Synergistic effects of climate and land-use change on representation of African bats in priority conservation areas

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Abstract

Bats are considered important bioindicators and deliver key ecosystem services to humans. However, it is not clear how the individual and combined effects of climate change and land-use change will affect their conservation in the future. We used a spatial conservation prioritization framework to determine future shifts in the priority areas for the conservation of 169 bat species under projected climate and land-use change scenarios across Africa. Specifically, we modelled species distribution models under four different climate change scenarios at the 2050 horizon. We used land-use change scenarios within the spatial conservation prioritization framework to assess habitat quality in areas where bats may shift their distributions. Overall, bats' representation within already existing protected areas in Africa was low (~5% of their suitable habitat in protected areas which cover ~7% of Africa). Accounting for future land-use change resulted in the largest shift in spatial priority areas for conservation actions, and species representation within priority areas for conservation actions decreased by ~9%. A large proportion of spatial conservation priorities will shift from forested areas with little disturbance under present conditions to agricultural areas in the future. Planning land use to reduce impacts on bats in priority areas outside protected areas where bats will be shifting their ranges in the future is crucial to enhance their conservation and maintain the important ecosystem services they provide to humans.

Keywords: Land-use Change, Climate Change, Chiroptera, Conservation, Zonation, Africa, Connectivity

1. **Introduction**

Current rates of species extinctions and declines are unprecedented (Butchart *et al.*, 2010). Species extinction rates are now 1,000 times higher than the ‘background’ rate (De Vos *et al.*, 2014). Across vertebrates, 16 to 33% of species are considered to be globally threatened (Hoffmann *et al.*, 2010). This biodiversity ‘crisis’ is driven by anthropogenic factors, such as overutilization of species, habitat destruction, pollution and the introduction of invasive species (Diamond, 1984). Human-induced climate change is also expected to affect species persistence into the future (Bellard .*et al.*, 2012). While the original cause of decline may be driven by one anthropogenic factor, extinction is often driven by multiple interacting pressures (Brook *et al.*, 2008). Hence, more studies are urgently needed to unveil the combined effects of extinction drivers on biodiversity.

Spatial conservation prioritization deals with the identification of priority areas where limited resources should be allocated for conservation actions (Moilanen *et al.*, 2009). An important goal of spatial conservation prioritization deals with the identification of areas where threats will impact biodiversity (Margules and Pressey 2000). However, conservation planning assessments often ignore the dynamic nature of threats (Moilanen *et al.*, 2009). Particularly, conservation planners should anticipate the rates and patterns of dynamic threats, such as future climate change and land-use change (Krauss *et al.*, 2010; Bellard *et al.*, 2012). Quantitative scenarios can be used to evaluate the impact of future socio-economic development pathways on biodiversity and ecosystem services to optimize current conservation actions to reduce future biodiversity loss (Pereira *et al.*, 2010).

Bats (Order Chiroptera) constitute about 23% of mammal diversity (Wilson and Reeder, 2005). Further, bats provide important ecosystem services such as predation of insects (Kalka *et al.*, 2008), seed dispersal (Shilton *et al.*, 1999) and pollination (Sazima *et al.*, 1989). They are also important bioindicators (Jones *et al*., 2009, Mehra *et al.*, 2011), as well as indicators of specific human impacts, such as the quality of water courses (Scott *et al*., 2010). Globally bats are under threat from anthropogenic activities, such as agricultural and urban expansion and over-utilisation of resources (Voigt and Kingston, 2016). Arguably, the highest threat to bats can be ascribed to widespread changes in land use systems predicted in the future (Hannah *et al*. 1995, Verburg *et al*., 2013), because these will impact bat fitness directly in terms of roost, food and water loss. At the same time, climate change will shift bats' ranges and likely drive species to local extinction (Rebelo *et al.*, 2010). However, it is less clear how synergistic effects of climate and land use change will affect priority areas for the conservation of bats (Hughes *et al.*, 2012).

Compared to other continents, African bats have been poorly monitored and knowledge of their distribution is still very scarce (Martin *et al*., 2013). More than 30% of African bat species are classified as threatened or data deficient (IUCN, 2014). Our goal was to identify the spatial priorities for the conservation of 169 bat species under expected climate and land use change across Africa. Our objectives were (i) to model bats 'distributions under present and future climatic conditions; (ii) assess bats' representation inside already existing protected areas; and (iii) identify priorities for conservation actions outside protected areas under future climate and land use change.

2. Materials and methods

2.1 Biodiversity features

Recorded locations for 169 bat species (14,050 total records with the number of locations per species ranging from 5 to 604) of the approximately 250 species in Africa were used to model species distributions (SDMs) for the African continent (Appendix Table A.1, Appendix Figure A.1). Because occurrence data were based on museum records and we lacked absence data we used MaxEnt to estimate the distribution for each bat species (Phillips *et al.*, 2006). Among the many options for building SDMs from presence-only species records (Latimer *et al.*, 2006; Thuiller *et al.*, 2009; Renner and Warton, 2013), MaxEnt has good predictive performance (Elith *et al.*, 2006; Radosavljevic and Anderson, 2014).

We downloaded 19 current climate variables from the World Clim for present climate and future climate in 2050 (Hijmans *et al*., 2005). We performed a principal components analysis on these variables to control for autocorrelation between variables (Garcia *et al.*, 2012; Schoeman *et al*. 2013). Variables with the largest eigenvalues associated with the principal component axes were extracted (n = 10 variables), and compared using a correlation matrix. For pairs with r>0.8, the variable with the higher eigenvalue was kept. Six variables were used in the SDMs: Temperature Seasonality, Minimum Temperature of Coldest Month, Mean Temperature of Warmest Quarter, Precipitation of Driest Quarter, Precipitation of Warmest Quarter, and Precipitation of Coldest Quarter. Future climate variables were derived from the Intergovernmental Panel on Climate Change (IPCC) AR5 scenarios RCP2.6 (Van Vuuren *et al.*, 2007), RCP4.5 (Smith and Wigley, 2006; Clarke *et al.*, 2007; Wise *et al.*, 2009), RPC6.0 (Fujino *et al.*, 2006; Hijioka *et al.*, 2008) and RPC8.5 (Riahi *et al.*, 2007).

SDM performance was evaluated with tenfold cross-validation, by partitioning data into two subsamples: one for calibration–validation and the other for evaluation (Hastie *et al.*, 2005). The average distribution likelihood from 10 repetitions was used as an input for the spatial conservation prioritization (see below). The predictive value of the likelihood maps were calculated against the test data using the receiver operator curve (ROC) value, which produces an area under the curve (AUC) value (Appendix Table A.2). The AUC value indicates the discriminatory value of the models to predict the likelihood of a presence point being higher than the likelihood of a pseudo-absence point (Phillips *et al.*, 2006). SDMs were run at 5 arc-minute resolution, which was also the resolution of the spatial conservation prioritization (see below) and suggested default settings for MaxEnt (Phillips and Dudík, 2008). We produced raster grids of the standard deviation for each species to be used in the prioritization analyses (Phillips and Dudík, 2006).

2.2 Spatial conservation prioritization

We implemented spatial priority ranking with the Zonation (v4) methods and software (Moilanen *et al.*, 2005; Lehtomäki and Moilanen, 2013; Di Minin *et al.*, 2014; Moilanen *et al.*, 2014) to identify the priority areas for the conservation of bats under future land use and climate change scenarios. As output, Zonation produces priority rank maps and corresponding performance curves, which describe how well represented each feature entered into the analysis is in any given top or bottom fraction of the priority map (landscape). The ranking balances all factors - including species distribution, connectivity, and possible costs - entered into the analysis. The additive-benefit function cell removal rule for aggregation of conservation value was used (see Moilanen *et al.*, 2011). The additive-benefit function computes a maximum-utility type solution, where value is additive across biodiversity features, and where feature-specific representation is converted to value via concave power functions, which most commonly are parameterized according to the canonical species-area curve (Moilanen, 2007).

