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# Protected African rainforest mammals and climate change

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## Introduction

Well-governed and effectively managed national parks, game reserves, wilderness areas and other legally established protected areas (PAs) provide a wide range of social, environmental and economic benefits worldwide (Ervin *et al.*, 2010). However, current reserve networks may be inadequate to protect sufficient amounts of biodiversity because of lack of representativeness of species and landscapes. Moreover, because of

their static nature, species may be driven out of reserves (Araújo *et al*., 2004), or may become extinct if unable to disperse to other suitable areas (Thuiller *et al*., 2005).

The Central African forest region is globally outstanding (Blom *et al*., 2004). PAs here cover over 12% of the total forest area (FAO, 2011). But, their effectiveness in protecting biodiversity over the longer term is affected by increasing human pressures (Fa *et al*., 2002) and vulnerability to 21st century human-induced climatic change (CC) (Velarde *et al*., 2005).

Studies aimed at safeguarding the existing sub-Saharan African vertebrate diversity have focused, often separately, on understanding the effectiveness of the existing PA networks on species (e.g. birds: Muriuki *et al*., 1997; mammals: Fjeldså *et al*., 2004) or on how potential exposure to CC impact these (García *et al*., 2012). Only Thuiller *et al*. (2006) evaluated whether national parks throughout Africa (at 0.16º resolution) will meet their mandate under future CC and land transformation conditions. Although these published projections are useful, new CC scenarios have been proposed (IPCC, 2013), and recent analyses of the mammal diversity in Africa (Fa *et al*., 2014) allow for assessments at higher spatial resolutions. Here, we present, for the first-time, analyses at 0.1º resolution, that examine the potential impact of CC on the protection of forest mammals within the Rainforest Biotic Zone (RBZ) in Central Africa.

**Methods**

*Study area*

The study area covered the limits of the RBZ (Kingdon *et al*., 2013); 10ºN, 10.5ºS, 8ºE and 36ºE. The region comprises the second largest and best-preserved area of contiguous tropical rainforest in the world, but evergreen/deciduous broadleaf forests and woody savannas, as well savanna and cropland-natural vegetation mosaic are also found (Friedl *et al*. 2010).

All or large parts of the Democratic Republic of the Congo, the Republic of the Congo, Central African Republic, Cameroon, Gabon, Equatorial Guinea, Uganda, Rwanda, Burundi, Angola, Nigeria, Tanzania and Sudan are represented (Fig. 1).

*Species data*

In total we used data for 165 mammals (11 Orders), >1 kg body mass and which were hunted for bushmeat, accounting for almost all land mammals in the region (Fa *et al*. (2014). We introduced susceptibility to hunting in our models as an additional layer of vulnerability to extinction beyond CC. For all species, we mapped their current and future distributions (at 0.1º resolution) by using favourability-function models (Acevedo & Real, 2012).

*Determining hot spots and weak spots*

We defined geographical hot spots as areas of high diversity, and weak spots as high diversity regions of special hunting vulnerability for wildlife (Fa *et al*., 2014). We employed hot spots and weak spots here, as described in Fa *et al*. (2014).

Mammalian richness was measured employing two surrogate indices based on accumulating favourability values obtained, for every species in every locality, through distribution modeling (Real *et al*., 2006; Estrada *et al*., 2008). Favourability models (Real et al., 2006; Acevedo & Real, 2012) can distinguish between localities whose environmental conditions favour the species' presence and localities where conditions are detrimental for the species, independently of the effect of the species' prevalence within the study area (Acevedo & Real, 2012). This allows for model combinations using fuzzy logic (Estrada *et al*., 2008; Barbosa & Real, 2012).

Presences and absences of the 165 study species were recorded in 1º resolution cells, using IUCN range maps (IUCN, 2014); this is the maximum spatial resolution at which extent of occurrence maps are suitable for distribution modeling (Hurlbert & Jetz,

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2007). Favourability models were trained for the entire African continent, considering 27 predictor variables describing topography, hydrography, climate, land cover/use and other anthropogenic pressures (see Appendices S2 and S3 in Fa *et al.*, 2014); we also accounted for the impact of dispersal barriers, geological history and biotic interactions through the trend surface approach (Legendre, 1993; Fa *et al.*, 2014).

