*

[2] http://glcf.umiacs.umd.edu/data/modis/vcf/

[3] http://srtm.usgs.gov/

4.3.4. Climate (Aridity)

WorldClim is a set of global climate layers (climate grids) with a spatial resolution of a square kilometre (Hijmans et al. 2005). The database contains monthly rainfall and maximum/minimum temperature estimates which were used to generate an aridity index using the following methodology for computing potential evapotranspiration (Thornthwaite 1948).

Potential evapotranspiration E for each month is estimated from monthly mean temp and monthly rainfall. E is the amount of water that could be evaporated from land, water, and plant surfaces if soil water were in unlimited supply. The Thornthwaite calculation of E is given by

$$E = 16.0\left(\frac{10T}{I}\right)^{a}$$

Where

E = monthly potential evapotranspiration (mm).
T = mean monthly temperature (C).
I = a heat index for a given area which is the sum of 12 monthly index values ***i***, where ***i*** is given by

$$i = \left(\frac{T}{5.0}\right)^{1.514}$$

a = an empirically derived exponent which is a function of **I**.

$$a = \left(6.75 \times 10^{-7}\right)I^{3} - \left(7.71 \times 10^{-5}\right)I^{2} + \left(1.792 \times 10^{-2}\right)I + 0.49239$$

Our aridity index ***Ih***[5] , is simply the annual rainfall in mm divided by the annual PET in mm. ***Ih*** has values from 0 to 1 or higher. The values can be characterised as follows.

Hyper-arid (Ih < 0.03), Arid (0.03 <= Ih < 0.20), Semi-arid (0.20 <= Ih < 0.50), Dry sub-humid (0.50 <= Ih < 0.65), Moist sub-humid (0.65 <= Ih < 0.75), Humid (0.75 <= Ih < 1.00) and Extremely humid (Ih > 1.00)[6]

[4] http://www.worldclim.org/

[5] Also termed the agro-climatic index, the moisture index or the UNESCO index in the literature

[6] http://reports.eea.eu.int/92-9167-056-1/en/page003.html

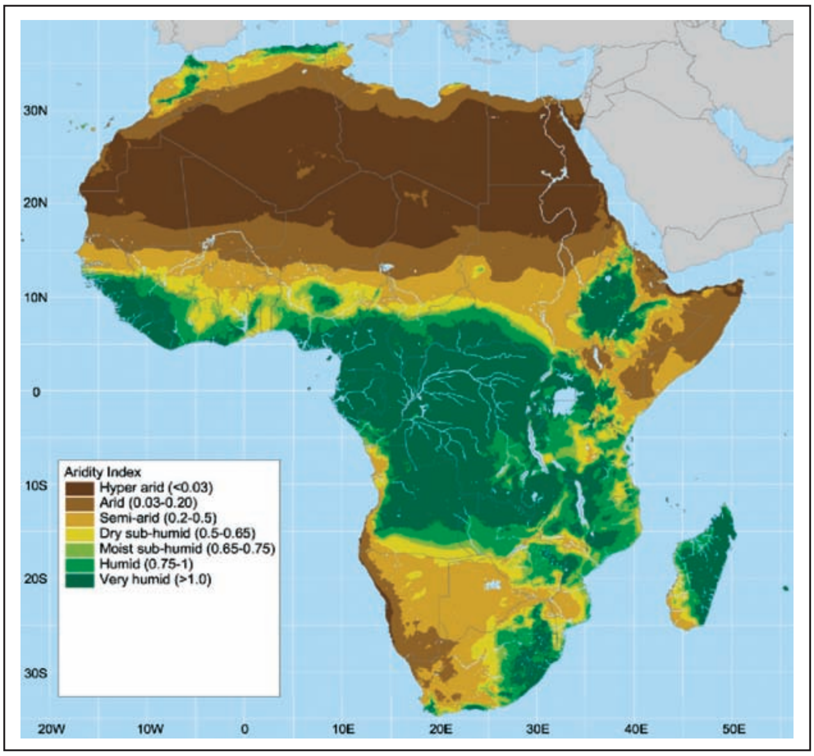

Figure 10. *Aridity index for Africa.*

4.3.5. Vegetation vigour (maximum NDVI and maximum NDWI)

1) NDVI, or Normalised Difference Vegetation Index, is a dimensionless index that is indicative for vegetation density and activity. It is calculated by comparing the red and near-infrared sunlight reflected by the surface (reflectance). S10 NDVI is a 10-day VEGETATION synthesis product that contains only the NDVI band (i.e. no spectral bands, no viewing and solar angles).

Healthy vegetation absorbs solar radiation in the photosynthetically active radiation (PAR) spectral region and scatters (reflects and transmits) in the near-infrared spectral region. Unhealthy (non-green) or sparse vegetation reflects more visible light and less near-infrared light. This difference in reflectance for different wavelengths, allows remote sensing instruments to measure the relative presence (or absence) of healthy, green vegetation, by simply measuring and comparing the reflectances. Live green plants appear relatively dark in the Red and relatively bright in the near-infrared. Typically, the evaluation is done by evaluating the following formula:

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

where NIR is the near-infrared reflectance and R is the reflectance of red light.

The product provided is a 10-day synthesis, which means that it combines daily atmospherically corrected data of all VEGETATION segments (measurements) of the given decade (10-day period) into a single image using the MVC (Maximum Value Composite) algorithm, which selects the pixels with the best ground reflectance values. We computed the maximum NDVI value over the period 1998 to 2005.

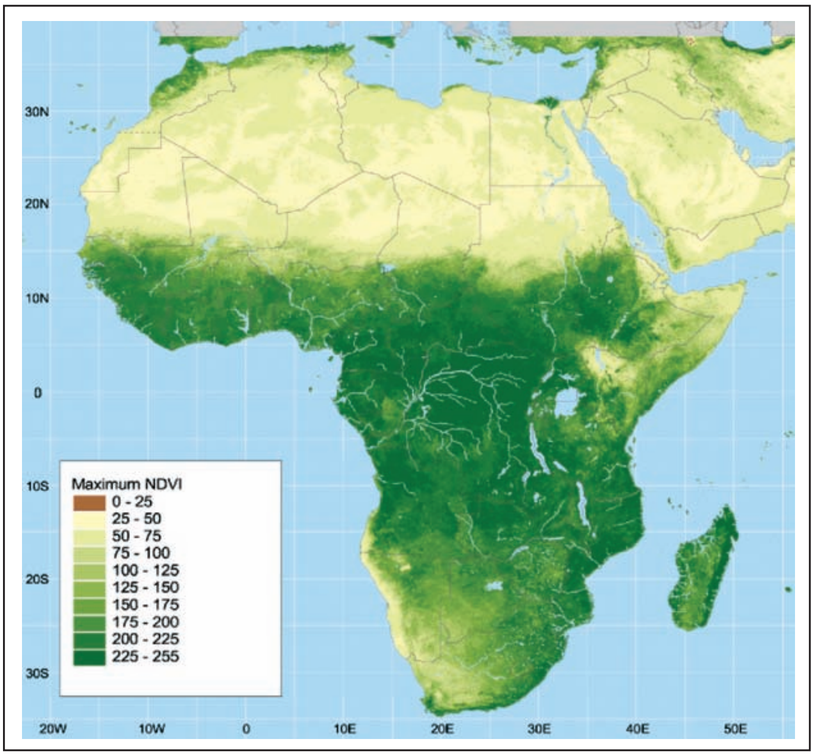

Figure 11. *Maximum NDVI values.*

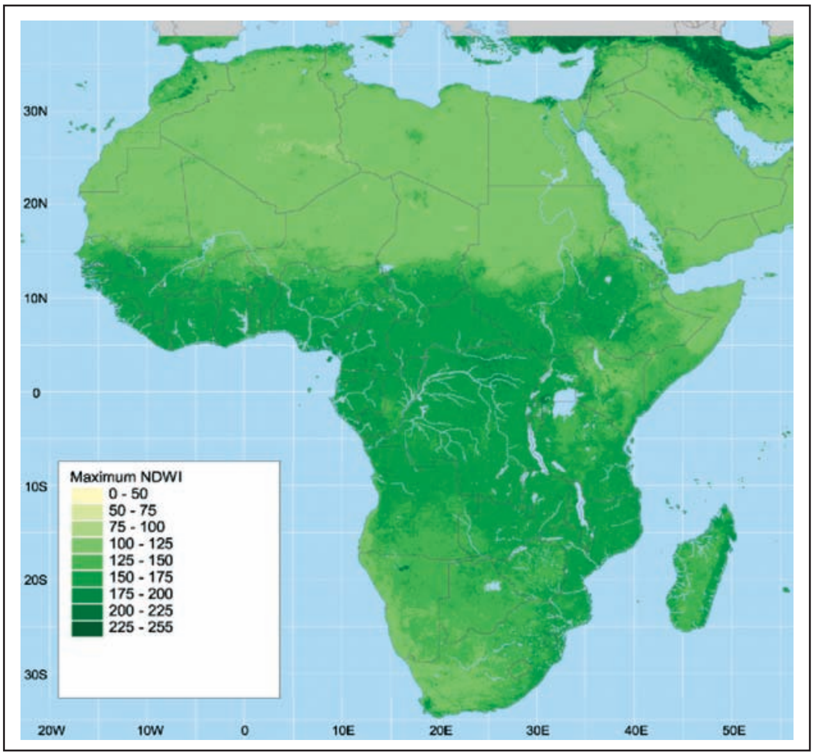

Figure 12. *Maximum NDWI values.*

2) NDWI, or Normalised Difference Water Index, is a dimensionless index that indicates the presence or absence of water on the surface and is calculated by comparing the shortwave and nearinfrared sunlight reflected by the surface (reflectance). NDWI is also sensitive to changes in liquid water content of vegetation canopies.

The Near Infrared (NIR) and Short Wave Infrared (SWIR) reflectance bands can be combined to compute the Normalized Difference Water Index (NDWI), according to the formula:

$$NDWI = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

where NIR is the reflectance in the Near Infrared band and SWIR is the reflectance in the Short Wave Infrared band. This formula is similar to that of NDVI, except for the fact that the NDWI formula contains the shortwave infrared reflectance, instead of the reflectance of visible (red) light. This usage of SWIR reflectance is exactly what makes NDWI more sensitive to water content.

Daily SPOT-VEGETATION images have been converted into ten-daily composites (S10), using the Maximum Value Compositing (MVC), to reduce atmospheric interferences (clouds), similarly as for the S10 NDVI product. The NIR and SWIR bands of those composites are used directly in the calculation of the NDWI values.

We computed the maximum NDWI value over the period 1998 to 2005. Both these products are fully documented in EU Report 22344.

4.3.6. Water bodies

Two data sources were used to generate a single water body presence map for Africa.

1) The Global Lakes and Wetlands Database (GLWD)[7] is a combination of best available sources for lakes and wetlands on a global scale (1:1 to 1:3 million resolution), represented as a GIS database which focuses in three coordinated levels on (1) large lakes and reservoirs, (2) smaller water bodies, and (3) wetlands (Lehner & Doll 2004). We extracted the large lakes and reservoir data and assigned each large water body a value of 100.

2) Small water bodies are understood here with respect to the VEGETATION instrument resolution, i.e. surfaces more or less covered by water with a size of about 1 km^2. The product includes both the detection of the water body itself during the last 10-day period, and information about its seasonality, i.e. when replenishment started, and when drying out was completed.

We extracted decadal data for 2000-2005 and for each pixel we determined the % of time which that pixel was identified as a water body, with values ranging from 0% to 100%. Following advice from Bruno Combal, a coastline buffer mask was applied to ignore any water body pixels within 30km of the coast. This product is documented in EU Report 22344.

These two datasets were merged whereby GLWD was given priority over the SWBD to create a map of water body presence as a % of the year.

[7] http://www.worldwildlife.org/science/data/globallakes.cfm

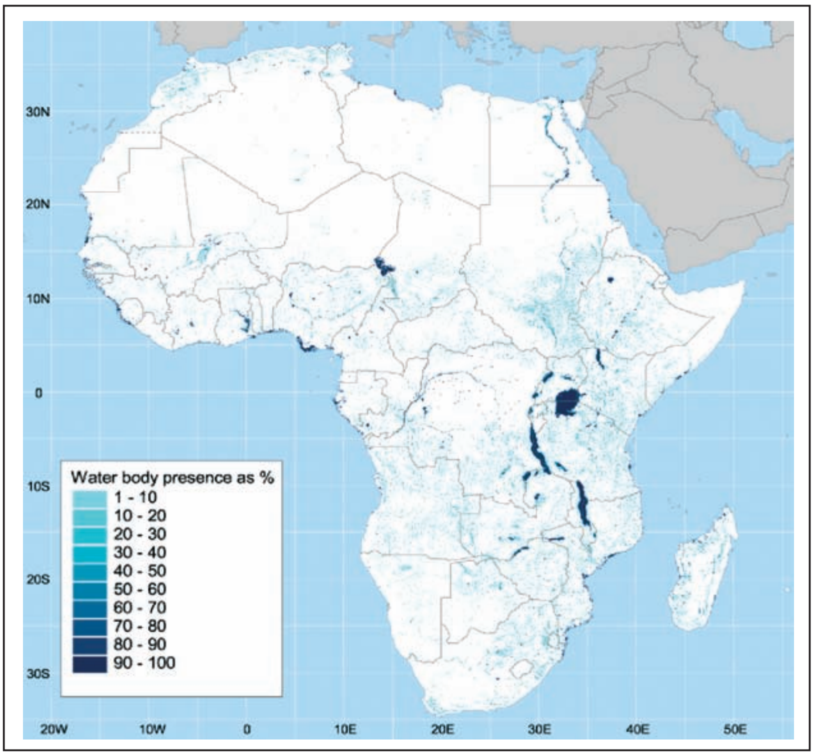

Figure 13. *Water body presence as a % of the year.*

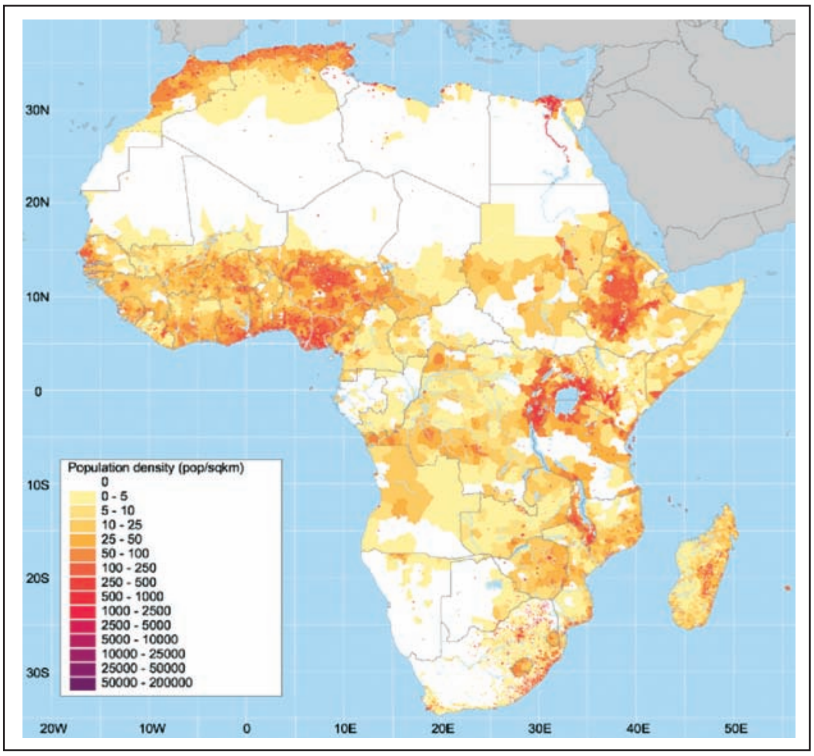

Figure 14. *Population density estimates for Africa from GPW v3 (circa 2000).*

4.4. Socio-economic data

4.4.1. Population counts and density

Gridded Population of the World (GPWv3[8]) is the third edition of a large-scale data product that demonstrates the spatial distribution of human populations across the globe. The purpose of the GPWv3 project is to provide a spatially disaggregated population layer that is compatible with datasets from social, economic, and earth science fields. The output is unique in that the distribution of human population is converted from national or subnational spatial units (usually administrative units) of varying resolutions, to a series of geo-referenced quadrilateral grids at a resolution of 2.5 arc minutes.