Appendix Figure A.2 shows a flowchart of analysis and data inputs used in Zonation. In Zonation, weights assigned to features influence the balance among features in the prioritization solution. Typically, weights have positive values, but can also be set to 0.0 in surrogacy analyses (Di Minin and Moilanen 2014), or even have negative values, for example when multiple opportunity costs are included in the analysis (Moilanen *et al*. 2011). In this study, species were weighted according to their current International Union for Conservation of Nature and Natural Resources (IUCN) Red List assessment: Least Concern (weight = 1), Near Threatened (weight = 2), Vulnerable (weight = 3) and Endangered (weight = 4) (Appendix Table A.1). As a precautionary measure, species that were Data Deficient were included with the same weight as vulnerable species in the analyses (Butchart and Bird, 2010).

To account for connectivity and the scale of landscape use of bat species, we induced aggregation by using distribution smoothing on species distribution grids (Moilanen *et al.*, 2014). Distribution smoothing is a species-specific aggregation method that emphasizes areas that are well connected to others, thereby resulting in a prioritization with more compact priority areas (Moilanen *et al.*, 2014). The smoothing effectively identifies important semi-continuous regions where the species has high levels of occurrence. In contrast, scattered occurrences in fragmented habitat lose relative priority. The connectivity of cells is determined with a smoothing kernel, where the radius of the kernel was approximated as the radius of the mean dispersal distances. In the analysis, we used the mean dispersal distances for three functional groups of bats to calculate the parameter of a dispersal kernel for each species. Moilanen *et al*. (2014) provide full details on how to calculate the parameter of the dispersal kernel based on dispersal distances. The average dispersal distance for each functional group of bats was estimated as: (i) open-air bats with long and narrow wings adapted for energetically efficient flight over long distances (Molossidae, Rhinopomatidae, Emballonuridae) - 40 km (Best *et al.*, 2003); clutter-edge bats with wings of intermediate length and area adapted for flight at the edges of vegetation (Vespertilionidae, Miniopteridae) - 25 km (Jacobs *et al.*, 2005); and clutter bats with short and broad wings adapted for slow manoeuvrable flight in cluttered space (Rhinolophidae, Hipposideridae, Nycteridae, Pteropodidae, Megadermatidae) - 5 km (Fenton, 1983; Fenton *et al.*, 1985).

A number of studies have found the thematic resolution of the dynamic land use change scenarios to be insufficient for an appropriate representation of habitat categories for many ecological applications, especially at fine spatial resolutions (Barbet-Massin *et al*., 2011, Martin *et al*., 2013). Particularly, land use categories that closely relate to the species-specific habitat requirements are amalgamated in broader land use systems that are less relevant to the species distribution. In addition, land use change scenarios may not adequately capture gradual changes in species distribution, and may contain classification errors (Cord *et al*. 2014). As such, we decided to use land-use change scenarios within the spatial conservation prioritization framework and not as predictor variables in species distribution models. In Zonation, we used global land-use change models developed independently from this study (van Asselen and Verburg, 2013) as condition layers. The condition layer represents information about the quality and degradation of land use categories and its influence on biodiversity features or groups of features (see e.g. Di Minin *et al*., 2016; Montesino Pouzols *et al*., 2014).

In the land-use change models, land-use changes are driven by macro-economic assessment of regional demand and supply of agricultural commodities (Kram and Stehfest, 2012), which accounts for local factors that either promote or constrain land-use change (Verburg *et al.*, 2013). The land-cover change scenario was based on the OECD Environmental Outlook to 2050 (OECD, 2012). Land availability, as well as socio-economic and biophysical conditions, steer the model to convert land use systems, either resulting into an expansion of human dominated land use systems over (semi-)natural systems, or leading to an intensification of land management to fulfill world-region scale demands. At the same time, the model simulates abandonment of agricultural practices and re-wilding. As a result, the model provides a good representation of the multiple drivers of habitat loss.

To better interpret results, we simplified the 29 original land use types (van Asselen and Verburg, 2013) into six distinct land use types that we considered to have similar habitat suitability for bats: (i) intensive and extensive agriculture; (ii) agriculture with natural mosaic; (iii) forest and low intensity agriculture; (iv) grassland and low intensity agriculture; (v) bare ground; and (vi) urban areas (Appendix Table A.3, Appendix Figure A.3). Present (2000) and future (2050) land use maps were converted to numerical data by assigning the six land use types condition values between 0 and 1. Condition values were assigned according to disturbance of natural habitat and intensity of use (Appendix Table A.4). We created condition layers for each functional bat group (Appendix Table A.1). To reduce uncertainty on the impact that land use change will have on the three functional bat groups, we accounted for both an optimistic and a pessimistic scenario. Under both scenarios, condition values were highest for forest and low intensity agriculture, land use (value of 1.0) and lowest for bare ground (Appendix Table A.4). The optimistic scenario assumed that human land use would have less of a negative impact on bat species. Under the pessimistic scenario, instead, agricultural and natural mosaics, grassland and low intensity agriculture, intensive and extensive agriculture, and urban were assumed to be more detrimental to bat species (with decreases of 0.3, 0.2, 0.3 and 0.2 in condition values respectively compared to the optimistic scenario) (Appendix Table A.4). The values in the original SDMs were then multiplied by the condition values for present and future (optimistic and pessimistic) scenarios, respectively, in Zonation. In the Zonation analyses, we used the transformed sets of SDMs for the present and future (optimistic and pessimistic) scenarios, respectively.

2.2.1 Shifts in spatial conservation priorities

In the analyses where climate change was considered, we used the connectivity interaction feature in Zonation, which allows the calculation of connectivity between the present and future distributions of a species (Carroll *et al.*, 2010; Kujala *et al.*, 2013; Moilanen *et al.*, 2014). Specifically, two connectivity distributions were used for each species. The connectivity from the current to the future distributions was used to consider dispersal from source areas to future distribution areas. The connectivity from the future to the present distributions was used to account for stepping-stones, which are expected to help species reach the core areas of their future distributions. The spatial scale of connectivity was set to the mean dispersal distances for the three functional groups of bats, as explained above. Thus, for each species we used four potentially relevant distribution models in spatial priority setting (present distribution, future distribution, dispersal source and stepping stone).

2.2.2 Accounting for uncertainty

We accounted for various sources of uncertainty in the analyses. First, we used the standard deviation grids for each SDM in an approach called distribution discounting to give the highest value to those species occurrences that have high mean likelihood and low standard deviation (Moilanen *et al.*, 2014). Distribution discounting was applied separately to the present and future modelled species distribution models before calculating connectivity between present and future layers. In addition, we accounted for the impacts of different climate scenarios (Appendix Figure A.4). Overall, a total of 18 scenarios (two for present optimistic and pessimistic land-use change scenarios; four optimistic and four pessimistic land-use change scenarios (for present conditions) for each IPCC scenario; and four optimistic and four pessimistic land-use change scenarios (for 2050 conditions) for each IPCC scenario) were developed (details are provided in Appendix Figure A.2). Finally, we averaged optimistic and pessimistic scenarios (for both present and future – 2050 – land use) into three main consensus scenarios (present; future climate with present land use; and future climate with future land use) (see e.g. Struebig *et al*., 2015) (Appendix Figure A.2).

Under each scenario, we carried out a gap analysis in order to understand what the representation levels for bats were inside already existing protected areas and then identified priority areas for bats' conservation action outside already existing protected areas. We did so by using a hierarchical mask that identified the locations of extant protected areas at a scale of 5 arc-minutes. This way it is guaranteed that the highest priorities are located in existing protected areas (Lehtomäki and Moilanen 2013). We extracted the protected areas from the World Database on Protected Areas (http://www.protectedplanet.net) by selecting only protected areas belonging to IUCN protected area categories I to VI to focus on areas with 'formal' protection. To define the core areas for bat conservation outside already existing protected areas we used the 17 percent of terrestrial land under protection promoted by Aichi target 11 of the Convention on Biological Diversity (Convention Biological Diversity, 2010; Tittensor *et al.*, 2014; Di Minin and Toivonen, 2015). We also compared the changes in area overlap of the top 17% priority selected cells between the different scenarios and between the different scenarios and land use types in ArcMap (ESRI, 2011).

