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High human density in the irreplaceable sites for African vertebrates conservation

Carlo Rondinini, Federica Chiozza, Luigi Boitani*

Department of Animal and Human Biology, Università di Roma "La Sapienza", Viale dell'Università 32, 00185 Roma, Italy

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ABSTRACT

The identification of priority sites that ensure the achievement of conservation goals is key to direct conservation efforts. An estimation of the level of vulnerability of each priority area allows the identification of sites that need urgent conservation action. We present a systematic reserve selection for 1654 African mammals and amphibians that uses habitat suitability models as estimates of the area occupied by each species. These are based on the geographic range and habitat preferences for each species, which we collected in the framework of the World Conservation Union (IUCN) Global Amphibian Assessment and IUCN Global Mammal Assessment. Our results showed that in addition to existing protected areas, approximately 2.8 million km^2 of land is irreplaceable to achieve the protection of 10% of the area occupied by all amphibians and mammals. This figure is higher than previous estimates from other studies. Most irreplaceable sites are located in the sub-Saharan region. More than half (55%) of the irreplaceable sites have high human population density; for only 17% the human population density is low. African amphibians and mammals have therefore to be conserved in densely populated areas where innovative management policies will be required to accommodate conservation successfully.

1. Introduction

The ongoing biodiversity crisis (Pimm et al., 1995) urges the development of conservation strategies. Indeed the existing global protected area network is ineffective in representing and protecting biological diversity (Rodrigues et al., 2004). Because the total amount of land that can be devoted to conservation is limited by social and economic factors, it is necessary to prioritise action among the sites important to conservation (Margules et al., 2002). Estimating the risk of loss of each area important to conservation allows the identification of sites that need urgent protection (Margules and Pressey, 2000).

The African continent is highly rich and diverse in species because it is centered on the equator (Gaston, 2000) and still contains large wilderness areas. Therefore, it has been the subject of both global and regional prioritization efforts (Balmford et al., 2001; Brooks et al., 2001; Burgess et al., 2002, 2006; Cowling and Pressey, 2003; Cowling et al., 2003; Rodrigues et al., 2004). While some of these studies tackled the issue of vulnerability of sites important for conservation, the broad-scale ones are based on coarse-resolution data on species distribution (either broad geographic ranges or point localities limited to sub-Saharan Africa and degraded to 1-degree grid cells).

In this paper, we quantify for the first time the amount of area densely populated by humans that is irreplaceable for the conservation of African mammals and amphibians: this is the area where conflicts between conservation and socio-economic needs are inevitable. The analysis is based on a

* *Corresponding author:* Tel.: +39 06 4969 4218; fax: +39 06 491135.
E-mail addresses: carlo.rondinini@uniroma1.it (C. Rondinini), federica.chiozza@fao.org (F. Chiozza), luigi.boitani@uniroma1.it L. Boitani).
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dataset of 1654 species for which we generated habitat suitability models at 1-km^2 resolution based on their habitat preferences inside their geographic ranges. We used the suitable areas as estimates of the species area of occupancy (Rondinini et al., 2005; Rondinini and Boitani, 2006) to assess the irreplaceability of sites, that is, the likelihood that a given area has to be protected to achieve a conservation goal (Pressey et al., 1994). We then estimated the vulnerability of completely irreplaceable sites due to human population pressures, identifying a subset of sites that represents the top priority in terms of importance to conservation and urgency of action.

2. Methods

2.1. *Estimation of the area of occupancy*

We determined the geographic ranges for each of 1654 species of African mainland vertebrates (641 amphibians and 1013 mammals). The sample contained more than 95% of all African species belonging to the two classes and covered the entire continent (excluding islands). For 1223 of these species we collected information concerning the species-habitat relationships in terms of type of land cover, elevation, and distance from water. We obtained the data from literature and experts (IUCN Global Amphibian Assessment and IUCN Global Mammal Assessment) and built on an existing data base for large- and medium-size African mammals (Boitani et al., 1999). All small mammal data will be freely available through the Global Mammal Assessment web site upon the completion of the data collection; data on large- and medium-size mammals are already available on the African Mammals Databank web site (www.gisbau.uniroma1.it/amd, accessed June 2006), and the Global Amphibian Assessment data are available on www.globalamphibians.org (IUCN, Conservation International and NatureServe 2004, accessed June 2006).