4.4.2. Roads

The current best available public domain spatial global road network dataset[9] is the 1:100,000 Vector Smart Map Level 0 (VMap0) data library from the National Imagery and Mapping Agency (NIMA 2000)[10]. The road vectors for Africa were extracted from this global layer and were improved by including road type characteristics from 1:4,000,000 paper maps (Michelin 2004a, 2004b, 2004c).

4.4.3. Urban areas and populated places

The Global Rural-Urban Mapping Project (GRUMP[11]) provides a new suite of data products that add rural-urban specification to GPWv3 (see section 4.4). This project was developed out of a need for researchers to be able to distinguish population spatially by urban and rural areas. The central data product resulting from GRUMP is a Gridded Population of the World with Urban Reallocation in which spatial and population data of both administrative units and urban extents are gridded at a resolution of 30 arc-seconds. Additional data sets resulting from GRUMP include a 30 arc-second land area grid showing urban areal extents worldwide, and a database of human settlements, their spatial coordinates, and populations.

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8 http://sedac.ciesin.columbia.edu/gpw/aboutus.jsp

9 See http://www.ciesin.columbia.edu/pdf/globalroads.pdf (Nelson et al 2006) for a review of global road databases

10 NIMA is now known as the National Geospatial Intelligence Agency (NGA).

11 http://sedac.ciesin.columbia.edu/gpw/aboutus.jsp

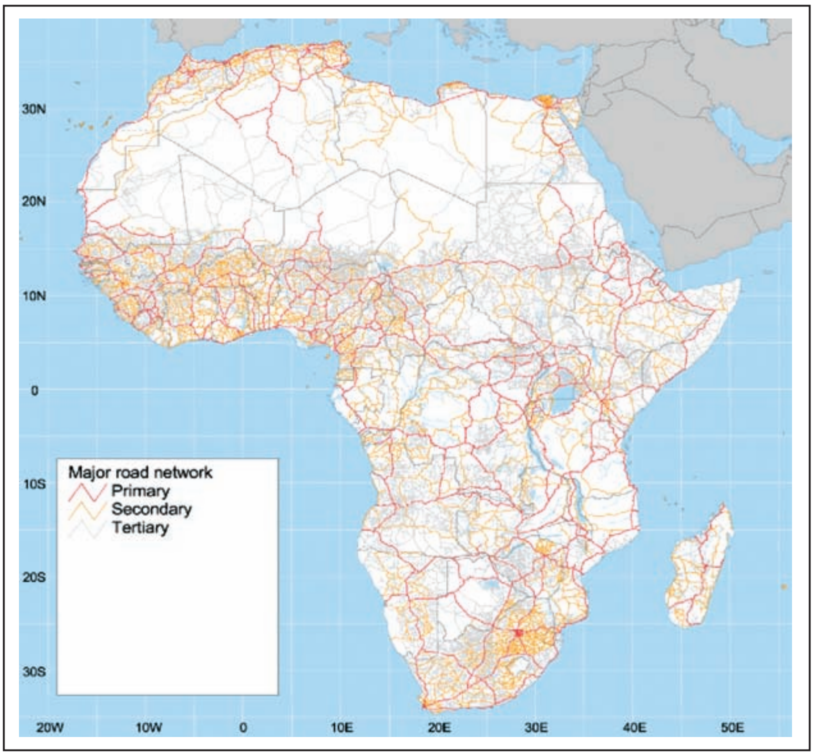


Figure 15. *Major roads in Africa, from VMap0 and Michelin data sources.*

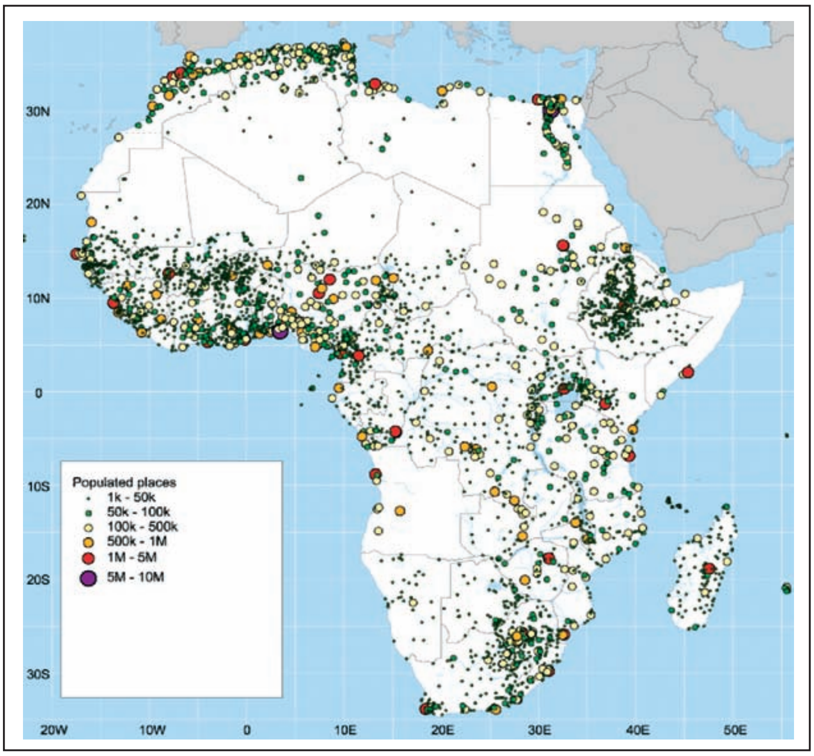


Figure 16. *Populated places and population estimates from GRUMP.*

5. Methods

5.1. Computing the indicators for species irreplaceability

The aim of this component of the analysis is to produce an index of the irreplaceability of each PA with respect to the amphibian, mammal, and globally threatened bird species included in the study. This will give an indication of the uniqueness of each protected area in terms of its species composition, or in other words, the conservation value of that protected area, with respect to known vertebrate species.

5.1.1. Methods

For both mammal and amphibian taxa, two different products were calculated. Firstly, in order to provide a general overview of the spatial distribution of species richness, endemism, and threat over the whole continent, a 1km resolution map was calculated using the geographical distributions of all species for the two different taxa. This was done, by giving a value of 1 to each 1km pixel in which a given species was found, and adding together all such maps for all African species of that taxon. This method was repeated separately for amphibians and mammals. Furthermore, a similar map for endemic species was calculated. We defined endemism to be the 25% of species from a taxon with the smallest geographical range. These species were selected (232 out of 930 amphibians, and 70 out of 280 mammals), and the range maps were added together to give the number of endemic species in each 1km pixel. These two maps were not produced for birds, since the IBA database for birds does not contain species distribution maps. Finally, the IUCN red list category of each species was used to produce a map for threatened species (of amphibians and mammals), using the same method of summing species ranges. We defined a threatened species to be listed as vulnerable, endangered, or critically endangered in the IUCN red list.

Secondly, an irreplaceability index (RI) was calculated for each protected area, with respect to all the species of a given taxon (amphibian, mammals and globally threatened birds). This was done by counting how many protected areas a species occurs in (*n*), and adding *1/n* to the RI of each of those protected areas. The same procedure was carried out for all species in a given taxon. The RI of a given PA is defined as:

$$RI_P = \sum_{i=1}^{t}\left(\frac{1}{n_s}\right)$$

Where **p** is a protected area, **n** is the number of PAs a species **s** is found in, and **t** is the total number of species in the taxon database. We chose this method of measuring biodiversity because it accounts for both high species richness of common species, but it also gives an increased weight to PAs which have a high number of species found in very few other PAs (i.e. endemic or threatened species). It is important to identify such protected areas, because the success of these PAs is essential to the survival of the species they contain, and furthermore essential to achieving the goal of reducing the rate of current biodiversity loss. Furthermore, this measure provides a basis for the intercomparison of protected areas, since the RI for a given PA, is a reflection of how that PA’s species composition is repeated in other protected areas.

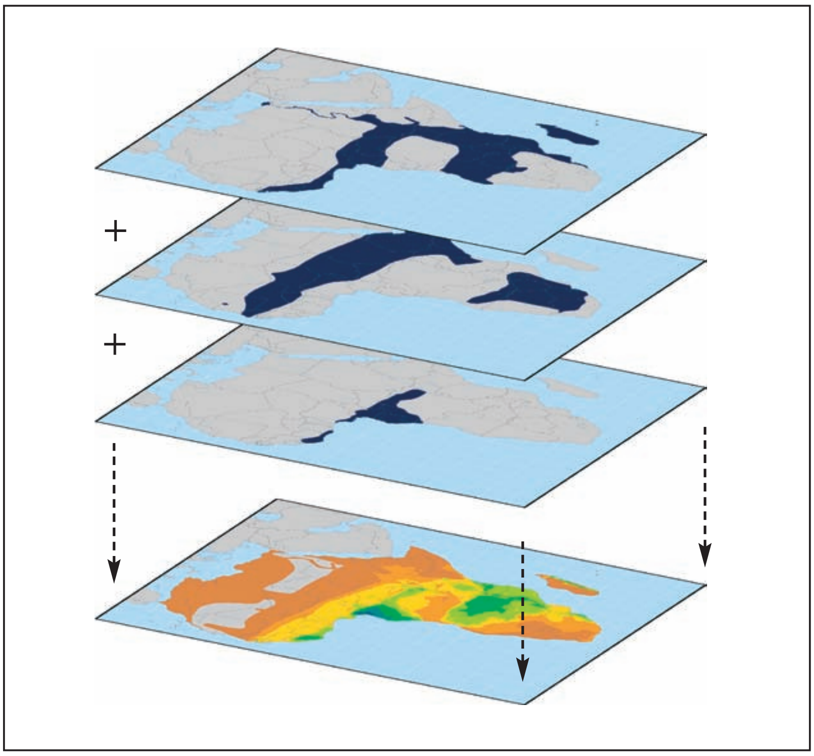


Figure 17. *Diagram to show the combination of layers of species extent of occurrence information to create a species richness map.*

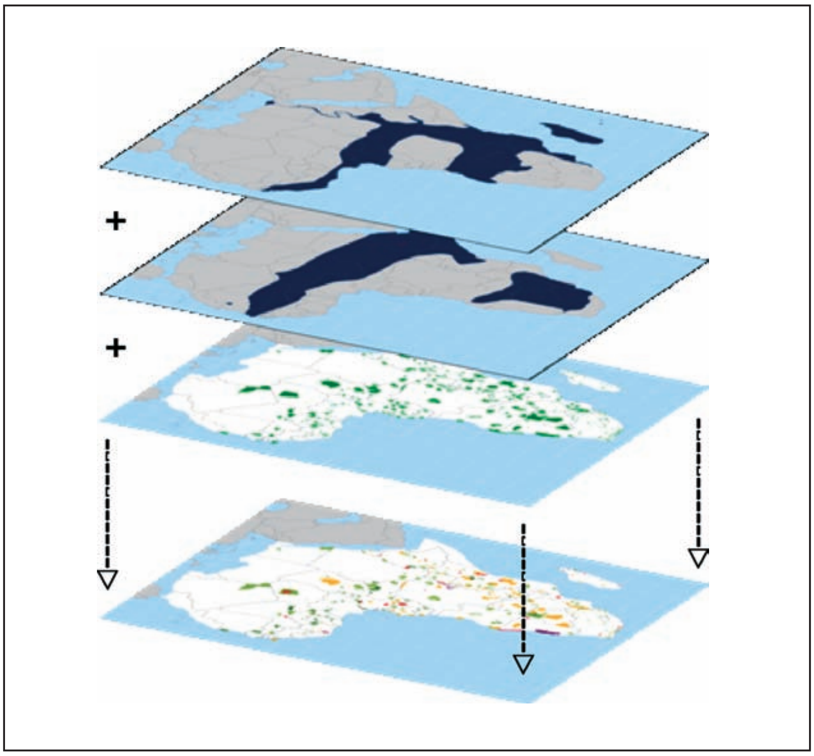


Figure 18. *Diagram to show the calculation of a PA's RI for mammals and amphibians.*

5.1.2. Data limitations and assumptions

The species distribution data included in this analysis reflect the current state of knowledge of the geographical distributions of the taxon assessed. They do not, of course, represent all amphibian, mammal and bird species in existence, but instead they are used as indicators of the diversity within that taxon.

There are a number of factors which can cause inaccuracy, or inconsistency in the results of our analysis. These can be divided into factors related to species data collection, and factors relating to our analysis techniques.

Data collection limitations

1. Uneven sampling. Since the species EOO data, derived from current literature and expert knowledge, are based on a priori studies, this means that the sampling density is not uniform across the whole continent. Therefore sampling is biased towards easily accessible areas. Relatively inaccessible areas, such as dense lowland rainforest, or conflict areas, will have a lower sampling rate. This results in:

(a) Amphibian species EOOs do not include all areas in which a species is found, and
(b) Species endemic to inaccessible areas will remain undiscovered until sampling improves.

2. Unsuitable areas within EOO. Currently, the GAA have only made available for download vector files for the EOO of each species. The academic literature suggests that modelling of suitable areas for each amphibian species has been done, but the resulting maps are currently not available for download. By using modelling techniques to identify suitable areas for each species, the AMD project showed that within mammal species' EOOs there are in fact many unsuitable areas for each species. Such an effect may be further exacerbated for amphibian species given that many exist in close proximity to wetlands, which may occur disparately within a large EOO. This highlights a shortfall in EOO data for species diversity mapping.

Irreplaceability Index limitations and assumptions

1. Species assigned to PAs in which they do not occur. Given that there maybe many unsuitable areas within a species EOO, and the accuracy of an EOO boundary may reduce as the range of the species increases, it is likely that many PAs include commission errors.

2. The conservation value of all species is equal. The concept of a flagship species, such as lions or elephants, is not accounted for in this analysis. This means that while the economic value of a protected area may be higher as a result of greater tourism, in terms of biodiversity it has no increased value just because it contains a flagship species. Studies have shown flagship (mammal) species are poor predictors of overall mammal and breeding bird diversity, with 6 flagship mammals representing the same biodiversity as 6 randomly chosen mammal species (Williams et al. 2000).

3. Mapping scales vary between taxa and species. For example, an amphibian with an extent of occurrence of 10km is mapped more precisely than a mammal which has a range of thousands of kilometres. The effect this would have on a PA's RI would be to give more influence to species with smaller ranges.

4. Does not account for networks of neighbouring PAs. Networks of connected PAs, such as the WAP park complex of Benin, Niger, and Burkina Faso, are vital to the maintenance of habitat, and essential for the maintenance of corridors for species with larger ranges.

5.2. Computing the indicator for PA habitat irreplaceability

5.2.1. Introduction

This component of the method aims to characterise the habitat of each Protected Area in Africa that have an area of at least 1,000 hectares. Typically a protected area contains a specific habitat that can be characterised by climate, terrain, land cover and human population. With such a characterisation, it is possible to identify similar areas within the same biome. Naturally some areas will be more similar to the PA habitat than others, and for some PAs there may be large areas of similar habitat and yet others PA habitats may be unique.

If, for each PA habitat, we can identify and rank areas based on their habitat similarity, we can create an indicator of the irreplaceability of the PA habitat (Habitat irReplaceability Index or **HRI**), and the more irreplaceable a PA habitat is, the higher it's ranking in a prioritisation scheme. A useful method for ranking areas in terms of their similarity to a defined habitat is based on the Mahalanobis distance metric.

5.2.2. Method

Mahalanobis distances provide a powerful method of measuring how similar a set of conditions is to an ideal set of conditions, and can be very useful for identifying which regions in a landscape are most similar to some "ideal" landscape. The smaller the distance, the more similar the conditions are. The Mahalanobis distance **D** is defined as:

$$D = \left(\sum_{v=1}^{n} \left(\left[x_v - \mu_v \right]^T \left[C \right]^{-1} \left[x_v - \mu_v \right] \right) \right)^{0.5}$$

Where, $\mathbf{x_v}$ is the value of the predictor variable **v**, $\boldsymbol{\mu_v}$ is the mean of variable **v** for the park, and **[C]** is the covariance matrix for all **n** variables in the park. The covariance matrix for **n** variables is given by:

$$[C] = \begin{bmatrix} \mathrm{cov}(x_1, x_1) & \mathrm{cov}(x_1, x_2) & \cdots & \cdots & \mathrm{cov}(x_1, x_n) \\ \mathrm{cov}(x_2, x_1) & \mathrm{cov}(x_2, x_2) & \cdots & \cdots & \mathrm{cov}(x_2, x_n) \\ \vdots & \vdots & \ddots & & \vdots \\ \vdots & \vdots & & \ddots & \vdots \\ \mathrm{cov}(x_n, x_1) & \mathrm{cov}(x_n, x_2) & \cdots & & \mathrm{cov}(x_n, x_n) \end{bmatrix}$$

Finally, the covariance between any two variables, $\mathbf{x_1}$ and $\mathbf{x_2}$, with means $\boldsymbol{\mu_1}$ and $\boldsymbol{\mu_2}$ and sample size m is given by:

$$\mathrm{cov}(x_1, x_2) = \sum_{i=1}^{m} \left(\frac{(x_1 - \mu_1)(x_2 - \mu_2)}{m} \right)$$

Note, that **D** requires the *inverse* covariance matrix.