3. Results

Priority areas for the conservation of bats outside existing protected areas fell in high species richness areas close to the equator (Fig. 1, Appendix Figure B.1). There was a greater shift between present and future priority areas when future land-use change was included in the analysis (Fig. 1, Appendix Table B.1). At the 17% priority areas, the overlap between present (Fig. 1A) and future climate change with present land use (Fig. 1B) was 81%, whereas the overlap between present (Fig. 1A) with future climate change and future land use (Fig. 1C) decreased to 63% (Appendix Table B.1). Under present land use and future climate (Fig. 1B), western and eastern African countries lose conservation priority areas to central African countries, such as the Central African Republic and The Democratic Republic of Congo. When both future land use change and climate change were included in the analysis (Fig. 1C), some priority areas shifted to the southern African region, specifically Angola, Zimbabwe and Zambia.

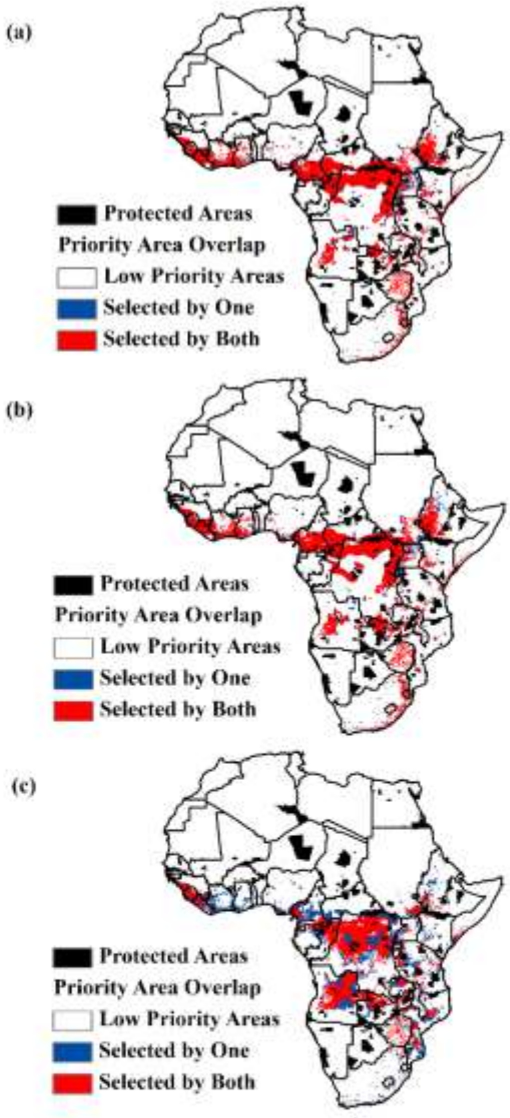

Figure 1. Overlap of spatial conservation priorities for bat conservation in Africa under (a) current climate and current optimistic and pessimistic land use scenarios; (b) future climate change and current optimistic and pessimistic land use scenarios; and (c) future climate and future optimistic and pessimistic land use scenarios. Areas within the 17% priority which were selected by both optimistic and pessimistic land use scenarios are in red and areas covered by either the optimistic or the pessimistic scenario are shown in blue. The priority rank maps for future climate change and current land use scenarios (b) and future climate and future land use scenarios (c) were averaged in a consensus scenario from four climate change scenarios for both the optimistic and the pessimistic land use scenarios.

The performance curves, which have direct correspondence to the priority rank maps, show that bat species are currently poorly represented (~ 5% on average) in existing protected areas (Fig. 2a, Appendix Table B.2). Importantly, the representation will decrease to 3% in the future because of the predicted shift in species distributions under climate change (Fig. 2b). Within the 17% top priority areas for conservation actions, the mean representation of bats was the lowest under future land use and climate change (Figs 2c, 3). At the 17% top priority areas for conservation action, there was a drop in representation of ~9% between present optimistic land use scenarios (Fig. 2a) and future climate and future pessimistic land use scenarios (Fig. 2c) for all functional bat groups.

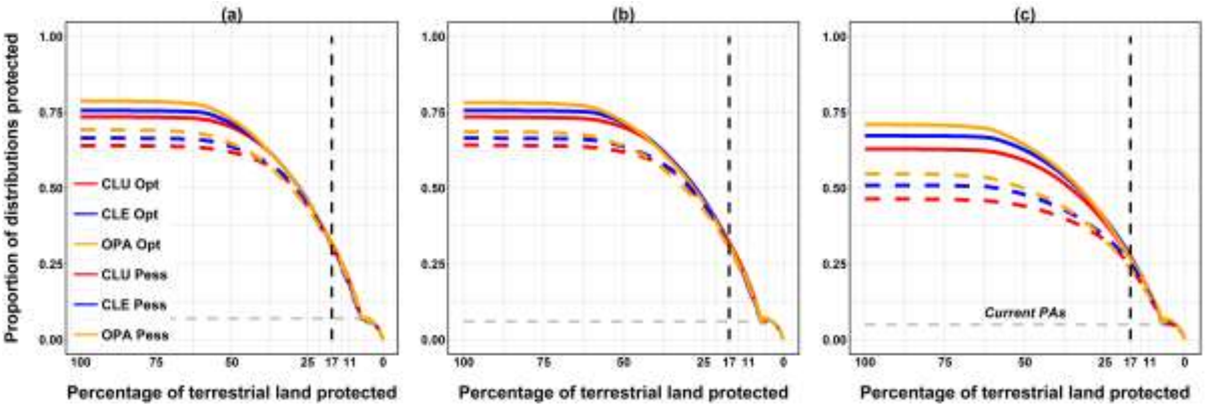

Figure 2. Performance curves, which quantify the mean proportion of the original distributions of three groups of bats in Africa at the 17% target for conservation, under (a) current climate and current optimistic and pessimistic land use scenarios; (b) future climate change and current optimistic and pessimistic land use scenarios; and (c) future climate and future optimistic and pessimistic land use scenarios. Open-air (OPA) = bats with long and narrow wings adapted for energetically efficient flight over long distances; clutter-edge (CLE) = bats with wings of intermediate length and area adapted for flight at the edges of vegetation; and clutter (CLU) = bats with short and broad wings adapted for slow manoeuvrable flight in cluttered space. Optimistic (opt) are the performance curves for optimistic land use scenarios and pessimistic (pess) are the performance curves for pessimistic land use scenarios. The horizontal dashed line in grey shows representation within current protected areas. The vertical line in black shows the 17% land target for conservation.

At the 17% top priority areas for conservation actions, the median, as well as the minimum and maximum, representations for clutter species was the lowest among the three functional groups of bats considered in the analyses (Figure 3). Particularly, the representation for clutter species was the lowest under the future land use and climate change scenarios (Figure 3). The representation for endangered species was the lowest under the future climate and future land use change scenarios (Appendix Table B.3).