To generate estimates of the area of occupancy inside the geographic range of each species (at 1 km^2 resolution) we used the species' habitat preferences. We reclassified as suitable or unsuitable the land classes of a land cover map (United States Geological Survey, 2000), the elevation values from a digital elevation model (United States Geological Survey, 2001a), and the distances to water from a map of water bodies and water courses (Environmental Systems Research Institute, 1993). For each species we used the intersection of suitable areas from the three environmental layers as the estimated area of occupancy. This estimation is more robust than other, more permissive estimates in terms of the prevalence of false positive errors (Rondinini and Boitani, 2006), which are dangerous in conservation because they may lead to the protection of sites that do not contain the species of interest (Loiselle et al., 2003). The modelling procedure and validation of results are fully described elsewhere (Rondinini et al., 2005). We performed all the cartographic data processing with ArcInfo GIS 8.3 (Environmental Systems Research Institute, CA, USA).

For 431 poorly known species (123 amphibians and 308 mammals), we were unable to collect enough information regarding species-habitat relationships, which prevented us from estimating habitat suitability inside their range. However, we included these species in the analysis and replaced their missing suitable area with the estimated geographic range. This was necessary as many of these species have restricted ranges and their removal from the sample would under-estimate the irreplaceability values of sites.

2.2. *Systematic selection of reserves*

To perform the systematic reserve selection exercise that is necessary to evaluate the irreplaceability of sites, three components have to be defined: (1) the boundaries of sites; (2) the elements of biodiversity to be conserved by these sites and (3) the conservation target to be achieved for each element (Margules and Pressey, 2000).

In order to generate a map of sites, we mapped existing reserves by merging the World Database on Protected Areas (World Database on Protected Areas Consortium, 2003) with the map of protected areas compiled by the IUCN/SSC Elephant Specialist Group (Blanc et al., 2003). We then divided the rest of the continent into planning units following watershed boundaries from the HYDRO1K map (United States Geological Survey, 2001b) and obtained 6876 planning units (mean size 4275 ± 57.6 SE km^2). The details on the procedures followed to obtain the final maps of protected areas and planning units are explained in Rondinini et al. (2005). We included all 1654 mapped species of amphibians and mammals among the elements of biodiversity to be conserved.

Our conservation targets were to protect the entire area occupied by each species if it was smaller than 1000 km^2; to protect 1000 km^2 if the area occupied was between 1000 and 10,000 km^2; or to protect 10% of the area occupied if it was larger than 10,000 km^2. In an earlier analysis, we demonstrated that the use of other targets resulted in only minor differences in the reserve selection outcome (Rondinini et al., 2005). The contributions to targets of existing reserves were taken into account. Newly selected reserves were added to the existing ones.

We performed the reserve selection analysis with the software MARXAN (Ball and Possingham, 2000). This program selects a set of sites based on their complementarity in terms of species represented (Ball and Possingham, 2000; Possingham et al., 2000). This means that sites are not selected because they are individually rich in species, but because pooled together they meet the pre-defined conservation target while reserving the minimal amount of area.

We selected the analysis input parameters as follows: algorithm, simulated annealing; number of simulations, 1000; iterations per simulation, 20,000; number of temperatures decreases per simulation, 10,000; and choice of the initial temperature and cooling factor, adaptive. We assigned a unitary cost to each planning unit, and a penalty factor of 10 for each species missing in the final reserve system. This way we ensured that the target was met for all species in the selected systems of reserves. The software and all procedural details are freely available online: http://www.ecology.uq.edu.au/marxan.htm (accessed June 2006).

2.3. *Irreplaceability and vulnerability*

Each of the 1000 simulations generated a system of protected areas that meets the specified target, although systems differed from each other in their composite sites. The irreplaceability value of each site was estimated as the number of times it was included in a system of protected areas. Therefore, sites selected 1000 times are completely irreplaceable and are needed in order to achieve the targets. In comparison, sites not selected in any of the 1000 reserve systems do not contribute to the achievement of the targets. The other sites are more or less interchangeable depending on their irreplaceability value.