When the predictor variables used to generate the mean vector and covariance matrix are normally distributed, then **D** is distributed approximately according to a χ^2 distribution with **n-1** degrees of freedom, and so we can convert **D** into **p**-values. The **p**-values (or probability values) range from 0.0 representing no similarity, through to 1.0 for areas which are identical. If the predictor variables are not normally distributed, then we can still make the conversion because it rescales the unbounded **D** values to a 0.0 to 1.0 range.

5.2.3. Application

The analysis uses nine raster variables (predictors) to characterise each PA. The variables describe the PA habitat in terms of climate, terrain and land cover. Human population is used later on in the process of creating the HRI for each PA.

The nine variables have been described in section 4.3. They are:

1. Percentage tree cover
2. Percentage herbaceous cover
3. Percentage barren cover
4. Elevation in metres
5. Slope in degrees
6. Aridity index
7. Percentage water body presence
8. NDVI
9. NDWI

For each PA, we compute the mean value of each variable and consequently the inverse covariance matrix. Then we identify the biome in which the PA is situated (the biome is defined in section 4.1-C) and compute a **D** value for each pixel within the biome[12]. This **D** grid is converted to a **p**-value grid with values from 0.0 (no similarity) to 1.0 (identical).

Below is one example of the **p**-value grid for Zakouma National Park in Chad. Areas in green represent areas that are very similar (90% similar and above) to the general habitat of Zakouma National Park. The black lines are biome boundaries, and white lines are country boundaries. The inset in the bottom left of the figure shows the park boundary in purple overlaid on the **p**-value grid. From this example, it is clear that the habitat contained within Zakouma is very geographically restricted, and hence highly irreplaceable.

[12] We apply a 120km buffer zone around the biome to account for the inherent inaccuracy in the coarse scale biome definitions.

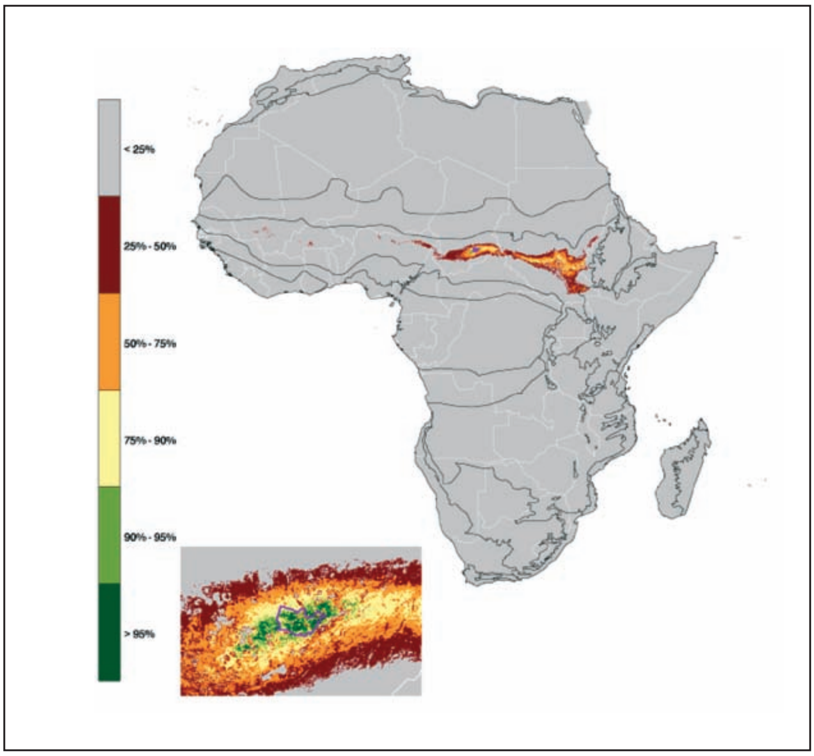


Figure 19. *Mahalanobis distances for Zakouma National Park, Chad. Inset (bottom left) shows more detail.*

The **p**-value grid is used as an input to the HRI for the PA. The HRI is based on the following three criteria; a pixel represents a potential replaceable habitat for the park if:

- The pixel is outside the park.
- Its **p**-value is 95% or better.
- The population density is less than or equal to the average population density with the park. Population is defined in section 4.4.

We then sum the total area[13] of the pixels that meet these criteria and divide it by the area of the PA to generate the **HRI** value. The smaller the **HRI**, the less replaceable a PA is, with a **HRI** of 0 suggesting that the PA habitat is unique and therefore irreplaceable. Conversely, a HRI greater than 1.0 suggests that there are potentially suitable habitats with a total area that is greater than the PA.

HRI does not account for the patch size of these potential replacement areas, or their location or distance from the PA. However, we generate a map of the **p**-value grids as in the example above for Zakouma so that these areas can be easily identified.

[13] All data are projected to Mollweide Equal Area projection for the area calculations.

5.3. Computing the indicator for threat to habitat

5.3.1. Introduction

This component of the method aims to quantify the level of threat to the PA - and by proxy the threat to species within the PA - by estimating the population pressure in the surrounding area. The premise here is that high population density within and around the PA implies:

- High pressure for land use conversion (conversion to agricultural use) in the buffer zone around the PA and within the PA itself.
- Higher levels of fishing and hunting in and around the PA.
- Higher risk of small scale deforestation (thinning) for timber and fuel.
- Higher risk of intentional burning and clearing.

Not all these factors may be applicable to a single PA, but if one or more of these risks are present then we suggest that this Population Pressure Index (**PPI**) is a reasonable indicator of these factors.

5.3.2. Method

Estimating the neighbouring population around each PA requires information on ambient population counts (population per administrative unit) and a definition of 'neighbourhood' or zone of influence around each PA. Typically, these zones are represented by a buffer based on Euclidean distance from the location of interest. In this case, this would create a distance buffer zone around each PA (for example 50km) and then the population within this distance would be estimated. A high population density would mean a high **PPI** score and high pressure.

However, distance is not a suitable measure for describing the potential zone of influence. Two points may be equidistant from a location, but if one point lies on a main road to the location, and the other does not and is also situated behind a natural barrier (river, mountain range), then the influence of that second point on the location is much less than that of the first point. If we replace Euclidean distance with economic distance, i.e. the cost in terms of financial or time resources, then we will be able to generate a much more appropriate measure of the zone of influence around a location, based on the potential accessibility of that location.

Geographical information systems (GIS) lend themselves naturally to the computation of accessibility indicators (Ritsema van Eck & de Jong 1999). GIS can represent networks, villages, or facilities and provide functions to compute distances to all spatial units within a region and to define relations among spatial objects. Consequently, certain accessibility measures can be computed using packages such as IDRISI, GRASS, and ArcInfo/ArcGIS/ArcView.

The COSTDISTANCE algorithm in ArcInfo requires two inputs, (i) a raster of the target locations (the PA in this case), and (ii) a cost-surface raster which represents the cost or time required to travel across each pixel in the study area. This cost must be estimated based on available environmental and infrastructure information (from Section 4). For example with a grid consisting of roads, we might estimate that a car can travel at 60km/hr. so all road cells in a 100m grid would be given the value 6

60 km/ hr = 60,000 m/hr = 1,000 m/min so 100m takes 6 seconds.

Or for areas with no road, we would look at the land cover, assume an average walking speed of 4km/hr, which we would reduced to 2km/hr for forest, giving values of 90 and 180 respectively.

4 km/ hr = 4,000 m/hr = 67 m/min so 100m takes 90 seconds.

2 km/ hr = 2,000 m/hr = 33 m/min so 100m takes 180 seconds.

So, we need to estimate travel speeds for

- road, with different speeds for different road types
- rivers
- land cover type
- international boundaries, where applicable
- slope

Slope is another factor which will affect speed of travel. A steeper gradient will have greater affect on speed of travel. For example slopes between 0 and 5 degrees may not have any influence so the factor would be 1, but slopes between 5 and 10 degrees would slow travel by half so the factor would be 2, etc. There is no accounting for slope direction, it is assumed that travelling both upslope and down-slope incurs a reduction in travel speed.

These factors are merged together into a cost-surface raster such that international boundaries have precedence over roads which in turn have precedence over rivers, and all other pixels are assigned cost values based on the land cover. These values are then multiplied by the slope factor to create the final cost-surface representing the estimated time to cross each pixel.

COSTDISTANCE creates an output raster in which each pixel is assigned the accumulative cost to the target location (in this case, the PA). The algorithm utilises the node/link cell representation. In the node/link representation, each centre of a cell is considered a node and each node is connected by links to its adjacent nodes. Every link has impedance associated with it. The impedance is derived from the costs associated with the cells at each end of the link (from the cost surface) and from the direction of movement. If moving from a cell to one of its four directly connected neighbours, the cost to move across the links to the neighbouring node is 1 times the cost of cell 1 plus the cost of cell 2 divided by 2.

$$a1 = cost1 + cost2 / 2$$

where **cost1** is the cost of cell 1, **cost2** is the cost of cell 2 and **a1** is the length of the link from cell 1 to cell 2. The accumulative cost is determined by the following formula.

$$accum\_cost = a1 + (cost2 + cost3) / 2$$

where **cost2** is the cost of cell 2, **cost3** is the cost of cell 3 and **accum_cost** is the accumulative cost to move into cell 3 and cell 1. If the movement is diagonal, the cost to travel over the link is 1.414216 (or the square root of 2), times the cost of cell 1 plus the cost of cell 2 divided by 2.

$$a1 = 1.414216(cost1 + cost2) / 2$$

But when determining the accumulative cost for diagonal movement the following formula must be used.

$$accum\_cost = a1 + 1.414216(cost2 + cost3) / 2$$

The result is a raster of travel time from the PA. This can be used in conjunction with the population data (from Section 4), to estimate the population within a certain travel time from the PA.

5.3.3. Application

PPI was estimated by generating an accessibility model using the road network, terrain and simplified land cover to estimate travel speed over each 1km pixel. The input layers were assigned the following costs:

Infrastructure and transport

- International borders: 1 hour delay = 60
- Primary roads: 60km/hr. = 1 minute to cross one 1km pixel = 1
- Secondary roads: 30km/hr = 2
- Tertiary roads: 15km/hr = 4
- Rivers: 10km/hr = 6

Land cover: was simplified to

- Urban: 2
- Water: 6
- Open land cover classes: 15 (plains for example)
- Closed land cover classes: 30 (open forests for example)
- Difficult land cover classes: 60 (closed forests for example)

Slope

- 0 to 5 degrees: cost × 1
- 5 to 10 degrees: cost × 2
- 10 to 15 degrees: cost × 3
- More than 15 degrees: cost × 4

These layers were merged to create the cost-surface, and this in conjunction with the PA[14] locations were input to a COSTDISTANCE in ArcInfo, which then computed travel time buffers around each PA . We then estimated the population density (based on yr 2000) within each of the 3 hour buffers. This population density is the Park Pressure Index **PPI**.

[14] This methodology is also available in ArcView 3.2 http://www.ciat.cgiar.org/access/index.htm

5.4. Computing the indicator for boundary pressure on a PA

5.4.1. Introduction

This section of the methodology attempts to quantify the amount of agriculture found in the immediate vicinity of the protected area. The assumption here is that the more agriculture found immediately next to the boundary of the PA, then the more pressure there is likely to be on land cover conversion within the boundary of the PA. This is considered a threat to the habitat and consequently the species found within the protected area.

5.4.2. Method

The GLC2000 Africa (Mayaux et al. 2004) dataset was used to identify land cover classes which con-tained a high proportion of anthropogenic influence. Table 1 summarises the classes used.

Table 1. GLC2000 land cover classes recoded by human (anthropogenic) influence.

Value	Class Name	High human influence?
0	Background	No
1	Closed evergreen lowland forest	No
2	Degraded evergreen lowland forest	No
3	Submontane forest (900 -1500 m)	No
4	Montane forest (>1500 m)	No
5	Swamp forest	No
6	Mangrove	No
7	**Mosaic Forest / Croplands**	**Yes**
8	Mosaic Forest / Savanna	No
9	Closed deciduous forest	No
10	Deciduous woodland	No
11	Deciduous shrubland with sparse trees	No
12	Open deciduous shrubland	No
13	Closed grassland	No
14	Open grassland with sparse shrubs	No
15	Open grassland	No
16	Sparse grassland	No
17	Swamp bushland and grassland	No
18	**Croplands (>50%)**	**Yes**
19	**Croplands with open woody vegetation**	**Yes**
20	**Irrigated croplands**	**Yes**
21	**Tree crops**	**Yes**
22	Sandy desert and dunes	No
23	Stony desert	No
24	Bare rock	No
25	Salt hardpans	No
26	Waterbodies	No
27	**Cities**	**Yes**

These classes were selected on the assumption that they represent areas which contain existing human settlements or agricultural activity. Since the interpretation of landuse information from

satellite derived products is notoriously problematic, the spatial accuracy of such a classification may have varying degrees of accuracy across the continent. However, the GLC2000 dataset is currently the best continent-wide land cover information available.
In order to quantify the boundary pressure on a protected area, the percentage of human influenced pixels was counted within an expanding buffer zone around the PA. This percentage was calculated for a range of buffer sizes, at 1km intervals, between 1km and 30km distance away from the boundary of the PA. Next, a weighting was applied to each buffer in the range, such that higher weight was given to the buffers closer to the PA boundary and lower weight to those further away. This weighting was calculated using a bisquare function and applied to the boundary pressure score for each buffer in the 1 to 30km range. Finally, for each PA, the sum of all the weighted scores was divided by the sum of all the bisquare weights, to create a final score of anthropogenic pressure.

Therefore, the equation for calculating the anthropogenic boundary pressure on a protected area is defined as

$$BP_p = \frac{\sum_{n=1}^{n=30} (h_n W_n)}{\sum_{n=1}^{n=30} W_n}$$

$$W_n = \left(\frac{1 - n^2}{r^2} \right)^2$$

where **BPp** is the boundary pressure score for a given protected area, **h** is the percentage of high human influenced pixels with a buffer of size **n**, **Wn** is the weighting for buffer size **n**, and **r** is a constant equal to 30, the maximum buffer size.

6. Results

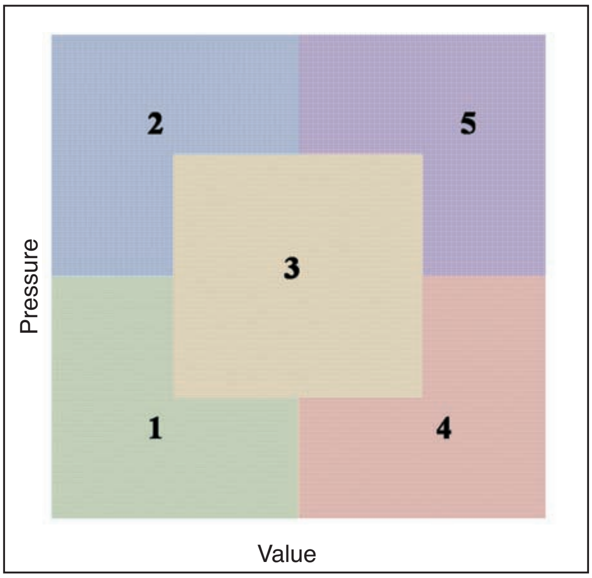
6.1. Biodiversity value and anthropogenic threats

The formulation of the 6 indicators of state and pressure for all 741 protected areas analysed in this study has created a huge amount of data which can be viewed, summarised and analysed in many different ways. We are keen to simplify this data as much as possible, whilst retaining the important information that can guide and inform policy makers. The raw values for each of the 6 indicators were standardised, in order to ensure the intercomparability. For a given indictor, the relative standing of each PA was calculated and expressed as a ranked percentage. Consequently, the “Index of Biodiversity Value” or “Value” was calculated as the average of the ranked percentage for amphibians, birds, mammals, and habitat indicators. The “Index of Anthropogenic Pressure” or “Pressure” was calculated as the average of the percentage rank for pressure from population, and pressure from agriculture. Both indices have values from 0 to 1. A score of 0 does not indicate no Value or no Pressure, the index simply reflects the relative ranking of the protected areas for each index.