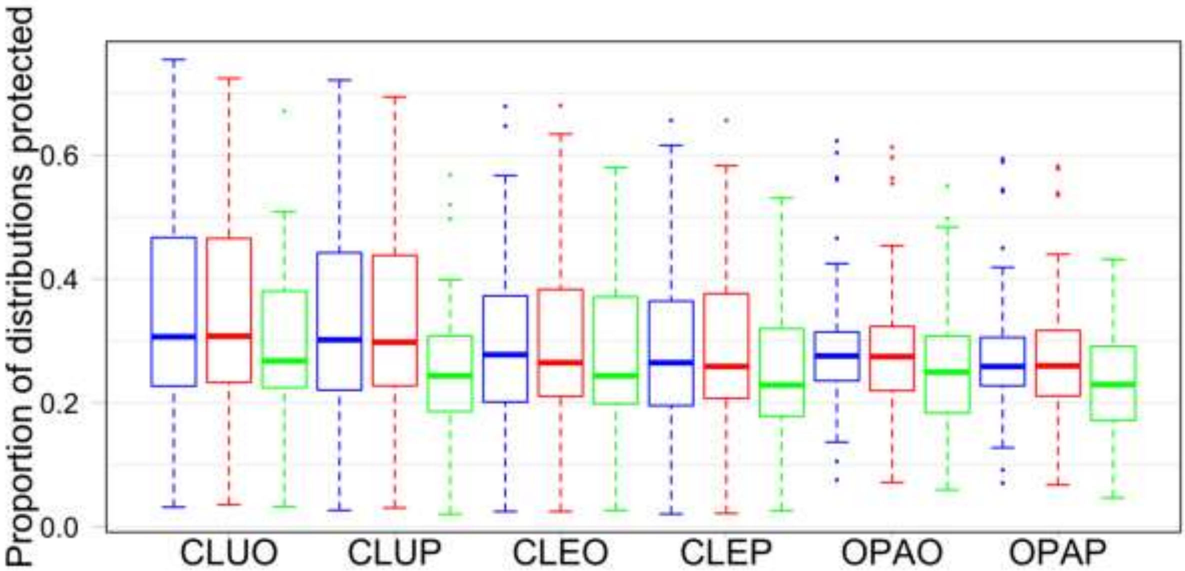

Figure 3. Box-and-whisker plot of representation levels for all bat species within the 17% target for conservation. The blue boxes represent current climate and current optimistic and pessimistic land use scenarios; red boxes represent future climate change and current optimistic and pessimistic land use scenarios; and the blue boxes represent future climate and future optimistic and pessimistic land use scenarios. CLUO stands for clutter under optimistic land use scenario, CLUP stands for clutter under pessimistic land use scenario, CLEO are clutter edge species under optimistic land use scenarios, CLEP are clutter edge species under pessimistic land use scenarios, OPAO are open air species with optimistic land use scenario and OPAP are open air species under pessimistic land use scenarios.

Finally, we found a shift in the land use classes represented within the 17% priority areas from the present to the future conditions (Table 1). Under present conditions, a large proportion of priorities were found in forested areas with low intensity agriculture. Under future land use, agricultural and natural mosaics and grasslands with low intensity agriculture will become more prevalent within the priority areas (Table 1).

Table 1. Percentage of the 17 percent priority areas within each land use type. The percentage was calculated for scenarios CCCO (current climate and current optimistic land use), CCCP (current climate and current pessimistic land use), FCCO (future climate and current optimistic land use), FCPO (future climate and current pessimistic land use), FCFO (future climate and future optimistic land use), FCFP (future climate future and future pessimistic land use)

	CCCO	CCCP	FCCO	FCCP	FCFO	FCFP
Intensive and extensive agriculture	1	1	8	7	3	1
Agriculture and natural mosaic	8	3	28	29	25	12
Forest and light use	69	74	26	28	42	55
Grassland and light use	8	8	22	21	14	13
Bare ground	14	14	14	15	15	18
Urban	0	0	1	1	0	0

4. Discussion

In this study, we identified priority areas for the conservation of bats in Africa. Our assessment for Africa is timely, as bats are a poorly monitored group and under increased threat because of overexploitation and persecution (Monadjem *et al.*, 2007). The conservation priority areas identified around the equatorial regions of Africa in this study correspond with the six central African hotspots and five of the six endemism hotspots of bat diversity in Africa (Herkt *et al.* 2016), Our results show an additional priority conservation area in central Angola near the hills and slopes on the east of the elevated Planato region to north-west Zambia and the southern tip of the Democratic Republic of Congo. Thus, similar to many other biodiversity conservation prioritization studies (see e.g. Myers *et al.*, 2000), biodiversity-rich areas are concentrated towards the tropics (Gaston, 2000; Willig *et al.*, 2003). We found that incorporating future land-use change in combination with climate change had a greater effect on changing the location of future conservation priority areas than those with present land use only (Hampe and Petit, 2005; Schmitz *et al.*, 2015). In addition, our results illustrate that future land-use change will reduce species' representation both in existing protected areas and in areas identified as priorities for conservation actions. Finally, we predict a decrease in the proportion of priority areas falling in natural forest and an increase in the proportion of priority areas falling in agricultural mosaics. This likely poses the greatest challenge for bat conservation in Africa.

Only few studies included land-use change scenarios when predicting shifts in priority areas for conservation action (see e.g. Struebig *et al.*, 2015). Many studies suggest that climate change is a stronger driver of change in species distribution than land-use change (e.g. Martin *et al.*, 2013). However, Hughes *et al.* (2012) found a more marked retraction in projected distributions in Southeast Asian bats when including future vegetation changes. Indeed, our results confirm the importance of accounting for land use change when identifying priority areas for conservation action. Our results also highlight the importance of preventing further forest loss in central Africa to enhance bat conservation (Dirizo *et al*., 2003). To better elucidate the synergistic effects of climate change and land use change, further studies should examine responses of bat species and assemblages to anthropogenic changes at finer scales (Kalda *et* al., 2015). The challenge is to link broad-scale assessments, as we did here, to finer scale land use practices (Margules and Pressey, 2000), and to integrate this information into local area conservation plans and assessments (Keith *et al.*, 2008).

Taking dispersal ability at the functional level into account, we found that clutter and clutter edge species are most influenced by future human land uses (Fig. 2), probably because both functional groups require woody vegetation structures to survive. Similarly, vulnerable species in this analysis comprised mainly clutter (3 species, *Rhinolophus ruwenzorii*, *Rhinolophus guineensis* and *Hipposideros marisae*) and clutter-edge (2 species, *Myotis bocagii* and *Mops trevori*) species, with only one open air species (*Taphozous hildegardeae*), and their representation in priority areas decreased under the future land use scenario. Although high mobility of bats enables them to utilise natural habitat patches even in human-dominated urban and agricultural landscapes (Duchamp and Swihart, 2008, Davidai *et al*. 2015), bat species exhibit high variability in dispersal abilities at the mesoscale, even within functional groups (Meyer *et al.* 2008; Taylor *et al.* 2012). Thus, our models could be markedly refined by using data on dispersal ability for individual species. Regardless, shifts in current versus future priority areas highlight the need for movement links and stepping stones between conservation priority areas at broad spatial scales across country borders (Williams *et al.*, 2005; Schmitz *et al.*, 2015). Active monitoring of bat species in all land use types could play an important role in identifying where corridors should be enhanced or preserved (Medellín *et al*., 2000).

Using target groups of indicator species to determine the status of biodiversity is an integral tool to asses and plan conservation strategies. These species should be sensitive to changes and sampled efficiently as well as yield objective results (Moreno *et al*., 2007). Bats play a number of key biological functions within ecosystems and represent an important group for biodiversity themselves (Wilson and Reeder, 2005). They also have life history traits such as low reproductive output and long life expectancy which render them effective bioindicators of the state of ecological systems, pertinently with regard to changes in climate, land use and habitat quality (Jones *et al.*, 2009; Cunto and Bernard, 2012, Heer *et al*., 2015). Presumably, bats are similarly useful bioindicators in biodiversity planning as typical surrogates such as mammals and birds (Di Minin and Moilanen, 2014; Rodriguez and Brooks, 2007; Jones *et al.* 2009). However, few studies have tested this, for example the correlation of bat responses to habitat change with those of other surrogate species (Rodriguez and Brooks, 2007). Thus, although bats may have great potential as bioindicators, other indicator taxa that exploit the landscape in similar ways should also be included in monitoring surveys (Pocock and Jennings, 2008).

In conclusion, our analyses identify priority areas for bat conservation by considering global change and accounting for connectivity using estimates of functional group dispersal. The combined effects of future land-use and climate changes will have marked effects on the distributions and thus conservation priority areas of African bats. We highlight the importance to preserve high value forest patches in central Africa. Our results show that areas where bats are likely to move following climate change might already be transformed to land uses that do not support bats. Although verified data on bat occurrence, particularly from Africa, are often lacking from open source databases (IUCN, 2015), predicting future distributional shifts in response to climate change and land use allocation, as we did here, is key to identifying priority areas for conservation actions under dynamic threats (Myers *et al.*, 2000). What is now needed are innovative conservation efforts at fine spatial scales within land use categories. These include efforts to stop habitat clearing, mitigate threats such as culling and utilisation of bats as bushmeat, and encourage maintenance or rehabilitation of natural vegetation to enhance connectivity (Voigt and Kingston, 2016). To increase the awareness of bats to urban planners we suggest routinely including bats in ecosystem service assessments (Kunz *et al.*, 2011). Some bat species may do well inside of transformed landscapes for example urban exploiters and adapters (Jung and Kalko 2011, Schoeman 2015, Jung and Threllfall 2016). In the African context, conservation strategies in priority areas that include human development are key (Lele *et al*., 2010). These strategies could, for example, involve community based education initiatives that focus on ecosystem services provided by bats (e.g. Lele *et al*., 2010; Boyles *et al*. 2011).