Some highly irreplaceable sites will not be at risk in the foreseeable future while some sites with moderate irreplaceability might be vulnerable to imminent destruction if not adequately protected (Pressey and Taffs, 2001; Pressey et al., 2004; Wilson et al., 2005). The combination between irreplaceability and vulnerability (the likelihood that an area will be disturbed or destroyed) allows identifying those sites that require immediate conservation action. We used the density of human population within sites as a proxy for vulnerability, because the presence of humans can be a cause of disturbance and threat to species that lead to biodiversity loss (Balmford et al., 2001). Data on human population density were obtained from the LandScan global population distribution dataset at 1-km^2 resolution, developed by the Oak Ridge National Laboratory (2003). We assigned sites to four classes of vulnerability corresponding to quartiles of human population density.

3. Results

The land surface occupied by the existing protected areas is approximately 3.44 million km^2 (ca. 10% of Africa). In order to achieve our target for amphibians and mammals, another 3.36 million km^2 are necessary, of which 2.78 million km^2 (an additional 9% of the African land surface) are completely irreplaceable (Table 1). These irreplaceable sites are mainly clustered in the tropical regions of West Africa from Guinea to Nigeria, along the eastern coast of Africa (the region that stretches from southern Somalia to Northeast South Africa), in the eastern montane region (encompassing the Ethiopian Highlands, the Eastern Arc Mountains and the Albertine Rift that includes portions of Rwanda, Burundi, Uganda, Tanzania and the Democratic Republic of Congo) and in the Cape region in South Africa (Fig. 1). Based on a visual comparison with peaks of species range-size rarity, highly irreplaceable areas seem to be mainly (but not exclusively) associated with narrow-range species with large targets relative to their total area of occurrence.

Approximately 9.5 million km^2 of land (ca. 30% of the continent) do not contribute to the achievement of the conservation targets for the species considered here. These sites are spread across the entire sub-Saharan Africa. These planning units tend to contain mostly species that have their targets fully achieved in existing protected areas and, in sub-Saharan Africa, they form haloes around protected areas in places, where species tend to be widespread. All of the desert and semi-desert regions (Sahara, Horn of Africa, part of Namib and Kalahari deserts) are characterised by intermediate values of irreplaceability (Fig. 1).

More than half of the irreplaceable area (55%) is in the upper quartile of human population density (Table 1), a percentage much higher than what would be expected if irreplaceability were randomly distributed with respect to human population (25%). On the other hand, the irreplaceable sites with low human population density and therefore, pre-

Table 1 – Irreplaceable and threatened areas in Africa

Irreplaceability	Human population density (inhabitants/km^2)			
	0.13–0.98	0.98–5.91	5.91–20.55	20.55–799.17
0	793,898 (2.70%)	2,621,763 (8.93%)	3,381,314 (11.51%)	2,723,577 (9.27%)
0.001–0.499	6,587,224 (22.43%)	2,942,345 (10.02%)	1,962,246 (6.68%)	1,770,517 (6.03%)
0.500–0.999	74,197 (0.25%)	67,592 (0.23%)	84,290 (0.29%)	135,036 (0.46%)
1	48,230 (0.16%)	404,299 (1.38%)	806,466 (2.75%)	1,525,824 (5.20%)

Area (km^2) of African land surface by increasing irreplaceability and human population density (proxy for threat). Values in parentheses are percentages of area relative to the total surface of the African continent. Irreplaceability values range from 0 (area never selected by reserve selection algorithm) to 1 (area always selected by the algorithm).