Favourability models were projected to a 0.1° resolution grid using the direct downscaling method (Bombi & d'Amen, 2012). Finally, only favourability values where species are known to occur according to IUCN were retained. In this step of the procedure, the distribution areas for subspecies were considered separately.

The diversity index used to define hot spots was the Accumulated Favourability ($AF_j$), calculated by summing the favourability ($F_i$) value of all $i$ taxa in each $j$ cell in the study area:

$$AF_j = \sum F_i \qquad\qquad (1)$$

Hot spots were then defined by selecting the highest 5% of $AF_j$ values. This cutoff matches the proportion of the study area that is currently covered by PA.

The diversity index used to define weak spots was the Unsustainable Accumulated Favourability ($UAF_j$), whose calculation is similar to that of $AF_j$ with the exception that each taxon's favourability value was weighted according to a measure of the taxon's vulnerability. For this weighting, we used the index of Potential Hunting Sustainability ($PHS$) that is the taxon's potential resilience to hunting according to ecological traits that are linked with extinction proneness (Cardillo *et al.*, 2005; Fa *et al.*, 2014). *PHS* was built according to the restrictive approach in Fa *et al.* (2014), which is based on a combination of four ecological traits: population density, habitat breadth,

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rarity and vulnerability. A detailed description of the procedure to calculate *PHS* is found in Fa *et al*. (2014). $UAF_j$ was finally computed as follows:

$$UAF_j = \sum [F_i \times (1 - PHS_i)] \qquad (2)$$

Weak spots were then defined by selecting the highest 5% of $UAF_j$ values.

*Hot spot and weak spot projection to future*

For each species/subspecies in each cell, future favourability values for 2050 were obtained by replacing present values with future values in the variables predicting favourability. Only climate, intact forest and rural population were considered to have changed by 2050, whereas the rest of variables were assumed not to vary significantly. In this way, for each taxon distribution, the relevance of predicted changes in climate, forest cover and population was proportional to the relative importance of these factors among the variables defining the model. Conservatism regarding expected responses of species to environmental changes was assumed, which is reasonable regarding predictions referred to less than 45 years from present.

The two most extreme greenhouse gas scenarios currently proposed by IPCC (2013) have been considered: RCP26 (optimistic) and RCP85 (pessimistic). Therefore, part of the uncertainty unavoidably linked to predictions based on climate forecasting was taken into account (Real *et al*., 2010). Climate future values were downloaded from WorldClim (http://www.worldclim.org/CMIP5). We chose forecasts based on the HADGEM2-ES global circulation model (GCM), because it has been proved to match the climatology in both tropics and extra-tropics (Collins *et al*., 2008; Brands *et al*., 2013).

The World Intact Forest Landscapes (IFL) 2000 map (Potapov *et al*., 2008) has been updated for the period 2006-2011 (http://www.intactforests.org). We have used the changes observed between 2000 and 2010 to model a forecast for 2050 using Markov chain analysis (Deadman & Brown, 1993), under the assumption that current geographical trends in deforestation are applicable to the following decades. We used IDRISI Selva software for this purpose (Eastman, 2012).

Future values of rural population density for 2050 were approximated using World Population Prospects: The 2012 Revision (United Nations, 2013). The medium scenario population growth estimates, which take the effects of AIDS into consideration (Musters *et al*., 2000), were used. A growth rate was then calculated for every country by dividing national population densities forecasted for 2050 with national densities in 2010. Values in the raster map for rural population density (Fa *et al*., 2014) were finally multiplied by the corresponding national rates.

In order to estimate $AF_j$ and $UAF_j$ values for 2050, future favourability maps for every species/subspecies were integrated in equations 1 and 2. Finally, the same diversity thresholds as for present hot spots and weak spots delimited future hot spots and weak spots.

*Diversity-based assessment of protection networks*

We assessed the suitability of the network of protected sites recorded at the World Database on Protected Areas (WDPA) (UNEP-WCMC, 2012), as a management tool for contributing to the conservation of high-diversity areas for hunted mammals (Fig 1). The goal of a network of protected sites is to ensure that all ecosystems and areas rich in species diversity are represented adequately in biodiversity management areas (Scott *et al*., 1993). Other criteria, such as representativeness (Margules, 1986), are the focus of ongoing works.