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6. References

Barbet-Massin, M., Thuiller, W. & Jiguet, F. (2011) The fate of European breeding birds under climate, land-use and dispersal scenarios. Global Change Biology, 18, 881–890.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. (2012) Impacts of climate change on the future of biodiversity. *Ecology Letters*, **15**, 365-377.

Best, T.L., Geluso, K.N. & Ammerman, L.K. (2003) Summer foraging range of Mexican free-tailed bats (*Tadarida brasiliensis mexicana*) from Carlsbad Cavern, New Mexico. *The Southwestern Naturalist*, **48**, 590-596.

Brook, B.W., Sodhi, N.S. & Bradshaw, C.J. (2008) Synergies among extinction drivers under global change. *Trends in ecology & evolution*, **23**, 453-460.

Boyles, J.G., Cryan, P.M., McCracken, G.F. & Kunz, T.H. (2011) Economic importance of bats in agriculture. *Science*, **332**, 41-42.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.-C. & Watson, R. (2010a) Global Biodiversity: Indicators of Recent Declines. *Science*, **328**, 1164-1168.

Butchart, S.H.M. & Bird, J.P. (2010b) Data Deficient birds on the IUCN Red List: What don't we know and why does it matter? *Biological Conservation*, **143**, 239-247.

Carroll, C., Dunk, J.R. & Moilanen, A. (2010) Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA. *Global Change Biology*, **16**, 891-904.

Clarke, L., Edmonds, J., Jacoby, H., Pitcher, H., Reilly, J. & Richels, R. (2007) Scenarios of greenhouse gas emissions and atmospheric concentrations. *US Department of Energy Publications*, 6.

Cord, A.F., Klein, D., Mora, F. & Dech, S. (2014) Comparing the suitability of classified land cover data and remote sensing variables for modeling distribution patterns of plants. *Ecological Modelling*, **272**, 129-140.

Convention Biological Diversity, 2010. Aichi biodiversity targets of the strategic plan 2011-2020. http://www.cbd.int/sp/targets/

Cunto, G.C. & Bernard, E. (2012) Neotropical bats as indicators of environmental disturbance: What is the emerging message? *Acta Chiropterologica*, **14**, 143-151.

Davidai, N., Westbrook, J.K., Lessard, J.-P., Hallam, T.G. & McCracken, G.F. (2015) The importance of natural habitats to Brazilian free-tailed bats in intensive agricultural landscapes in the Winter Garden region of Texas, United States. *Biological Conservation*, **190**, 107-114.

De Vos, J. M., Joppa, L. N., Gitleman, J. L., Stephens, P. R., Pimm, S. L. (2014). Estimating the normal background rate of species extinction. *Conservation Biology*. **29,** 452–462

Di Minin, E., Veach, V., Lehtomäki, J., Montesino-Pouzols, F. & Moilanen, A. (2014) *A quick introduction to Zonation*. University of Helsinki.

Di Minin, E., Slotow, R., Hunter, L.T.B., Montesino Pouzols, F., Toivonen, T., Verburg, P.H., Leader-Williams, N., Petracca, L., Moilanen, A., 2016. Global priorities for national carnivore conservation under land use change. Sci. Rep. 6, 23814.

Di Minin, E. & Moilanen, A. (2014) Improving the surrogacy effectiveness of charismatic megafauna with well-surveyed taxonomic groups and habitat types. *Journal of Applied Ecology*, **51**, 281-288.

Di Minin, E. & Toivonen, T. (2015) Global Protected Area Expansion: Creating More than Paper Parks. *BioScience*, biv064.

Dirzo, R. & Raven, P.H. (2003) Global state of biodiversity and loss. *Annual Review of Environment and Resources*, **28**, 137-167.

Diamond, J.M. (1984) Historic extinctions: a rosetta stone for understanding prehistoric extinctions. *Quaternary extinctions: a prehistoric revolution.* (ed. by P.S. Martin and R.G. Klein), pp. 824-862. Tucson, University of Arizona Press.

Duchamp, J.E. & Swihart, R.K. (2008) Shifts in bat community structure related to evolved traits and features of human-altered landscapes. *Landscape Ecology*, **23**, 849-860.

Elith, J., Graham, C.H., Anderson, R.P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Jin, L., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. Overton, J., Peterson, A.T. & Phillips, S.J. (2006) Novel methods improve prediction of species distributions from occurrence data. *Ecography*, **29**, 129-151.

ESRI (2011), ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Fenton, M. (1983) Roosts used by the African bat, *Scotophilus leucogaster* (Chiroptera: Vespertilionidae). *Biotropica*, **15**, 129-132.

Fenton, M., Brigham, R., Mills, A. & Rautenbach, I. (1985) The roosting and foraging areas of *Epomophorus wahlbergi* (Pteropodidae) and *Scotophilus viridis* (Vespertilionidae) in Kruger national park, South Africa. *Journal of Mammalogy*, **66**, 461-468.

Fujino, J., Nair, R., Kainuma, M., Masui, T. & Matsuoka, Y. (2006) Multi-gas mitigation analysis on stabilization scenarios using AIM global model. Multigas Mitigation and Climate Policy. *The Energy Journal*, **Special Issue**

Garcia, R.A., Burgess, N.D., Cabeza, M., Rahbek, C. & Araújo, M.B. (2012) Exploring consensus in 21st century projections of climatically suitable areas for African vertebrates. *Global Change Biology*, **18**, 1253-1269.

Gaston, K.J. (2000) Global patterns in biodiversity. *Nature*, **405**, 220-227.

Hampe, A. & Petit, R.J. (2005) Conserving biodiversity under climate change: the rear edge matters. *Ecology Letters*, **8**, 461-467.

Hannah, L., Carr, J.L. & Lankerani, A. (1995) Human disturbance and natural habitat: a biome level analysis of a global data set. *Biodiversity & Conservation*, **4**, 128-155.

Hastie, T., Tibshirani, R., Friedman, J. & Franklin, J. (2005) The elements of statistical learning: data mining, inference and prediction. *The Mathematical Intelligencer*, **27**, 83-85.

Heer, K., Helbig-Bonitz, M., Fernandes, R.G., Mello, M.A. & Kalko, E.K. (2015) Effects of land use on bat diversity in a complex plantation-forest landscape in northeastern Brazil. *Journal of Mammalogy*, gyv068.

Herkt, K.M.B., Barnikel, G., Skidmore, A.K. & Fahr, J. (2016) A high-resolution model of bat diversity and endemism for continental Africa. *Ecological Modelling*, **320**, 9-28.

Hijioka, Y., Matsuoka, Y., Nishimoto, H., Masui, M. & Kainuma, M. (2008) Global GHG emissions scenarios under GHG concentration stabilization targets. *Journal of Global Environmental Engineering*, 97-108.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology **25**: 1965-1978.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T.M., Butchart, S.H., Carpenter, K.E., Chanson, J., Collen, B. & Cox, N.A. (2010) The impact of conservation on the status of the world's vertebrates. *science*, **330**, 1503-1509.

Hughes, A.C., Satasook, C., Bates, P.J.J., Bumrungsri, S. & Jones, G. (2012) The projected effects of climatic and vegetation changes on the distribution and diversity of Southeast Asian bats. *Global Change Biology*, **18**, 1854-1865.

IUCN. *The IUCN Red List of Threatened Species. Version 2014.2.* (2014). Available at: http://www.iucnredlist.org

IUCN 2015. *The IUCN Red List of Threatened Species. Version 2015-3.* <http://www.iucnredlist.org>. Downloaded on 13 September 2015.