Results were then classified using the inter-quartile ranges, to simplify display and visual interpretation. Simplifying the six indices in this manner provides a classification that can be easily tabulated, charted or mapped to highlight protected areas and regions with both higher Value and higher Pressure.

The following colour scheme is used in the charts and maps in the results section.

1. lower Value & lower Pressure
2. lower Value & higher Pressure
3. average Value & average Pressure
4. higher Value & lower Pressure
5. higher Value & higher Pressure



Clearly, class 5 is the most critical, with classes 3 and 4 also of interest for identifying protected areas with higher than average Value, and classes 2 and 3 also of interest for protected areas with higher than average Pressures.

The scatter plot below (Figure 20) shows the distribution of all 741 studied protected areas according to our classification. There are 144 protected areas in class 5 (higher Value & higher Pressure).

Figure 21 shows the same data, but averaged to give one data point per country. Countries in white are non ACP, and ESP (Spain) and PRT (Portugal) are for protected areas in the Canary Islands and Madeira respectively. In general, islands and smaller countries have higher Pressure due to higher population density, while Central African countries generally have higher Value due to the higher biodiversity in tropical forest regions.

6.2. Comparison with existing assessments of conservation priorities

There are several internationally recognised assessments of conservation priorities that relate to globally important levels of biodiversity and anthropological pressures. Some are focused specifically on protected areas, others are broader and identify large regions of biodiversity importance. We can compare our Value and Pressure indices against these schemes by determining the number of assessments that overlap with each protected area.

The two broad scale assessments we consider are

(i) Conservation International Biodiversity Hotspots [CI], and
(ii) World Wildlife Fund Global 200 Ecoregions [WWF].

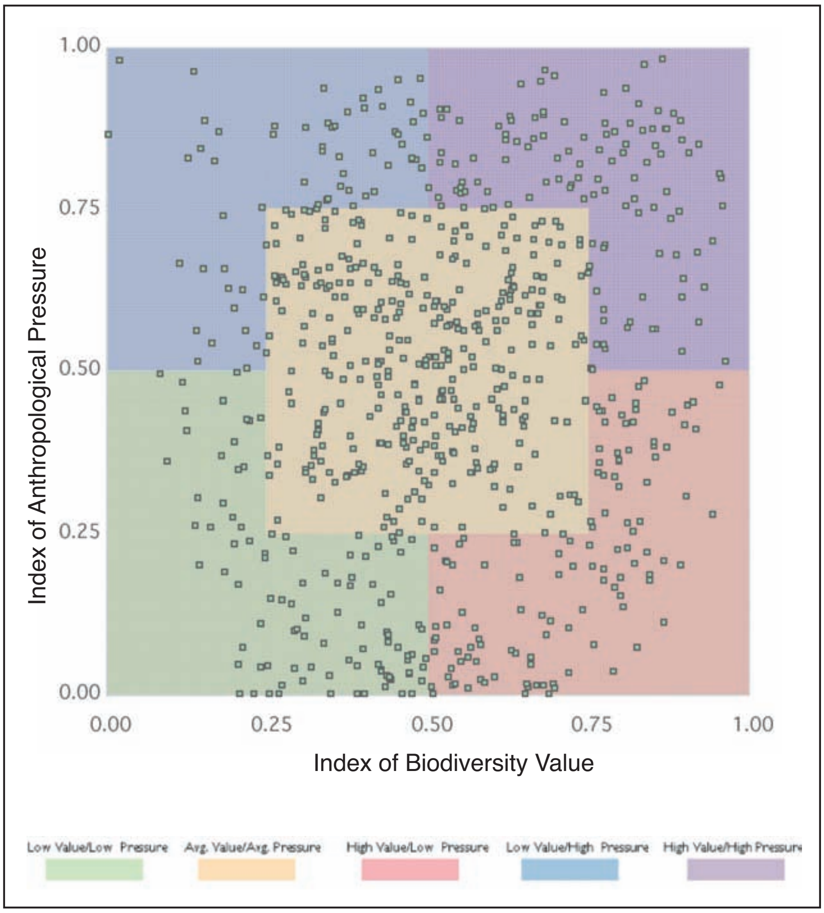


Figure 20. *Scatter plot of Biodiversity Value against Anthropogenic Pressure for all 741 protected areas.*

At a smaller scale, identifying areas amenable to management, and with similar sizes to protected areas we have

(iii) BirdLife International Important Bird Areas [IBA].

The four 'protected area level' assessments we consider are

(iv) Alliance for Zero Extinction protected areas [AZE],
(v) Ramsar wetlands of international importance, [Ramsar]
(vi) UNESCO World Heritage [WH] sites, and
(vii) UNESCO Biosphere Reserves [MAB].

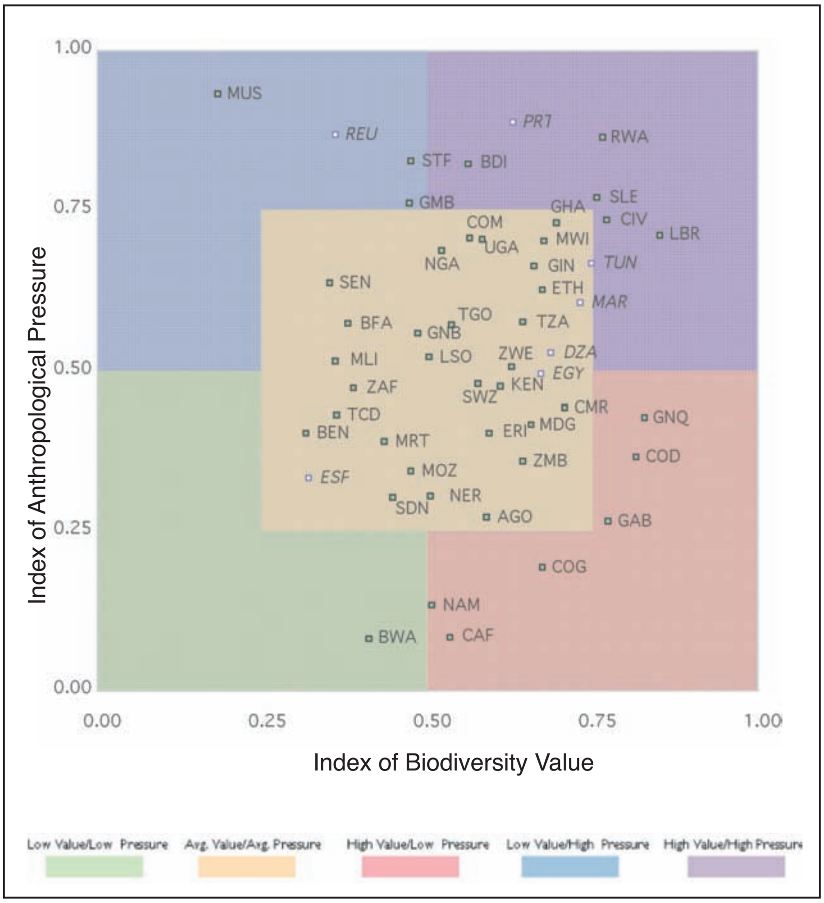


Figure 21. *Scatter plot of Biodiversity Value against Anthropogenic Pressure, averaged by country*

We group IBAs with CI and WWF together as "broad scale assessments" due to the extensive areal coverage of IBAs compared to the other four protected area level assessments.

Of our 741 protected areas, 370 are within CI hotspots and 434 are within WWF ecoregions. Some 399 overlap with IBAs while 24 are also AZE sites, 69 are Ramsar wetlands, 46 are WH sites and 41 are UNESCO MAB sites.

Of the 144 protected areas that are in the "higher Value & higher Pressure" class, 75% are in CI hotspots and 71% are in the WWF global 200 ecoregions. This shows that our "higher Value & higher Pressure" classification has a very good correspondence with other internationally recognised broad scale assessments. Furthermore, 75% are also IBAs, so the classification also agrees with a small scale but broad coverage conservation assessment. The 144 protected areas overlap with 38% of the World Heritage sites, 28% of Ramsar wetland sites, 29% of UNESCO MAB sites and 38% of AZE sites.

A protected area can belong to zero, one, or more of these seven conservation assessments, and we can plot the average of the Value and Pressure indices based on the overlap of protected areas with these assessments. Since we have both broad scale and protected area level assessments, we will consider membership of all seven assessments together, and then membership of the three broad scale assessments as a subset.

The chart below (Figure 22) shows the average "Value & Pressure" scores for all protected areas classified by the number of conservation assessments they overlap with. It also shows the number of protected areas per class above each bar. From the chart we see that protected areas that overlap with many assessments have higher "Value and Pressure" scores than protected areas that overlap with few assessments. This suggests that our indices are in consistent agreement with other recognised assessments of conservation priorities.

The next chart (Figure 23) shows the same kind of information but only for the three broad scale assessments of conservation priorities (CI, WWF and IBA). This time, we also plot the separate Value and Pressure indices as well as their average "Value & Pressure". Again, the same trend is evident with protected areas that overlap with all three assessments having higher value and higher "Value & Pressure" than protected areas that do not overlap. The trend is not so clear for Pressure.

The following two maps (Figure 24 and 25) show the distribution of the protected areas in relation to the CI hotspots and WWF global 200 ecoregions. There are clear geographic clusters of protected areas in the critical High Value & High Pressure class in Eastern Madagascar, the Rift Valley and Ethiopian Highlands, coastal West Africa and coastal South Africa. The two maps show how our results reflect the differences between CI's Biodiversity Hotspots and WWF's G200 ecoregions. CI prioritise high value, and high pressure, which agrees well with the purple points, whereas WWF prioritise only high value, which coincides well with red and purple points.

It is important to remember that these two maps represent differences in species richness and rarity between ecosystems. They reflect trends in biodiversity value and pressure at the continental scale, but have little relevance for allocation of conservation funding. For example, one would expect tropical forest ecosystems in Madagascar, or the Congo basin to have higher biodiversity value compared to savannah ecosystems in the Sahel in West Africa, but it does not necessarily mean that they should receive less funding.

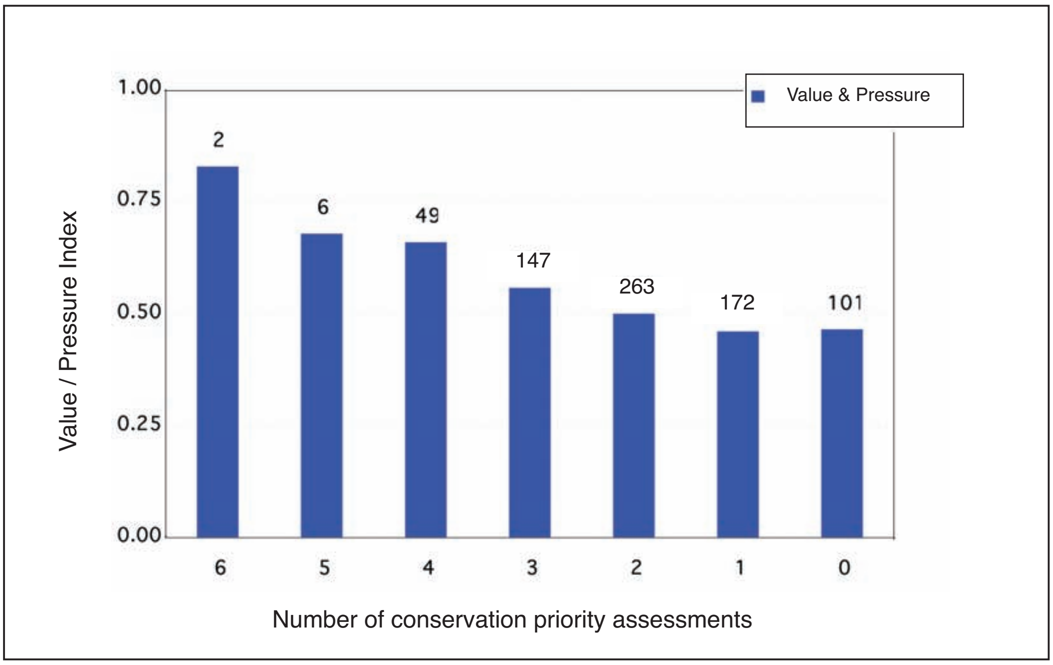


__Figure 22.__ The average Value and Pressure indices for protected areas that overlap with zero or more assessments of conservation priorities.

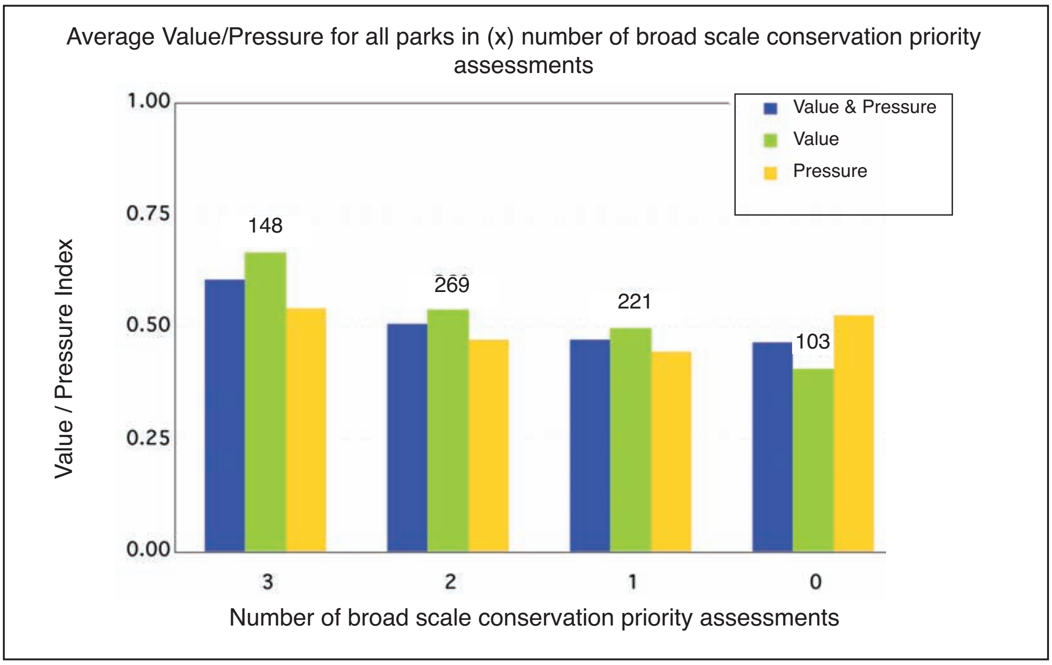


__Figure 23.__ Value and Pressure indices for protected areas that overlap with zero or more broad scale assessments of conservation priorities.