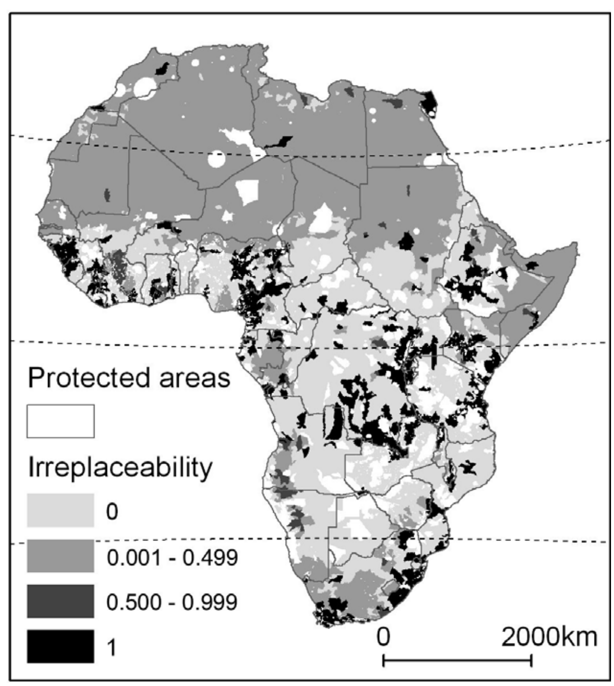

Fig. 1 – Distribution of irreplaceability values across Africa. Irreplaceability values: 0, sites never included in reserve systems designed to protect amphibians and mammals; 0.001–0.499, sites included in less than half of these reserve systems; 0.500–0.999, sites included in more than half of these reserve systems; 1, sites always included in these reserve systems (irreplaceable sites). See text for a detailed explanation of the conservation targets.

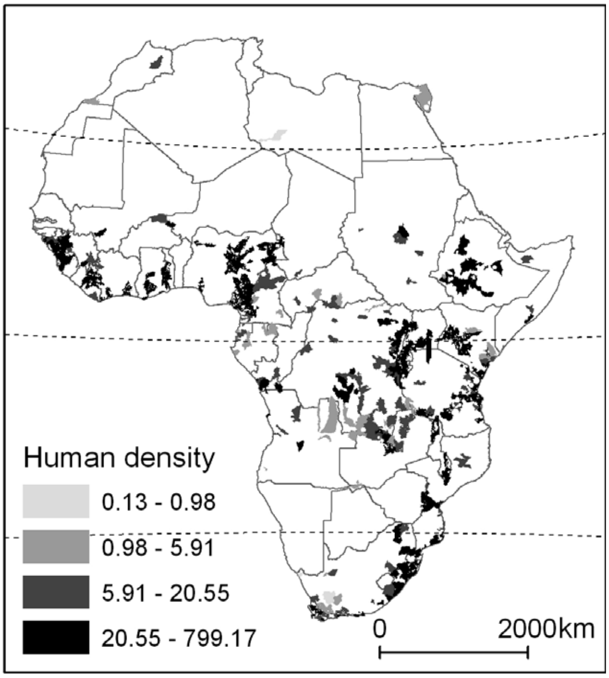

Fig. 2 – Threat to irreplaceable sites across Africa. Irreplaceable sites divided in four classes based on their mean human population density. Class boundaries correspond to the quartiles of the distribution of human population density across Africa.

dicted to not be under imminent threat, occupy only 0.48 million km^2, corresponding to 17% of all irreplaceable sites (Table 1). The geographic distribution of highly vulnerable and irreplaceable sites reflects the overall distribution of irreplaceable sites, with the notable exception of some sites in the Cape region (South Africa), in the Congo river basin, and at the border between Democratic Republic of Congo, Angola and Zambia, where human population density inside irreplaceable sites is low (Fig. 2). The few irreplaceable sites north of the Sahel hold human population at low or intermediate levels of density.

4. Discussion

The results obtained in this study show that an alarmingly high proportion (more than half) of the area that is completely irreplaceable for the conservation of African amphibians and mammals has high human population density.