Jacobs, D.S., Barclay, R.M. & Schoeman, M.C. (2005) Foraging and roosting ecology of a rare insectivorous bat species, *Laephotis wintoni* (Thomas, 1901), Vespertilionidae. *Acta Chiropterologica*, **7**, 101-109.

Jones, G., Jacobs, D.S., Kunz, T.H., Willig, M.R. & Racey, P.A. (2009) Carpe noctem: the importance of bats as bioindicators. *Endangered Species Research*, **8**, 93–115.

Jung, K. & Kalko, E.K. (2011) Adaptability and vulnerability of high flying Neotropical aerial insectivorous bats to urbanization. *Diversity and Distributions*, **17**, 262-274.

Jung, K. & Threlfall, C.G. (2016) Urbanisation and Its Effects on Bats—A GlobalUrbanisation and Its Effects on Bats—A Global Meta-Analysis. *Bats in the Anthropocene: Conservation of Bats in a Changing World*, pp. 13-33. Springer.

Kalda, O., Kalda, R. & Liira, J. (2015) Multi-scale ecology of insectivorous bats in agricultural landscapes. *Agriculture, Ecosystems & Environment*, **199**, 105-113.

Kalka, M.B., Smith, A.R. & Kalko, E.K. (2008) Bats limit arthropods and herbivory in a tropical forest. *Science*, **320**, 71-71.

Keith, D.A., Akçakaya, H.R., Thuiller, W., Midgley, G.F., Pearson, R.G., Phillips, S.J., Regan, H.M., Araújo, M.B. & Rebelo, T.G. (2008) Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models. *Biology Letters*, **4**, 560-563.

Kram, T. & Stehfest, E. (2012) The IMAGE model suite used for the OECD Environmental Outlook to 2050. *PBL Netherlands Environmental Assessment Agency report,* **500113002**

Krauss, J., Bommarco, R., Guardiola, M., Heikkinen, R.K., Helm, A., Kuussaari, M., Lindborg, R., Öckinger, E., Pärtel, M., Pino, J., Pöyry, J., Raatikainen, K.M., Sang, A., Stefanescu, C., Teder, T., Zobel, M. & Steffan-Dewenter, I. (2010) Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. *Ecology Letters,* **13**, 597-605.

Kujala, H., Moilanen, A., Araújo, M.B. & Cabeza, M. (2013) Conservation planning with uncertain climate change projections. *PloS One,* **8**, e53315.

Kunz, T.H., Braun de Torrez, E., Bauer, D., Lobova, T. & Fleming, T.H. (2011) Ecosystem services provided by bats. *Annals of the New York Academy of Sciences,* **1223**, 1-38.

Latimer, A.M., Wu, S., Gelfand, A.E. & Silander Jr, J.A. (2006) Building statistical models to analyze species distributions. *Ecological Applications*, **16**, 33-50.

Lehtomäki, J. & Moilanen, A. (2013) Methods and workflow for spatial conservation prioritization using Zonation. *Environmental Modelling & Software,* **47**, 128-137.

Lele, S., Wilshusen, P., Brockington, D., Seidler, R. & Bawa, K. (2010) Beyond exclusion: alternative approaches to biodiversity conservation in the developing tropics. *Current Opinion in Environmental Sustainability*, **2**, 94-100.

Margules, C.R. & Pressey, R.L. (2000) Systematic conservation planning. *Nature*, **405**, 243-253.

Martin, Y., Van Dyck, H., Dendoncker, N. & Titeux, N. (2013) Testing instead of assuming the importance of land-use change scenarios to model species distributions under climate change. *Global Ecology and Biogeography*, **22**, 1204-1216.

Medellín, R.A., Equihua, M. & Amin, M.A. (2000) Bat diversity and abundance as indicators of disturbance in Neotropical rainforests. *Conservation Biology*, **14**, 1666-1675.

Mehra, M., Brandl, R., Hothorn, T., Dziock, F., Förster, B. & Müller, J. (2011) Land use is more important than climate for species richness and composition of bat assemblages on a regional scale. *Mammalian Biology*, **76**, 451–460.

Moilanen, A., Franco, A.M., Early, R.I., Fox, R., Wintle, B. & Thomas, C.D. (2005) Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proceedings of the Royal Society of London B: Biological Sciences*, **272**, 1885-1891.

Moilanen, A. (2007) Landscape zonation, benefit functions and target-based planning: unifying reserve selection strategies. *Biological Conservation*, **134**, 571-579.

Moilanen, A., Wilson, K.A. & Possingham, H.P. (2009) *Spatial conservation prioritization: quantitative methods and computational tools*. Oxford University Press Oxford, UK.

Moilanen, A., Anderson, B.J., Eigenbrod, F., Heinemeyer, A., Roy, D.B., Gillings, S., Armsworth, P.R., Gaston, K.J. & Thomas, C.D. (2011) Balancing alternative land uses in conservation prioritization. *Ecological Applications*, **21**, 1419-1426.

Moilanen, A., Meller, L., Arponen, A., Kujala, H. & Kukkala, A. (2014) *Zonation spatial conservation planning framework and software v. 4.0, User Manual*.

Moilanen, A., Anderson, B.J., Eigenbrod, F., Heinemeyer, A., Roy, D.B., Gillings, S., Armsworth, P.R., Gaston, K.J. & Thomas, C.D. (2011) Balancing alternative land uses in conservation prioritization. *Ecological Applications*, **21**, 1419-1426.

Montesino Pouzols, F., Toivonen, T., Di Minin, E., Kukkala, A., Kullberg, P., Kuusterä, J., Lehtomäki, J., Tenkanen, H., Verburg, P.H., Moilanen, A., 2014. Global protected area expansion is compromised by projected land-use and parochialism. *Nature* 516, 383–386.

Moreno, C.E., Sánchez-Rojas, G., Pineda, E. & Escobar, F. (2007) Shortcuts for biodiversity evaluation: a review of terminology and recommendations for the use of target groups, bioindicators and surrogates. *International Journal of Environment and Health*, **1**, 71-86.

Monadjem, A., Taylor, P., Cotteri, F., Kityo, R. & Fahr, J. (2007) Conservation status of bats in sub-Saharan Africa. *Bat Research News*, **48**, 267.

Meyer, C.F.J., Fründ, J., Lizano, W.P. & Kalko, E.K.V. (2008). Ecological correlates of vulnerability to fragmen- tation in Neotropical bats. J *Journal of Applied Ecology*, **45**, 381–391

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853-858.

OECD (2012) OECD environmental outlook to 2050: the consequences of inaction. In, Paris.

Pereira, H.M., Leadley, P.W., Proença, V., Alkemade, R., Scharlemann, J.P., Fernandez-Manjarrés, J.F., Araújo, M.B., Balvanera, P., Biggs, R. & Cheung, W.W. (2010) Scenarios for global biodiversity in the 21st century. *Science*, **330**, 1496-1501.

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, **190**, 231–259.

Phillips, S.J. & Dudík, M. (2008) Modeling of species distributions with Maxent : new extensions and a comprehensive evaluation. *Ecography*, **31**, 161-175.

Pocock, M.J.O. & Jennings, N. (2008) Testing biotic indicator taxa: the sensitivity of insectivorous mammals and their prey to the intensification of lowland agriculture. *Journal of Applied Ecology*, 45, 151 – 160

Radosavljevic, A. & Anderson, R.P. (2014) Making better Maxent models of species distributions: complexity, overfitting and evaluation. *Journal of Biogeography*, **41**, 629-643.

Rebelo, H., Tarroso, P. & Jones, G. (2010) Predicted impact of climate change on European bats in relation to their biogeographic patterns. *Global Change Biology*, **16**, 561-576.

Renner, I.W. & Warton, D.I. (2013) Equivalence of MAXENT and Poisson point process models for species distribution modeling in ecology. *Biometrics*, **69**, 274-281.

Riahi, K., Grübler, A. & Nakicenovic, N. (2007) Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological Forecasting and Social Change*, **74**, 887-935.

Rodrigues, A.S.L. & Brooks, T.M. (2007) Shortcuts for biodiversity conservation planning: the effectiveness of surrogates. Annual Review of Ecology, Evolution, and Systematics, **38**, 713–737.