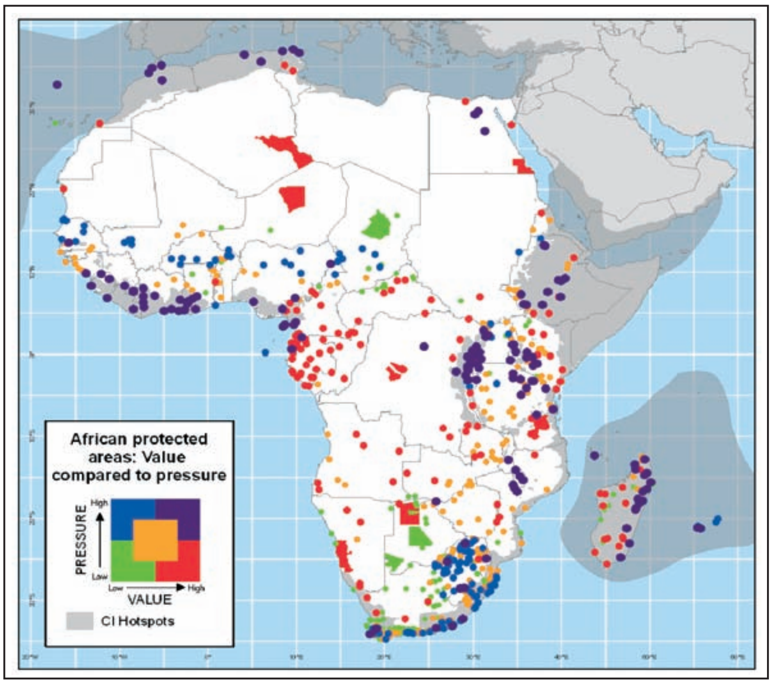


Figure 24. *Comparison of Value and Pressure for 741 protected areas in Africa. Conservation International's Biodiversity Hotspots are displayed in grey. Protected areas of a size greater than 2.5 million hectares are displayed as a polygon, and below this threshold as a point.*

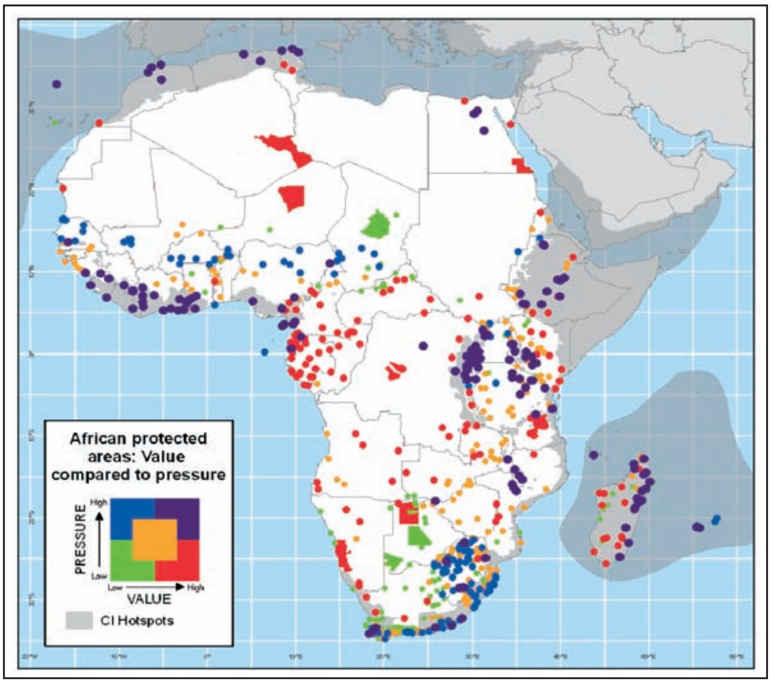


Figure 25. *Comparison of Value and Pressure for 741 protected areas in Africa. The World Wildlife Fund's G200 priority ecoregions are displayed in grey. Protected areas of a size greater than 2.5 million hectares are displayed as a polygon, and below this threshold as a point.*

6.3. EC assistance to protected areas in Africa

Using the PASTIS database, we have identified the 96 protected areas in our database of 741 parks that are receiving or have received funding assistance from the EC. We do not distinguish between projects that have closed, are ongoing or which were planned and did not eventually happen. The purpose here is to simply determine whether EC assistance is targeting protected areas that we have identified as having (i) higher biodiversity value or having (ii) both higher biodiversity value & higher anthropogenic pressure. We have made the distinction between higher Value alone and higher Value & higher Pressure because we believe that most decisions to provide assistance are based on biodiversity Value rather than both Value and Pressure.

The chart below (Figure 26) has highlighted these 96 protected areas that have received EC assistance. There is a trend of EC assistance in higher Value protected areas – the majority of the EC protected areas are towards the right hand side of the scatter plot - but not such a clear trend of assisting protected areas facing higher Pressures.

If we tabulate all the protected areas in the PASTIS database that have received funding and highlight their Value and Pressure (Table 2) we see that a high percentage, 68% (or 65 out of 96) of EC assisted protected areas have higher biodiversity Value. This percentage is quite high for many countries, from 100% in 12 countries, e.g. Congo (DRC), Congo, Côte d'Ivoire, Equatorial Guinea, Ghana, Gabon and others, down to none for Burkina Faso and Senegal. However, the story is not so clear when we consider the more restrictive - and previously hard to define consistently - higher Value & higher Pressure class where the percentage drops to 28% (or 27 out of 88), with Ghana scoring 100%, but many other coun-tries scoring 0%.

Again, we can plot our average Value and Pressure indices based on the number of overlapping conservation assessments for all EC funded protected areas (Figure 27). The trend between "Value & Pressure" and number of conservation assessments is striking. The two outliers are no assessments (two protected areas) or all seven assessments (two protected areas), which we discount as it makes no sense to graph an average of two figures.

The next chart (Figure 28) shows the results for the three broad scale conservation assessments (CI, WWF and IBA). Again the same trend is evident with protected areas that overlap with all three assessments having higher Value, higher Pressure and higher "Value & Pressure" than protected areas that overlap with fewer assessments. The maps below (Figures 29 and 30) how the location of these EC funded protected areas in relation to the CI hotspots and WWF ecoregions.

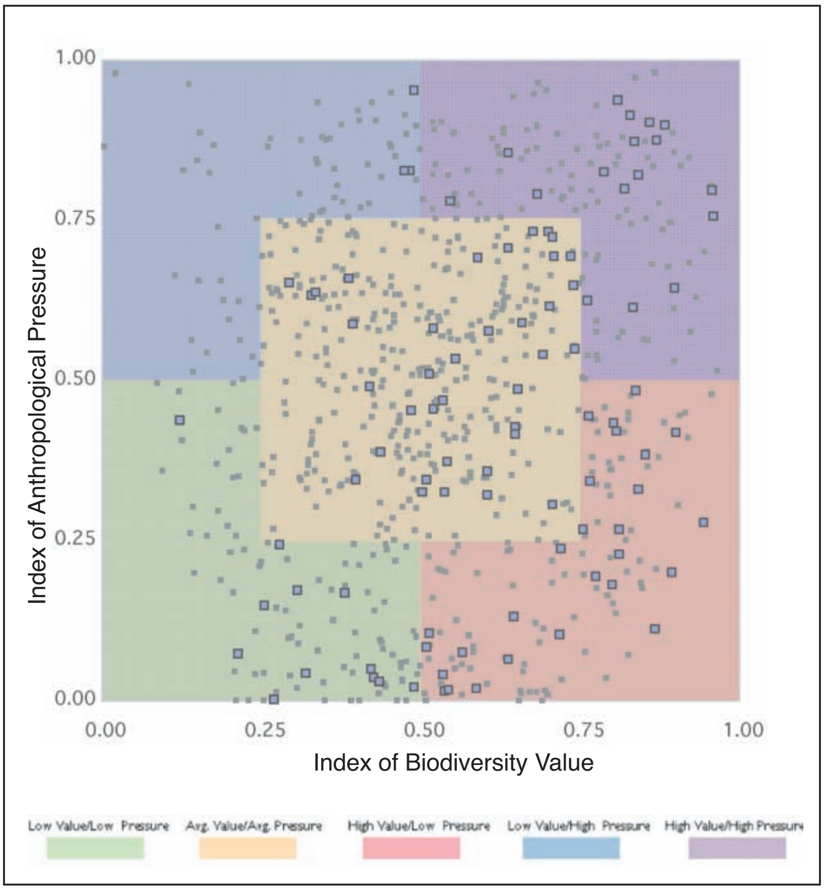


Figure 26. *Scatter plot of Value against Pressure for 96 EC funded areas.*

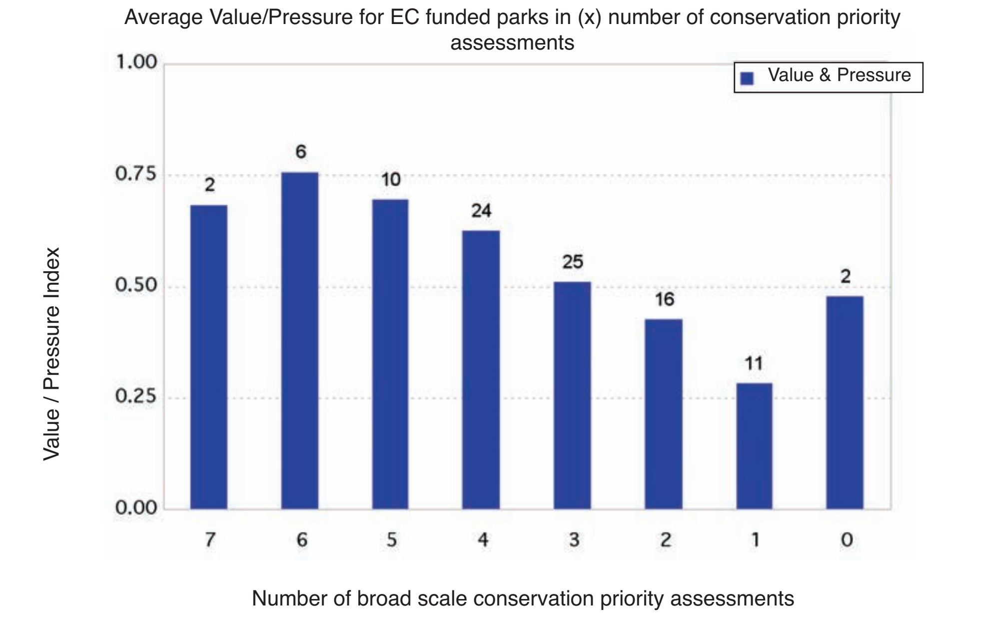


Figure 27. *The average Value and Pressure indices for EC protected areas that overlap with zero or more conservation assessments.*

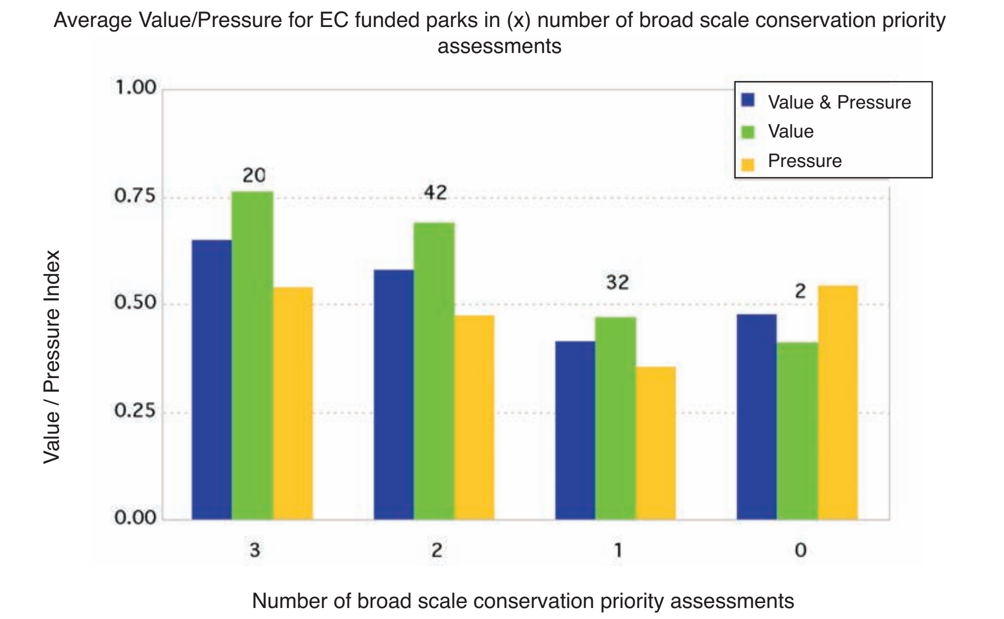


Figure 28. *Value and Pressure indices for EC protected areas that overlap with zero or more broad scale conservation assessments.*

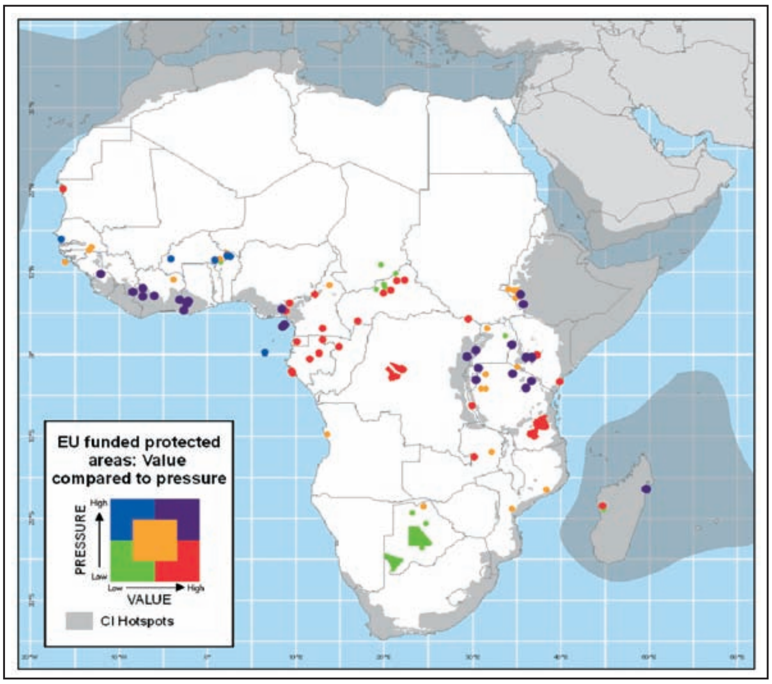


Figure 29. *Comparison of Value and Pressure for 96 EC funded protected areas in Africa. Conservation International's Biodiversity Hotspots are displayed in grey. Protected areas of a size greater than 2.5 million hectares are displayed as a polygon, and below this threshold as a point.*

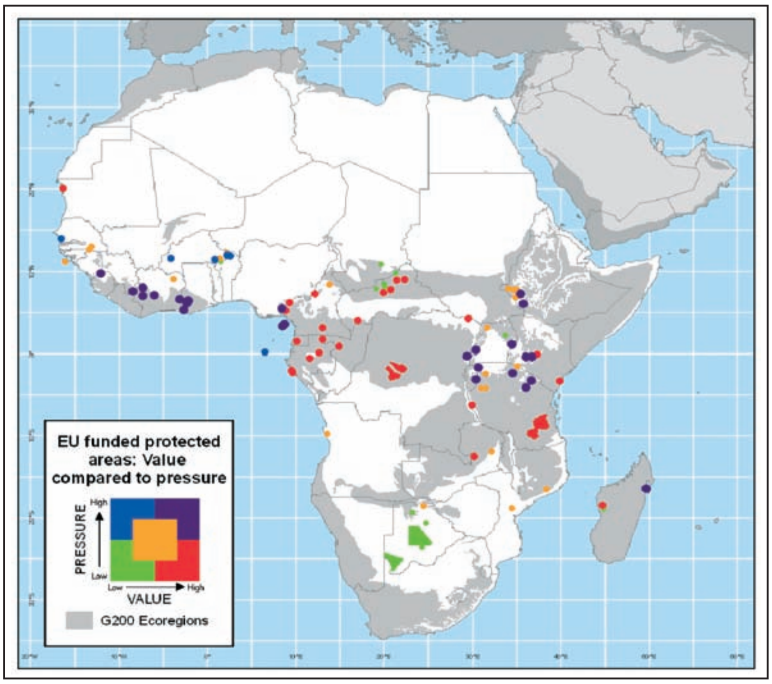


Figure 30. *Comparison of Value and Pressure for 96 EC funded protected areas in Africa. The World Wildlife Fund's G200 priority ecoregions are displayed in grey. Protected areas of a size greater than 2.5 million hectares are displayed as a polygon, and below this threshold as a point.*

Table 2. Protected areas that receive EC funding and their classification by Value and Pressure.