Only sites at the WDPA defined as geographically bounded polygons, and subject to legal protection (excluding Ramsar sites since these have no legal denomination) were considered. We then calculated the proportion of the surface area in hot spots and weak spots included in a protected site. This operation was repeated using the future geographical limits forecasted for both hot spots and weak spots.

**Results and discussion**

Hot spots and weak spots significantly overlapped (97.1%), occupying substantial areas north of the Congo River (Fig. 2), as proposed by Fjeldså *et al*. (2004) for the all-mammals diversity analyses. But, the area occupied could decrease by 21.1 - 29.5% for hot spots (Fig. 2A), or by 23.4 - 32.8% for weak spots (Fig. 2B) depending on whether the most optimistic (RCP26) or the most pessimist emission scenario (RCP85) was considered. This would largely affect a north-to-south corridor along the western part of the study region.

Only 15.1% of hot spots were included in the current PA network; a percentage that could increase 0.8 - 1.3% by 2050 (15.9% - 16.4%, depending on the gas emission scenario chosen), as a result of hot spots shrinking principally outside PAs. Similarly, 16.4% of weak spots were included in the PA network, and expected to increase 0.9 – 2.0% by 2050 (17.3% - 18.4%). Our finding that the percentage PA within hot and weak spots would increase by 2050 indicates that the current PA network includes favourable conditions that allow species to persist after a potential retraction of rainforests due to CC.

In this paper, we focused exclusively on understanding the fate of significant mammalian richness and vulnerability areas in Central Africa. We showed that only a relatively small number of PAs lie within their boundaries; 84.9% of hot spots and 83.7% of weak spots remain unprotected. Thus, protection of hot spots and weak spots

must, in our estimation, become an important conservation commitment given that these species blocks are probable centres of expansion in future CC scenarios. In fact, our hot spots and weak spots directly correspond to the 'Cameroon-Gabon 'Atlantic Rainforest Refuge' and the 'Central African Lowland Refuge', respectively; areas that during former forest reduction periods retained source populations of many mammals (Morley & Kingdon, 2013).

Although we argue that conservationists should not concentrate exclusively on the preservation of hot spots and weak spots at the expense of addressing other important regions in Central Africa (Kareiva & Marvier, 2003). In fact, areas outside our hot spots, such as the Cameroon Highlands (of very high mammalian endemism), would appear of significant conservation importance if a representativeness-based criterion were used (see Margules, 1986). These areas have also been highlighted as relatively unprotected by Fjeldså *et al*. (2004).

Conservation of Central Africa refuges must focus on supporting dispersal, colonisation and re-establishment processes, especially maintaining connectivity between high quality habitats spanning the distributional ranges of priority taxa, and restoring degraded zones. Finally, CC adaptation would require that sufficient area is maintained under adequate protection, to increase the resilience of existing populations and reduce species vulnerability to environmental changes (Bertzky *et al*., 2011).

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FIGURE LEGENDS


**Fig. 1.** Map of the study region showing the network of protected sites recorded at the World Database on Protected Areas (WDPA) (UNEP-WCMC, 2012) as pink polygons. Rainforests (dark green) and woody savannas (light green) are represented as in the MODIS Collection 5 global land cover (Friedl *et al*. 2010). The green line indicates the limits of the Rainforest Biotic Zone. National borders are represented as grey lines.


**Fig 2.** Distribution of hot spots and weak spots in the Rainforest Biotic Zone. a) Hot spots (high mammal-diversity areas) derived from the Accumulated Favourability (*AF*) of 208 mammal taxa belonging to 165 species. b) Weak spots (areas with high diversity of mammals vulnerable to hunting) derived from the Unsustainable Accumulated Favourability (*UAF*). Hot spots and weak spots are outlined in white. Color bars indicate present and predicted accumulated favourability values. Protected sites from the World Database on Protected Areas (WDPA) are outlined in dark brown.

| | Present | 2050<br>RCP26 greenhouse<br>gas scenario | 2050<br>RCP85 greenhouse<br>gas scenario |