Sazima, I., Vogel, S. & Sazima, M. (1989) Bat pollination ofEncholirium glaziovii, a terrestrial bromeliad. *Plant Systematics and Evolution*, **168**, 167-179.

Schmitz, O.J., Lawler, J.J., Beier, P., Groves, C., Knight, G., Boyce Jr, D.A., Bulluck, J., Johnston, K.M., Klein, M.L. & Muller, K. (2015) Conserving biodiversity: Practical guidance about climate change adaptation approaches in support of land-use planning. *Natural Areas Journal*, **35**, 190-203.

Schoeman, M.C., Cotterill, F., Taylor, P.J. & Monadjem, A. (2013). Using potential distributions to explore environmental correlates of bat species richness in southern Africa: effects of model selection and taxonomy. *Curr. Zool.* **59**, 279–293.

Schoeman, M,C. (2015) Light pollution at stadiums favors urban exploiter bats. *Animal Conservation*,

Schnitzler, H.-U. & Kalko, E.K.V. (2001) Echolocation by Insect-Eating Bats. *BioScience*, **51**, 557-569.

Scott, S.J., McLaren, G., Jones, G. & Harris, S. (2010) The impact of riparian habitat quality on the foraging and activity of pipistrelle bats (*Pipistrellus spp*.). *Journal of Zoology*, **280**, 71–378.

Shilton, L.A., Altringham, J.D., Compton, S.G. & Whittaker, R.J. (1999) Old World fruit bats can be long–distance seed dispersers through extended retention of viable seeds in the gut. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, **266**, 219-223.

Smith, S.J. & Wigley, T.M.L. (2006) Multi-Gas Forcing Stabilization with the MiniCAM. *Energy Journal*, **3**, 373-391.

Struebig, M.J., Wilting, A., Gaveau, D.L., Meijaard, E., Smith, R.J., Fischer, M., Metcalfe, K., Kramer-Schadt, S. & Consortium, B.M.D. (2015) Targeted Conservation to Safeguard a Biodiversity Hotspot from Climate and Land-Cover Change. *Current Biology*, **25,** 372-378

Taylor, G.K., Carruthers, A.C., Hubel, T.Y. & Walker, S.M. (2012) Wing morphing in insects, birds and bats: mechanism and function. *Morphing Aerospace vehicles and structures*, 11-40.

Thuiller, W., Lafourcade, B., Engler, R. & Araújo, M.B. (2009) BIOMOD–a platform for ensemble forecasting of species distributions. *Ecography*, **32**, 369-373.

Tittensor, D.P., Walpole, M., Hill, S.L., Boyce, D.G., Britten, G.L., Burgess, N.D., Butchart, S.H., Leadley, P.W., Regan, E.C. & Alkemade, R. (2014) A mid-term analysis of progress toward international biodiversity targets. *Science*, **346**, 241-244.

van Asselen, S. & Verburg, P.H. (2013) Land cover change or land-use intensification: simulating land system change with a global-scale land change model. *Global Change Biology*, **19**, 3648-3667.

Verburg, P.H., van Asselen, S., van der Zanden, E.H. & Stehfest, E. (2013) The representation of landscapes in global scale assessments of environmental change. *Landscape Ecology*, **28**, 1067-1080.

Van Vuuren, D.P., Den Elzen, M.G., Lucas, P.L., Eickhout, B., Strengers, B.J., van Ruijven, B., Wonink, S. & van Houdt, R. (2007) Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Climatic Change*, **81**, 119-159.

Voigt, C.C. & Kingston, T. (2016) Bats in the Anthropocene: conservation of bats in a changing world. In. Springer

Williams, P., Hannah, L., Andelman, S., Midgley, G., AraúJo, M., Hughes, G., Manne, L., Martinez-Meyer, E. & Pearson, R. (2005) Planning for Climate Change: Identifying Minimum-Dispersal Corridors for the Cape Proteaceae. *Conservation Biology*, **19**, 1063-1074.

Willig, M.R., Kaufman, D.M. & Stevens, R.D. (2003) Latitudinal gradients of biodiversity: pattern, process, scale, and synthesis. *Annual Review of Ecology, Evolution, and Systematics*, **34,** 273-309.

Wilson, D.E. & Reeder, D.M. (2005) *Mammal species of the world: a taxonomic and geographic reference*. JHU Press.

Wise, M., Calvin, K., Thomson, A., Clarke, L., Bond-Lamberty, B., Sands, R., Smith, S.J., Janetos, A. & Edmonds, J. (2009) Implications of limiting CO2 concentrations for land use and energy. *science*, **324**, 1183-1186.

Appendix A

Supplementary Methods

Table A.1 List of species used in the analyses Records from southern Africa: Schoeman et al. 2013. Records from East Africa: Swynnerton and Hayman (1951); Aellen (1957); Hayman and Hill (1966); Verschuren (1967); Niort (1970); Anciaux de Faveaux (1972); Verschuren (1980); Kock (1981); Aggundey and Schlitter (1984); Schlitter and Aggundey (1986); Baeten et al. (1984); Kock and Howell (1988); Montfort (1992); Heller el al. (1994); Fahr et al. (2002); Stanley and Kock (2004); Stanley et al. (2005a); Stanley et al. (2005b); Stanley et al. (2005c); Stanley et al. (1996); Thorn et al. (2007); Bergmans (1997); Rovero et al. (2007); Stanley and Foley (2008); Stanley (2009); Kock and Stanley (2009); Kock et al. (2000); Thorn and Kerbis Peterhans (2009); and a visit to the Mammal Department, National Museums of Kenya, Nairobi (by AM). Records from the Horn of Africa: Funaioli and Lanza (1968); Kock (1969); Largen et al. (1974); Hill (1975); Koopman (1975); McLellan (1986); Hill et al. (1988); Kock and Howell (1988); Varty and Hill (1988); Duckworth et al. (1993); Yalden et al. (1996); Kruskop and Lavrenchenko (2000); Kruskop and Lavrenchenko (2006); Pearch et al. (2001); Fenton and Eger (2002); Benda et al. (2004); Lavrenchenko et al. (2004); and Bergmans (1988). Records from Central Africa: Hayman et al. (1966); Aellen (1952); Lunde and Beresford (1997); van Cakenberghe et al. (1999); Cotterill (2001); Eger and Schlitter (2001); Eisentraut (1956); Hill (1968); Hutterer and Joger (1982); Hutterer et al. (1992); Monadjem and Fahr (2007); Peterson and Smith (1973); Seamark and van Cakenberghe (2012); Thorn et al. (2007); Vielliard (1974); Hill (1983); Bergmans (1989); Bergmans (1990); Lunde et al. (2001); Schlitter et al. (1982); Dorst (1963); Aellen and Brosset (1968); Bergmans (1988); Brosset (1966a); Dowsett et al. (1991); Allen (1917); Ansell (1974); Bergmans (1997); Bergmans (1989); Fahr and Ebigbo (2003); Fahr et al. (2002); Gallagher and Harrison (1977); Harrison (1975); Heller et al. (1994); Kearney and Seamark (2005); Kock and Howell (1988); Schouteden (1947); van Cakenberghe and de Vree (1985); Verschuren (1967); Jones (1971); Brosset (1966b); Csorba et al. (2003); and Malbrant and Maclatchy (1949). Records from West Africa: Robbins (1980); Green (1983); Koch-Weser (1984); Koopman et al. (1978); Kock (1969); Seamark and van Cakenberghe (2012); Decher and Fahr (2007); Grubb et al. (1998); Aellen (1956); Aellen (1963); Bergmans (1989); Eisentraut and Knorr (1957); Fahr and Ebigbo (2003); Fahr et al. (2002); Fahr et al. (2006); Konstantinov et al. (2000); Kock (1969); Lopes and Crawford-Cabral (1992); Monard (1939); Bergmans et al. (1974); Cotterill (2001a); Cotterill (2001b); de Vree (1971); Fahr and Kalko (2011); Lim and Van Coeverden De Groot (1997); Coe (1975); Hill (1982); Koopman (1989); Koopman et al. (1995); Monadjem et al. (2013);

Monadjem et al. (In Press); Denys et al. (2013); Kuhn (1965); Monadjem and Fahr (2007); Monadjem (2011); Verschuren (1977); Wolton et al. (1982); Koopman (1975); Meining (2000); Sidiyene and Tranier (1990); Qumsiyeh and Schlitter (1981); Fairion (1980); Kock (1978); Poche (1975); Happold (1987); Hill et al. (1988); Adam and Hubert (1972); Adam and Hubert (1976); Adam et al. (1993); Bohme and Hutterer (1979); Poulet (1972); Decher et al. (2010); Weber and Fahr (2009); and Kock et al. (2002).