The sites that are irreplaceable to achieve protection for amphibians and mammals are mostly concentrated in sub-Saharan Africa, the part of the continent that is richer in species (Rondinini et al., 2005) and endemism. This is especially true for amphibians, which are less diverse in North Africa (Rondinini and Boitani, 2006). Some of the irreplaceable sites broadly overlap with those identified using the hotspots approach (Guinean Forests of West Africa, Cape Floristic Region, Eastern Arc and Coastal Forests of Kenya and Tanzania) (Myers et al., 2000), the ecoregional approach (ecoregions in Liberia, Cameroon, Ethiopia, Uganda, Kenya, Tanzania, South Africa) (Burgess et al., 2006), and a global gap analysis (sites in Liberia, Cameroon, Ethiopia, Uganda, Kenya, Tanzania, Mozambique, South Africa) (Rodrigues et al., 2004). Nonetheless our more detailed data on species distribution allow for a more accurate identification of priority sites (e.g. in the Cape region, where only a fraction of the irreplaceable area is densely populated). Furthermore, we identify additional priority sites in Guinea and Sierra Leone; Nigeria; Democratic Republic of Congo; and South Africa. This is because the coarse data used in previous studies contain more false positives than our habitat suitability models, thus may lead to the conclusion that species are protected in sites where they are actually absent (Rondinini et al., 2005). On the other hand, the false negative errors of our habitat suitability models reduce the efficiency of our reserve selection analysis, because some sites where species are erroneously considered absent may be overlooked. For a full discussion of the implications of errors in species distribution data for conservation planning see Rondinini et al. (2006).

The sites that do not contribute to the achievement of the conservation targets are interspersed with highly irreplaceable sites in forests and savannahs of sub-Saharan Africa. The bimodal distribution of the irreplaceability values of sites in forest and savannah likely stems from the high fragmentation of these biomes, due to the higher human impact and consequent changes of land use towards non-natural habitat. Because our analysis is based on habitat suitability models, even adjacent sites are estimated to host very different numbers of species depending on the land cover types they contain. On the other hand, desert and arid regions (Sahara, Horn of Africa, Namib and Kalahari) have intermediate values of irreplaceability that are comparable to each other. The habitats occupied by desert and semi-desert species are overall less impacted by humans and less fragmented. As a consequence habitat suitability assumes more even values across the species range, and sites in desert and arid regions are more interchangeable. The intermediate values of irreplaceability in deserts should not be interpreted as indices of low conservation priority per se, because a proportion of the desert and semi-desert sites are indispensable to achieve the conservation targets for species that occur in these habitats (Rondinini et al., 2005).

More than half of the irreplaceable sites are vulnerable because of the high density of human population. This is more than double than expected if these sites were randomly distributed with respect to human population density. Previous studies have found a positive correlation between species richness and human population density (e.g. Cincotta et al., 2000; Balmford et al., 2001; Araujo, 2003; Luck et al., 2004; Evans and Gaston, 2005). At a finer spatial scale Chown and colleagues (2003) found in South Africa that the existing positive correlation between species richness and human density is caused by the positive response of each with increasing levels of primary productivity and mean annual precipitation. Balmford and colleagues (2001) analysed the distribution of sub-Saharan vertebrates in 1-degree cells and concluded that, in a system that represented each species once, about 40% of the cells selected were densely populated. Our study extends their conclusion much further, because we demonstrate that for less species, at finer resolution, with a real-world target and a more robust analysis, the conflict is more extensive that previously thought.

The few exceptions to the coincidence of high irreplaceability and high vulnerability of sites are found in the Congo basin, at the border between Democratic Republic of Congo, Zambia and Angola, and in the Cape region of South Africa. The remaining habitat in the Congo tropical wilderness areas still provides remarkable opportunities for conservation. Nevertheless concerted planning in these areas will be essential to ensure successful conservation amid development of rural areas associated with the agricultural expansion (Gorenflo and Brandon, 2005). In most of the Cape region, human density is relatively low, and the land is better managed with already good coverage of protected areas.

In Africa, irreplaceable sites where human population density is low occupy less that 500,000 km^2. Even if these sites were all set aside for conservation purposes, they would account only for 17% of all sites irreplaceable for conserving amphibians and mammals. The majority of irreplaceable sites contain high population densities and expanding human populations. This evidence leaves little room for reservation as a successful conservation strategy. The conservation of African vertebrates cannot be achieved without the development of innovative management policies to accommodate conservation inside development areas.

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