Area Name	*Country*	*High Value*	*High Pressure*	*High Value & High Pressure*
Count	***96***	***65***	***41***	***27***
Kisama	Angola	Yes	Yes	
Ruvubu	Burundi	Yes	Yes	Yes
Boucle de la Pendjari	Benin			
W (Benin)	Benin		Yes	
W du Burkina Faso	Burkina Faso		Yes	
Pama	Burkina Faso		Yes	
Arly Total Faunal Reserve	Burkina Faso		Yes	
Arly Partial Faunal Reserve	Burkina Faso			
Mare aux Hippopotames	Burkina Faso		Yes	
Chobe	Botswana	Yes		
Makgadikgadi	Botswana			
Moremi	Botswana			
Khutse	Botswana			
Gemsbok	Botswana			
Central Kalahari	Botswana			
Ngotto	Central African Republic	Yes		
Bamingui-Bangoran	Central African Republic			
Manovo-Gounda-Saint Floris	Central African Republic	Yes		
Avakaba Presidential Protected area	Central African Republic			
Ouandjia-Vakaga	Central African Republic	Yes		
Gribingui-Bamingui	Central African Republic			
Koukourou-Bamingui	Central African Republic	Yes		
Aouk-Aoukale	Central African Republic			
Zone Pilote de la Sangba	Central African Republic	Yes		
Mont Peko	Côte d'Ivoire	Yes	Yes	Yes
Mont Nimba	Côte d'Ivoire	Yes	Yes	Yes
Comoe	Côte d'Ivoire	Yes		
Marahoue	Côte d'Ivoire	Yes	Yes	Yes
Mont Sangbe	Côte d'Ivoire	Yes	Yes	Yes
Dja	Cameroon	Yes		
Korup	Cameroon	Yes		
Takamanda	Cameroon	Yes		
Benoue	Cameroon			
Tchabal Mbabo	Cameroon	Yes		
Salonga	Congo, DRC	Yes		
Virunga	Congo, DRC	Yes	Yes	Yes
Garamba	Congo, DRC	Yes		

Area Name	*Country*	*High Value*	*High Pressure*	*High Value & High Pressure*
Odzala - Koukoua	Congo, Republic of the	Yes		
Omo	Ethiopia	Yes	Yes	Yes
Gambella	Ethiopia	Yes		
Abobo-Gog	Ethiopia	Yes		
Godere	Ethiopia	Yes	Yes	
Sele Anderacha	Ethiopia	Yes		
Gura Ferda	Ethiopia			
Yeki	Ethiopia	Yes	Yes	Yes
Shako	Ethiopia		Yes	
Ivindo	Gabon	Yes		
Loango	Gabon	Yes		
Minkebe	Gabon	Yes		
Lopé	Gabon	Yes		
Petit Loango	Gabon	Yes		
Bia	Ghana	Yes	Yes	Yes
Tano Suraw Extension	Ghana	Yes	Yes	Yes
Ankasa River	Ghana	Yes	Yes	Yes
Afao Hills	Ghana	Yes	Yes	Yes
Anhwiaso East	Ghana	Yes	Yes	Yes
Upper Wassaw	Ghana	Yes	Yes	Yes
Badiar	Guinea	Yes	Yes	
Archipel de Bolama - Bilagós	Guinea-Bissau			
Monte Alén	Equatorial Guinea	Yes		
Pico de Basilé	Equatorial Guinea	Yes	Yes	Yes
Caldera de Luba	Equatorial Guinea	Yes	Yes	Yes
Lake Nakuru	Kenya	Yes	Yes	Yes
Masai Mara	Kenya			
Aberdare	Kenya	Yes	Yes	Yes
Mount Kenya	Kenya	Yes		
Arabuko Sokoke	Kenya	Yes		
Mananara-Nord	Madagascar	Yes	Yes	Yes
Tsingy de Bemaraha - Strict Nature Reserve	Madagascar	Yes		
Tsingy de Bemaraha - National Protected area	Madagascar			
Gorongosa / N'Hambita	Mozambique	Yes		
Gilé	Mozambique			
Banc d'Arguin	Mauritania	Yes		
W du Niger	Niger		Yes	
Cross River	Nigeria	Yes	Yes	Yes

Area Name	*Country*	*High Value*	*High Pressure*	*High Value & High Pressure*
Akagera	Rwanda	Yes	Yes	Yes
Niokolo-Koba	Senegal			
Delta du Saloum	Senegal		Yes	
Outamba-Kilimi	Sierra Leone	Yes	Yes	Yes
Obo	Sao Tome and Principe		Yes	
Zakouma	Chad			
Selous	Tanzania	Yes		
Moyowosi	Tanzania		Yes	
Mahale Mountain	Tanzania	Yes		
Kigosi	Tanzania	Yes		
Serengeti	Tanzania	Yes	Yes	Yes
Tarangire	Tanzania	Yes	Yes	Yes
Mount Meru Game Reserve	Tanzania	Yes	Yes	Yes
Mount Meru National Protected area	Tanzania	Yes		
Biharamulo	Tanzania	Yes	Yes	
Alungamosimosi	Uganda			
Mt Elgon	Uganda	Yes	Yes	Yes
Zoka	Uganda			
Kibale	Uganda	Yes	Yes	Yes
North Luangwa	Zambia	Yes		
Kasanka	Zambia	Yes		

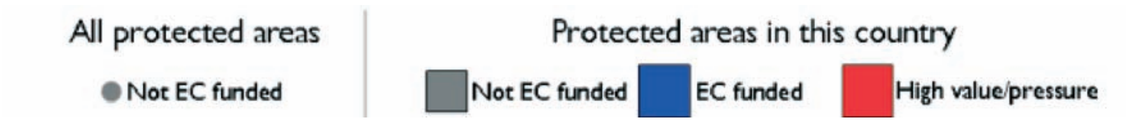
6.4. Identifying valuable and pressured protected areas with no EC assistance

The scatter plots can be used to look at protected areas on a country by county basis to show us how the protected areas score on Value and Pressure, and whether they have received EC assistance or not. The following section uses example from three countries, Ghana, Côte d'Ivoire and Ethiopia.

The scatter plots are as before, but now include more symbols to identify protected areas that are

(i) Not EC funded – small grey dot,
(ii) Country specific – grey square,
(iii) Country specific and EC funded – blue square
(iv) Country specific, not EC funded and in the higher Value & higher Pressure class – red square.

The legend for the following charts is shown below



Ghana

For Ghana, there are 16 protected areas in our database, and that 6 (blue squares) of them are EC funded. The scatter plot (Figure 31) clearly shows that all the EC funded protected areas are in the critical higher Value & higher Pressure classification. It also shows that there are 4 other protected areas (red squares) which could be considered for future funding.

Côte d' Ivoire

The story is similar for Côte d'Ivoire (Figure 32). There are 11 protected areas in total, 5 of which are EC funded and 4 of these are in the critical zone, but there are 5 other protected areas in that zone too that could be considered for future funding.

Ethiopia

For Ethiopia (Figure 33), there are 25 protected areas in total, 8 of which receive EC funding, and al-though all 8 of these have higher Value, only 1 has higher Value & higher Pressure, whilst there are 9 other unfunded protected areas in the critical zone.

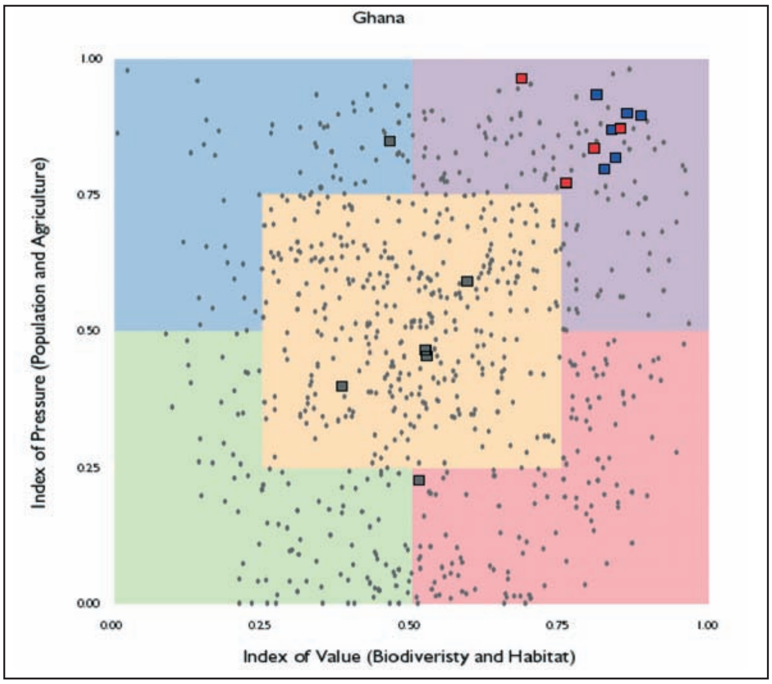


Figure 31. *Scatter plot of Value against Pressure for protected areas in Ghana, including information on EC funding.*

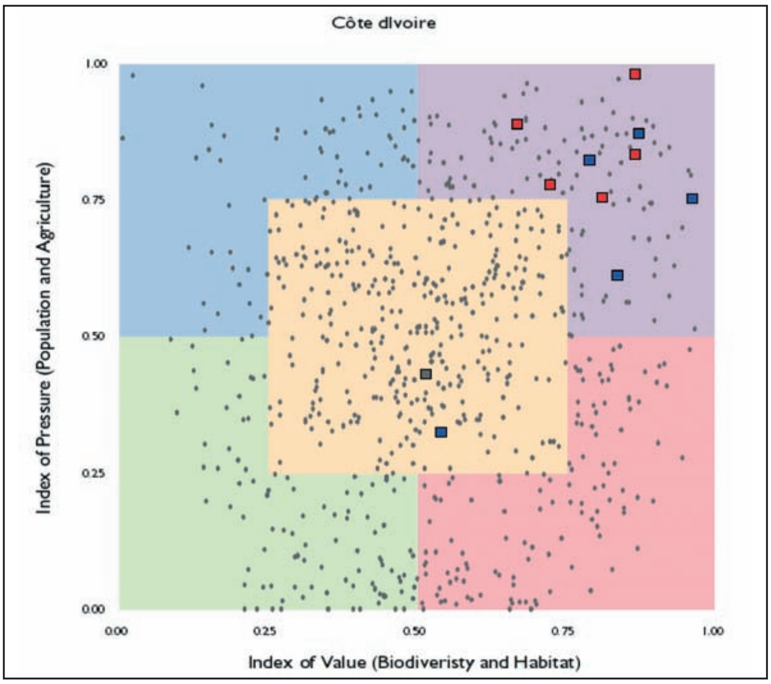


Figure 32. *Scatter plot of Value against Pressure for protected areas in Côte d'Ivoire, including information on EC funding.*

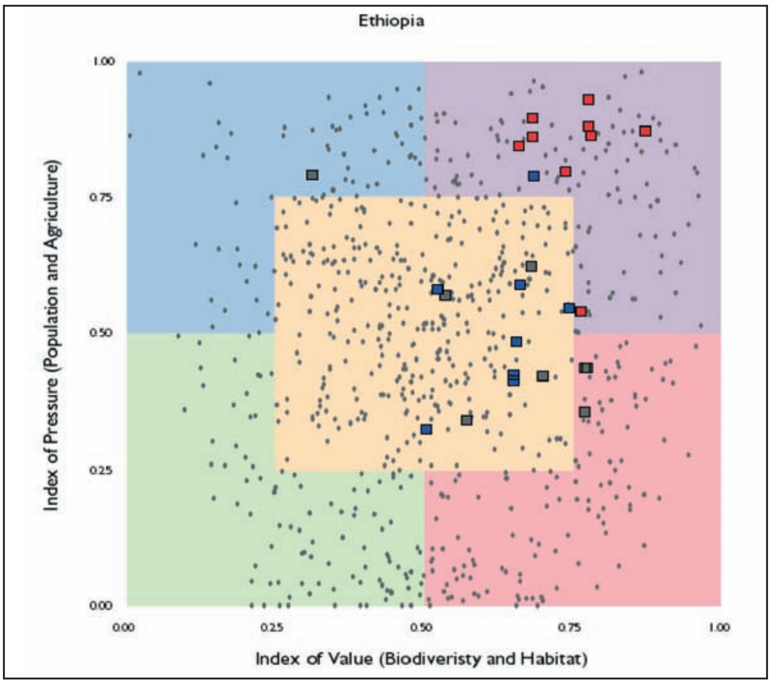


Figure 33. *Scatter plot of Value against Pressure for protected areas in Ethiopia, including information on EC funding.*

There are spatial variations in the targeting of critical protected areas by the EC. In some countries the targeting is excellent, in others the link between important protected areas and assistance is not so clear. There are 117 protected areas that have higher Value & higher Pressure but which do not receive any EC funding. These 117 protected areas can be tabulated by country (Table 3) and by ecoregion (Table 4).

This high level of agreement between our list of critical protected areas and the three conservation assessments suggests that our methodology has identified a plausible short list of protected areas that should be considered for future funding initiatives. Furthermore, identifying protected areas that belong to several other assessments of conservation priorities may be a good indicator for successful cooperation with other international agencies and hence a greater likelihood of sustainability and higher impact.

Finally we have listed these 117 protected areas along with their overlap with other conservation priority assessments (table 5). Of the 117 protected areas, 106 are in ACP countries. Of the 106 critical ACP protected areas, 77 (73%) also overlap IBAs, 79 (75%) are within CI hotspots and 75 (71%) are within WWF global 200 ecoregions.

Table 3. Number of 'critical' protected areas per country. Non ACP countries in italics

Africa countries	*Critical protected areas*	*Africa countries*	*Critical protected areas*
Count	**117**		
Algeria	3	Madagascar	15
Angola	0	Malawi	7
Benin	0	Mali	0
Botswana	0	Mauritania	0
Burkina Faso	0	Mauritius	0
Burundi	1	*Morocco*	4
Cameroon	3	Mozambique	0
Central African Republic	0	Namibia	0
Chad	0	Niger	0
Comoros	1	Nigeria	2
Congo, DRC	2	*Portugal (Madeira)*	1
Congo, Republic of the	0	*Reunion*	2
Côte d'Ivoire	5	Rwanda	4
Egypt	3	Sao Tome and Principe	0
Equatorial Guinea	1	Senegal	0
Eritrea	0	Sierra Leone	2
Ethiopia	9	South Africa	11
Gabon	1	Sudan	0
Gambia, The	1	Swaziland	0
Ghana	4	Tanzania	0
Guinea	3	Togo	8
Guinea-Bissau	0	*Tunisia*	0
Kenya	6	Uganda	2
Lesotho	0	Zambia	13
Liberia	2	Zimbabwe	0

Table 4. Number of 'critical' protected areas per ecoregion.

Ecoregions	*Critical protected areas*	*Ecoregions*	*Critical protected areas*
Guineo-Congolian	23	Kalahari-Highveld	0
Zambezian	12	Tongaland-Pondoland	4
Sudanian	6	Sahel	0
Somlia-Masai	9	Sahara	3
Cape	3	Mediterranean / Sahara	0
Karoo-Namib	0	East Malagasy	14
Mediterranean	9	West Malagasy	1
Afromontane	17	Maderira	1
GC / Zambezia	0	Sao Tome & Principe	0
GC / Sudania	1	Reunion	2
Lake Victoria	10	Marutius	0
Zanzibar-Inhambane	1	Comoros	1

Table 5. ‘Critical’ protected areas and their overlap with other conservation priority assessments. Non ACP protected areas in *italics*

Area Name	*Country*	*IBA*	*CI*	*WWF*	*WH*	*MAB*	*Ramsar*	*AZE*
Count	**117**	77	79	75	15	7	13	6
Kibira	Burundi	Yes	Yes	Yes				
Tai	Côte d'Ivoire	Yes	Yes	Yes	Yes	Yes		Yes
Banco	Côte d'Ivoire		Yes	Yes				
N'Zo	Côte d'Ivoire	Yes	Yes	Yes				
Azagny	Côte d'Ivoire	Yes	Yes	Yes			Yes	
Iles Ehotile	Côte d'Ivoire		Yes				Yes	
Douala - Edéa	Cameroon		Yes	Yes				
Lac Ossa	Cameroon		Yes	Yes				
Mozogo - Gokoro	Cameroon							
Kahuzi -Biega	Congo, DRC	Yes	Yes	Yes	Yes			Yes
Yangambi forest and floral reserve	Congo, DRC			Yes		Yes		
Lake Dziani Boundouni	Comoros	Yes	Yes				Yes	
Djurdjura	*Algeria*	*Yes*	*Yes*	*Yes*		*Yes*		
Belezma	*Algeria*	*Yes*	*Yes*	*Yes*				
Réserve Intégrale du Lac Tonga	*Algeria*	*Yes*	*Yes*	*Yes*			*Yes*	
Qarun Lake (Quaron)	*Egypt*	*Yes*						
Wadi el Assuity or Wadi el Assuti	*Egypt*							
Wadi el Rayan	*Egypt*	*Yes*						
Tama	Ethiopia		Yes	Yes				
Awash	Ethiopia	Yes	Yes	Yes	Yes			
Abijatta-Shalla Lakes	Ethiopia	Yes	Yes	Yes				
Awash West	Ethiopia		Yes	Yes				
Simien Mountains	Ethiopia	Yes	Yes	Yes				Yes
Simien National Protected area	Ethiopia	Yes	Yes	Yes	Yes			
Nechisar	Ethiopia	Yes	Yes	Yes				
Bale	Ethiopia	Yes	Yes	Yes				
Alledeghi	Ethiopia		Yes					
Akanda	Gabon	Yes		Yes			Yes	
Nini-Suhien	Ghana		Yes	Yes				
Bomfobiri	Ghana		Yes	Yes				
Kakum	Ghana	Yes	Yes	Yes				
Owabi	Ghana		Yes	Yes			Yes	
Massif du Ziama	Guinea	Yes	Yes	Yes		Yes		
Mount Nimba	Guinea	Yes	Yes	Yes	Yes	Yes		Yes
Konkouré	Guinea	Yes	Yes	Yes			Yes	
Baubolon	Gambia, The	Yes						
Monte Temelón	Equatorial Guinea			Yes				
Nairobi	Kenya	Yes		Yes				
Ol Donyo Sabuk	Kenya	Yes		Yes				
Lake Bogoria	Kenya	Yes	Yes				Yes	
Mount Elgon	Kenya	Yes	Yes			Yes		Yes
Ruma	Kenya	Yes		Yes				
Kakamega	Kenya	Yes						
Sapo	Liberia	Yes	Yes	Yes				
Cape Mount	Liberia	Yes	Yes					
Merja Zerga	Morocco	Yes	Yes	Yes			Yes	
Talassantane	Morocco	Yes	Yes	Yes				
Merja Sidi Boughaba	Morocco		Yes	Yes			Yes	

Area Name	***Country***	***IBA***	***CI***	***WWF***	***WH***	***MAB***	***Ramsar***	***AZE***
Lac d'Afennourir	Morocco	Yes	Yes	Yes			Yes	
Andohahela	Madagascar	Yes	Yes	Yes	Yes			Yes
Zahamena	Madagascar	Yes	Yes	Yes	Yes			
Marojejy	Madagascar	Yes	Yes	Yes	Yes			
Betampona	Madagascar	Yes	Yes	Yes				
Lokobe	Madagascar	Yes	Yes	Yes				
Analamazoatra	Madagascar	Yes	Yes	Yes				
Anjanaharibe-Sud	Madagascar	Yes	Yes	Yes				
Manongarivo	Madagascar	Yes	Yes	Yes				
Manombo	Madagascar		Yes	Yes				
Ambatovaky	Madagascar	Yes	Yes	Yes				
Mangerivola	Madagascar	Yes	Yes	Yes				
Ranomafana	Madagascar	Yes	Yes	Yes	Yes			
Mantadia	Madagascar	Yes	Yes	Yes				
Masoala	Madagascar	Yes	Yes	Yes	Yes			
Analamerana	Madagascar	Yes	Yes	Yes				
Lengwe	Malawi	Yes						
Liwonde	Malawi	Yes						
Lake Malawi	Malawi	Yes			Yes			
Nkhota-Kota	Malawi	Yes		Yes				
Majete	Malawi							
Mwabvi	Malawi							
Lake Chilwa	Malawi	Yes		Yes			Yes	
Okomu	Nigeria	Yes	Yes					
Kashimbila	Nigeria							
Laurisilva of Madeira	*Portugal*		*Yes*	*Yes*	*Yes*			
Piton de la Fournaise	*Reunion*	*Yes*	*Yes*	*Yes*				
Cilaos	*Reunion*	*Yes*	*Yes*	*Yes*				
Volcans	Rwanda	Yes	Yes	Yes		Yes		
Nyungwe	Rwanda	Yes	Yes	Yes				
Gishwati	Rwanda		Yes	Yes				
Mukura	Rwanda		Yes	Yes				
Western Area	Sierra Leone	Yes	Yes	Yes				
Loma Mountains	Sierra Leone	Yes	Yes	Yes				
Ichkeul	*Tunisia*	*Yes*	*Yes*	*Yes*		*Yes*	*Yes*	
Boukornine	*Tunisia*		*Yes*	*Yes*				
Mikumi	Tanzania	Yes	Yes					
Swaga Swaga	Tanzania			Yes				
Mkomazi	Tanzania	Yes	Yes	Yes				
Ngorongoro Conservation Area	Tanzania	Yes	Yes		Yes	Yes		
Maswa	Tanzania	Yes		Yes				
Arusha	Tanzania	Yes	Yes					
Ibanda	Tanzania	Yes						
Pande	Tanzania	Yes	Yes	Yes				
Bugungu	Uganda		Yes	Yes				
Toro	Uganda		Yes	Yes				
Ajai	Uganda	Yes		Yes				
Gorilla (Mgahinga)	Uganda	Yes	Yes	Yes				
Rwenzori Mountians National Protected area	Uganda	Yes	Yes	Yes	Yes			
Bwindi Impenetrable National Protected area	Uganda	Yes	Yes	Yes	Yes			
Murchison Falls	Uganda	Yes	Yes				Yes	

Area Name	Country	IBA	CI	WWF	WH	MAB	Ramsar	AZE
Lake Mburo	Uganda	Yes					Yes	
Kibale Forest Corridor	Uganda	Yes	Yes	Yes				
Kigezi	Uganda	Yes	Yes					
Katonga	Uganda							
Kyambura	Uganda	Yes	Yes	Yes				
Rwenzori Mountains	Uganda	Yes	Yes	Yes				
Pilansberg	South Africa	Yes						
Blouberg	South Africa	Yes	Yes	Yes				
Kluitjieskraal	South Africa	Yes	Yes	Yes				
Waterval	South Africa		Yes	Yes				
Cape Peninsula	South Africa	Yes	Yes	Yes				
Golden Gate Highlands	South Africa	Yes		Yes				
Sterkfontein Dam	South Africa	Yes						
Addo Elephant	South Africa		Yes					
Dwesa-Cwebe	South Africa	Yes	Yes					
East London Coast	South Africa		Yes					
Sabie Sabie	South Africa		Yes					
Victoria Falls	Zimbabwe				Yes			

The final map in this section (Figure 34) shows the location of the 117 critical protected areas that have both higher Value & higher Pressure but which do not currently receive EC funding. Cross-referencing with parks funded by other donors will reduce this list further, but this map provides a preliminary idea of where future funding could be focused. The protected areas are shown in relation to the CI Biodiversity Hotspots. The overlap between CI hotspots and these critical protected areas is evident.

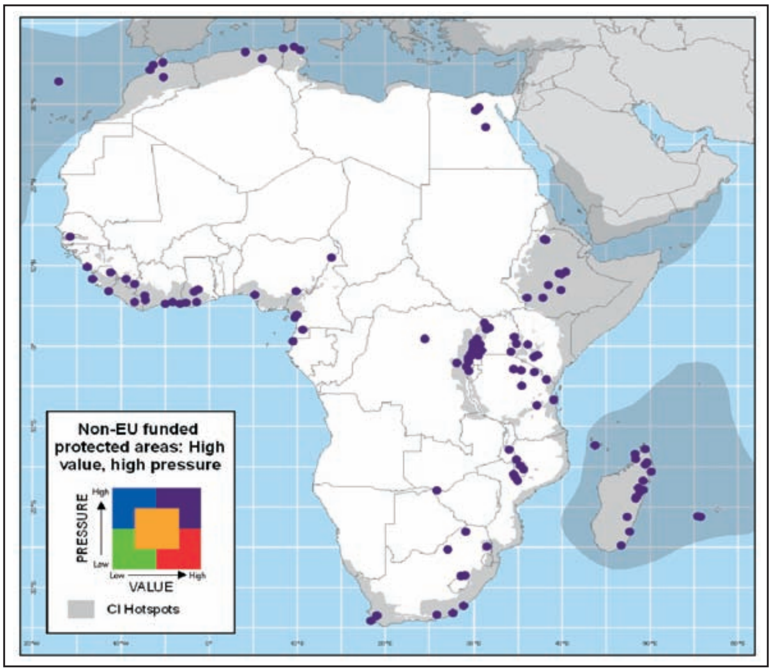


Figure 34. *The 117 "critical" (i.e. higher Value & higher Pressure) protected areas in Africa, which do not currently receive EC funding. Conservation International's Biodiversity Hotspots are displayed in grey. Protected areas of a size greater than 2.5 million hectares are displayed as a polygon, and below this threshold as a point.*

6.5. Internet site

6.5.1. Stratification by country and Ecoregion

There are many factors which determine the level of overseas development assistance (ODA) given to a particular country. Often, the conflict status, level of corruption, or perception of effective governance affect the amount of ODA a country receives. Therefore, in presenting our results at the country level, we assume that the decision maker has already decided upon the country, but wants to know where the money will be most effective within that country. Our aim is to highlight the valuable protected areas within a country, and the level of perceived pressure on these protected areas.

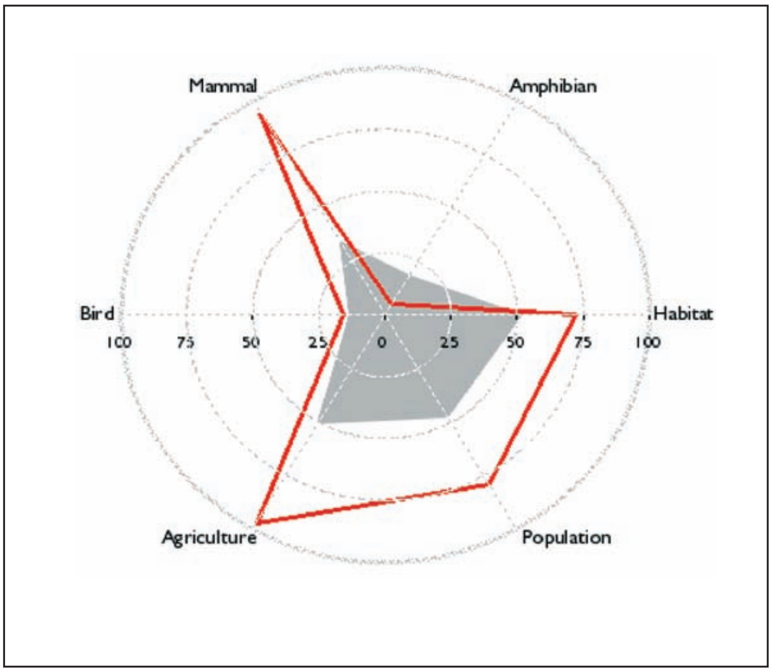


Figure 35. *Example radar plot of all indicators for a given protected area (red), against the average of all protected areas in the country (grey).*

As a second step, to put the protected area in a different context, we also stratify our results by ecoregion. While it may be less relevant to the decision making process, it does give the user secondary information on the importance of the chosen protected area in relation to potentially similar protected areas. For example, suppose that a chosen protected area is the most valuable protected area in a country, but if this protected area has a low value compared to other PAs in the same ecoregion, it may be more appropriate to provide funding to the second most valuable PA in the country.

If the ecoregion stratification were not to be used in the decision making process, conservation spending would be unevenly focused on the highest value ecoregions, such as the Afromontane ecoregion.

The results for each protected area are presented in two forms – firstly as a radar plot to show the relevance of all the indicators in relation to the country average – and secondly as a series of bar graphs to show for each indicator how the PA performs both at the country level and at the ecoregion level.

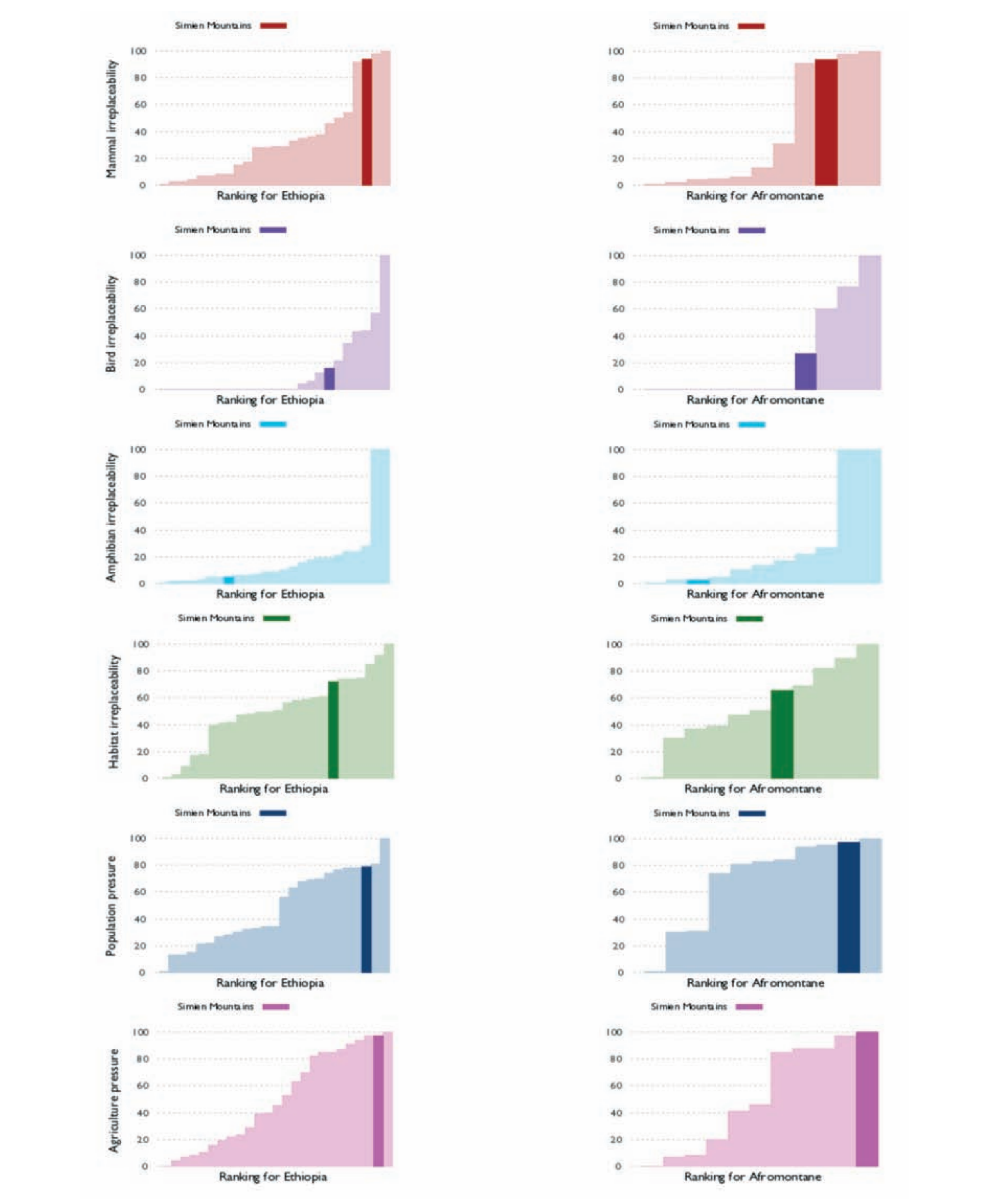


Figure 36. *Bar charts of the relative value of the Simien Mountains National Park in Ethiopia at (left) country level and (right) ecoregion level.*

6.5.2. Internet site

The above information, and other derived information on each protected area is available via our website at

http://www-tem.jrc.it/PA/index.html

For each protected area, the following information can be accessed for each protected area:

- Overview of the protected areas, including links to conservation databases
- Radar plot of species, habitat and pressure indices
- Bar charts of each index relevant to other PAs in the same country and same ecoregion
- Map of the location of similar habitats to the PA
- List of amphibian, bird and mammal species which occur within the PA, including:
  - Threat status of each species
  - % of species extent which is protected
  - Importance of the PA to the protection of that species
  - Maps of each species extent
  - Link to further information from the IUCN.
- Phenological cycle over the previous 20 years
- Average monthly temperature and rainfall
- Rainfall, NDVI, NDWI, small waterbody and fire seasonality
- Country level indicators, comprising of:
  - Environmental Performance Index
  - Millennium Development Goals
  - World Development Indicators
  - Earth Trends Indicators

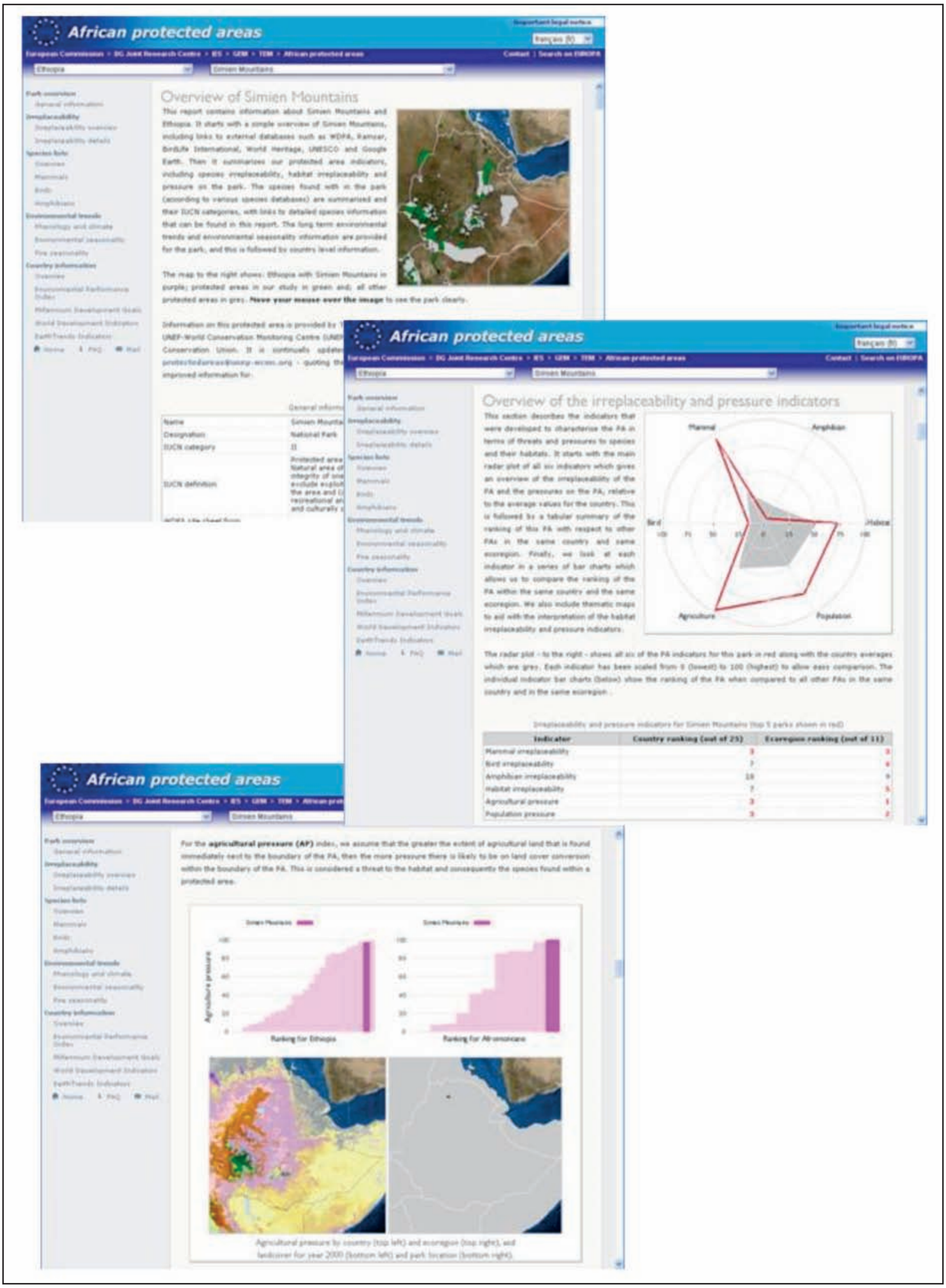


Figure 37a. *Examples taken from the web page report of Simien Mountains, Ethiopia. The same information is available for all 741 protected areas included in the study.*

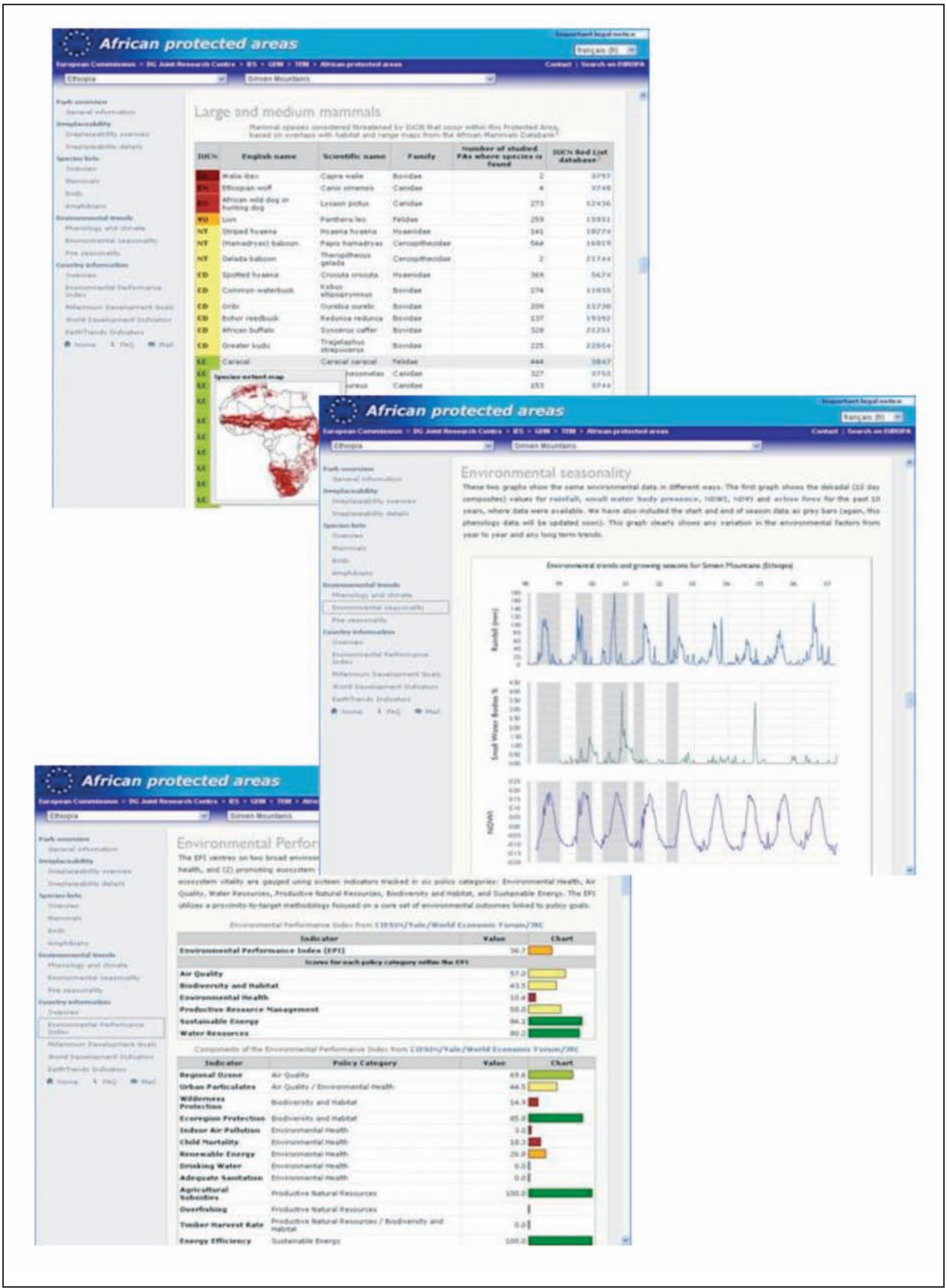


Figure 37b. *Examples taken from the web page report of Simien Mountains, Ethiopia. The same information is available for all 741 protected areas included in the study.*

7. Assessment of the methodology

We realise that the species and protected area information is of variable quality and this variation will inevitably affect the results. This was one of the key reasons for reducing our detailed data down to two key indices (Value and Pressure). As new data and better information become available we will integrate them into future assessments.

Species information

The species data that we have used is the best available, but is still incomplete. The list of mammal species used in the assessment is not comprehensive. It excludes distributions of elephants, white rhinos, and all small mammals. The mammals assessment also excludes Madagascar. We have included three taxa and will include more if and when continental or global assessments become available. The next priority is to include plant data which will affect our final assessment.

There is concern that the species maps are sometime not accurate enough to be used in conjunction with small protected areas. We have tried various combinations of the species maps and found that our ranking of parks based on irreplaceability is robust to changes in the species maps. We will continue to assess this sensitivity with a multi-scale analysis of species irreplaceability from country down to protected area level. It will also contribute to the literature on potential gaps in the protected area network.

All species are treated equally

We assume each species has an equal value. No extra or diminished value is assigned to a species based on its preferred habitat, threat status, abundance, or any other characteristic. In this analysis, a 3000kg *Hippopotamus amphibius* (Common hippopotamus) has an equal importance to a 100g *Hyperolius ocellatus* (golden-eyed tree frog); similarly the critically endangered *Pan paniscus* (Bonobo) is given the same weighting as the lower risk *Bufo regularis* (African Common Toad). In giving equal weight to each species, we ensure that our species indicators are purely a reflection of the diversity and rarity of species within a protected area. In other words, we are measuring the uniqueness of the species composition of a given protected area.

A common concern of this approach is that we do not give a higher weight to species on the IUCN red list of endangered species. In response to this, we would argue that because threatened species tend to have smaller distributions, and are therefore found in fewer protected areas, they have a greater affect on a PA's indicator score. Furthermore, by avoiding the assignment of weights to certain species, we avoid the introduction of subjectivity into the indicator. Allowing the user flexibility to assign higher importance to certain components of the analysis, as well as overcomplicating the analysis, would lay the system open to abuse, by adjusting the parameters until the a priori desired shortlist was produced.

Biodiversity and funding

To our knowledge, this is the first time that such a detailed assessment has been attempted on a continental scale. It is also the first time that an assessment of the pressures upon/value of protected areas have been linked to assistance. It would be extremely useful if we could include assistance from other major donors and agencies to produce a more complete picture of biodiversity related funding in Africa. This would probably reduce the shortlist of critical unfunded parks, and would be a valuable resource both inside and outside the Commission.

We were unable to locate any meaningful and consistent information on the impact of EC assistance to protected areas in Africa. Such information is difficult to acquire, subjective in nature, expensive and may not be factored into the project cycle. Furthermore, impact can often only be measured over a duration that is much longer than that of the funded project. If this online resource is maintained over a longer period then impact information can be included on a park by park basis or from the impact assessments of regional initiatives (eg ECOFAC).

Calibration

All of our indicators are currently uncalibrated. The pressure scoring system, while robust in our estimation, remains uncalibrated. Assessments of recent land cover change within and around parks with different scores will enable a fuller assessment of how well this index describes pressure on parks. We also recognise that the effectiveness of park management will be a big factor in determining the actual pressure on protected areas.

Improving the assessment

Many protected areas function not only internally but within their periphery. This is particularly true for migratory species like elephants, gnus, and the Western Giant Eland. In future versions, this analysis will evaluate larger spatial units thus taking into account ‘ecological corridors’ and the protected area complexes (e.g., the three components of Park W together instead of three independent evaluations).

The variability of habitats within protected areas (e.g. Virunga from the lakes to the mountains) is not currently taken into account, but will be in future versions of the assessment. One way to achieve this would be to split the habitat irreplaceability analysis into components; water bodies, terrain, vegetation, climate for example, which would then be combined into a more realistic habitat assessment.

8. Conclusions

Online tool for assessing and monitoring protected areas in Africa

We have developed a continent wide and consistent methodology for assessing the value and pressures on protected areas across Africa. The assessment is based on quantifiable and objective accepted measures using the most up to date and accurate information for Africa. This information can be made available in several forms – web pages, PDF documents, tables and charts. The information on the website is updated every 10 days for environmental trend information, and as and when new species, protected area and funding data becomes available. This website could be a valuable too for assisting and informing policy makers for biodiversity related policies and interventions.

Agreement with internationally recognised conservation priority assessments

Our classification of the 144 most important protected areas based on the two criteria of Biodiversity Value and Anthropogenic Pressures is in close agreement with broad scale conservation priority assessments by Conservation International, BirdLife International and the World Wildlife Fund. Specifically, 75% are in CI hotspots, 71% are in the WWF global 200 ecoregions, and 75% are also IBAs. It can be argued that our scheme benefits from a more objective and consistent assessment of anthropogenic threats than previous assessments.

EC assistance for biodiversity to protected areas

Our analysis of the EC funding to date shows that, across all ACP countries in Africa, the EC has a good record for targeting protected areas that have higher than average Biodiversity Value, but the record is quiet poor if we factor in Anthropogenic Pressures as another criterion for targeting. In many cases this apparently poor targeting of funds may be explained by the fact that the EU has chosen not to fund a park which is already well funded by other donors.

The relationship between funding and Biodiversity Value also varies from country to country, with countries like Ghana and Côte d'Ivoire having excellent targeting both in terms of Value and Pressure, through to countries like Ethiopia where targeting is closely related to Value but not Pressure, and finally several other countries where there is no discernable link between funding and either Value or Pressure.

EC funded parks that overlap with several internationally recognised conservation priority assessments have higher Value and Pressure scores than those that do not.

Identifying protected areas for consideration for future assistance

We have created a tentative shortlist of 106 protected areas (out of the 741 protected areas in the study) in ACP countries in Africa that should be taken into consideration in future funding proposals. A very high percentage of these also overlap with broad scale internationally recognised conservation priority assessments (77 or 73% are also IBAs, 79 or 75% are in CI hotspots and 75 or 71% are in the WWF global 200 ecoregions), which again demonstrates that our methodology is identifying a plausible set of important protected areas. Furthermore, within these ‘critical’ protected areas, those that belong to more than one conservation priority assessment have higher Value and higher Pressure scores, which suggests that the method can also be used to rank or prioritise ‘critical’ protected areas.

This shortlist is not exhaustive – there may well be other parks that should be considered that did not make the list due to other criteria (such as plant diversity) or gaps in our species data. These caveats also apply to the discussion on existing funding, where a protected area may have received funding for reasons that were not considered in our analysis. Similarly, a protected area may not have received funding because it is already well funded by another donor. However, this list is a valuable tool for stimulating debate, highlighting opportunities, assisting the decision making process and for providing us with valuable feedback so that we can improve and update our methods of analysis. Inclusion of information from other conservation priority assessments will also be useful in making decisions, as these are often based on field verified information.

Additionally, it is recognised that there are still gaps in the protected area network, meaning many areas of higher biodiversity value remain unprotected, and as such unrecognised by this analysis.

Identifying unfunded parks that overlap with several conservation priority assessments may be a good indicator for successful cooperation with other international agencies and hence a greater likelihood of sustainability and higher impact. Alternatively, critical parks that belong to few such initiatives can be considered 'gaps' in our collective knowledge which could also be targeted.

By providing specific and up to date information on protected areas that may be in need of further assistance we can identify critical gaps in the EC assistance to protected areas in Africa.

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European Commission

EUR 22780 EN – Joint Research Centre, Institute for the Environment and Sustainability
Title: Evaluating Protected Areas in Africa
Authors: A.J. Hartley, A. Nelson, P. Mayaux, J-M. Grégoire
Luxembourg: Office for Official Publications of the European Communities
2007 – X, 70 pp. – 21 x 29.7 cm
EUR - Scientific and Technical Research series; ISSN 1018-5593

Abstract
This is the first consistent, continent-wide assessment of protected areas in Africa, based on (i) their value for conservation and (ii) anthropogenic pressures. It is based on the most up-to-date, scientifically accepted, and publicly available information on species, environment and socio-economics. Over 1,600 species across 741 protected areas in 50 countries have been studied. This report presents a scaleable information system, meaning that the user can assess a given protected area in the context of others in the continent as a whole, in the same Ecoregion, same country, or same locality. Consequently, a variety of users are foreseen, from European policy makers, to regional and country level planners, and even managers of individual protected areas. This information is available online in a series of reports for each protected area and each country. Furthermore, to assist future EC funding decisions, we analyse the relationship between protected areas that have recently received EC assistance and our measures of conservation value and pressure.