Species	**Functional Group**	**Conservation Status**	**No. Records**
Asellia tridens	Clutter	Least concern	26
Cardioderma cor	Clutter	Least concern	84
Casinycteris argynnis	Clutter	Least concern	11
Chaerephon aloysiisabaudiae	Open air	Least concern	9
Chaerephon ansorgei	Open air	Least concern	65
Chaerephon bemmeleni	Open air	Least concern	15
Chaerephon bivittatus	Open air	Least concern	51
Chaerephon chapini	Open air	Least concern	24
Chaerephon major	Open air	Least concern	46
Chaerephon nigeriae	Open air	Least concern	73
Chaerephon pumilus	Open air	Least concern	538
Cistugo lesueuri	Clutter edge	Least concern	19
Cistugo seabrae	Clutter edge	Least concern	14
Cloeotis percivali	Clutter	Least concern	36
Coleura afra	Open air	Least concern	66
Eidolon helvum	Clutter	Near threatened	333
Epomophorus angolensis	Clutter	Near threatened	21
Epomophorus crypturus	Clutter	Least concern	127
Epomophorus gambianus	Clutter	Least concern	176
Epomophorus labiatus	Clutter	Least concern	199
Epomophorus minimus	Clutter	Least concern	59
Epomophorus wahlbergi	Clutter	Least concern	249
Epomops buettikoferi	Clutter	Least concern	65
Epomops dobsonii	Clutter	Least concern	34
Epomops franqueti	Clutter	Least concern	174
Eptesicus floweri	Clutter edge	Least concern	8
Eptesicus hottentotus	Clutter edge	Least concern	51
Glauconycteris alboguttata	Clutter edge	Least concern	5
Glauconycteris argentata	Clutter edge	Least concern	38
Glauconycteris beatrix	Clutter edge	Least concern	16
Glauconycteris humeralis	Clutter edge	Data deficient	9
Glauconycteris poensis	Clutter edge	Least concern	34
Glauconycteris variegata	Clutter edge	Least concern	82

Hipposideros abae	Clutter	Least concern	42
Hipposideros beatus	Clutter	Least concern	53
Hipposideros caffer	Clutter	Least concern	540
Hipposideros cyclops	Clutter	Least concern	110
Hipposideros fuliginosus	Clutter	Least concern	30
Hipposideros gigas	Clutter	Least concern	74
Hipposideros jonesi	Clutter	Near threatened	25
Hipposideros marisae	Clutter	Vulnerable	8
Hipposideros megalotis	Clutter	Least concern	14
Hipposideros ruber	Clutter	Least concern	270
Hipposideros vittatus	Clutter	Near threatened	104
Hypsignathus monstrosus	Clutter	Least concern	146
Hypsugo anchietae	Clutter edge	Least concern	51
Hypsugo bellieri	Clutter edge	Least concern	7
Hypsugo crassulus	Clutter edge	Least concern	12
Hypsugo eisentrauti	Clutter edge	Data deficient	6
Hypsugo musciculus	Clutter edge	Data deficient	12
Kerivoula argentata	Clutter	Least concern	35
Kerivoula cuprosa	Clutter	Data deficient	5
Kerivoula lanosa	Clutter	Least concern	54
Kerivoula phalaena	Clutter	Least concern	13
Kerivoula smithii	Clutter	Least concern	15
Laephotis angolensis	Clutter edge	Data deficient	5
Laephotis botswanae	Clutter edge	Least concern	30
Laephotis namibensis	Clutter edge	Least concern	6
Laephotis wintoni	Clutter edge	Least concern	10
Lavia frons	Clutter	Least concern	254
Lissonycteris angolensis	Clutter	Least concern	174
Megaloglossus woermanni	Clutter	Least concern	105
Micropteropus pusillus	Clutter	Least concern	240
Mimetillus moloneyi	Clutter edge	Least concern	66
Mimetillus thomasi	Clutter edge	Not evaluated	11
Miniopterus fraterculus	Clutter edge	Least concern	26
Miniopterus inflatus	Clutter edge	Least concern	60
Miniopterus minor	Clutter edge	Data deficient	10
Miniopterus natalensis	Clutter edge	Least concern	313
Miniopterus villiersi	Clutter edge	Not evaluated	25
Mops brachypterus	Open air	Least concern	5
Mops condylurus	Open air	Least concern	279
Mops demonstrator	Open air	Not evaluated	25
Mops leonis	Open air	Least concern	29
Mops midas	Open air	Least concern	66
Mops nanulus	Open air	Least concern	32
Mops niveiventer	Open air	Least concern	32

Mops spurrelli	Open air	Least concern	24
Mops thersites	Open air	Data deficient	40
Mops trevori	Clutter edge	Vulnerable	10
Myonycteris relicta	Clutter edge	Least concern	5
Myonycteris torquata	Open air	Data deficient	78
Myopterus daubentonii	Open air	Least concern	7
Myopterus whitleyi	Clutter edge	Least concern	15
Myotis bocagii	Clutter edge	Vulnerable	127
Myotis scotti	Clutter edge	Least concern	9
Myotis tricolor	Clutter edge	Least concern	85
Myotis welwitschii	Clutter	Least concern	53
Nanonycteris veldkampii	Clutter edge	Near threatened	59
Neoromicia brunnea	Clutter edge	Least concern	15
Neoromicia capensis	Clutter edge	Data deficient	504
Neoromicia cf. melckorum	Clutter edge	Least concern	13
Neoromicia guineensis	Clutter edge	Data deficient	31
Neoromicia helios	Clutter edge	Least concern	15
Neoromicia nana	Clutter edge	Not evaluated	604
Neoromicia pusillus	Clutter edge	Least concern	5
Neoromicia rendalli	Clutter edge	Least concern	69
Neoromicia somalica	Clutter edge	Least concern	68
Neoromicia tenuipinnis	Clutter edge	Least concern	119
Neoromicia airuluensis	Clutter	Least concern	96
Nycteris arge	Clutter	Least concern	100
Nycteris aurita	Clutter	Least concern	21
Nycteris gambiensis	Clutter	Least concern	57
Nycteris grandis	Clutter	Least concern	88
Nycteris hispida	Clutter	Least concern	350
Nycteris intermedia	Clutter	Least concern	18
Nycteris macrotis	Clutter	Data deficient	234
Nycteris major	Clutter	Least concern	8
Nycteris nana	Clutter	Least concern	47
Nycteris thebaica	Clutter	Least concern	593
Nycteris woodi	Clutter edge	Least concern	27
Nycticeinops schlieffeni	Open air	Near threatened	243
Otomops martiensseni	Clutter edge	Data deficient	43
Pipistrellus aero	Clutter edge	Not evaluated	6
Pipistrellus grandidieri	Clutter edge	Not evaluated	26
Pipistrellus hesperidus	Clutter edge	Least concern	123
Pipistrellus inexspectatus	Clutter edge	Data deficient	7
Pipistrellus nanulus	Clutter edge	Least concern	41
Pipistrellus rueppellii	Clutter edge	Least concern	98
Pipistrellus rusticus	Clutter edge	Least concern	75
Platymops setiger	Open air	Least concern	19

Plerotes anchietae	Clutter	Data deficient	10
Rhinolophus alcyone	Clutter	Least concern	36
Rhinolophus blasii	Clutter	Least concern	61
Rhinolophus capensis	Clutter	Least concern	27
Rhinolophus clivosus	Clutter	Least concern	283
Rhinolophus darlingi	Clutter	Least concern	151
Rhinolophus deckenii	Clutter	Near threatened	12
Rhinolophus denti	Clutter	Least concern	31
Rhinolophus eloquens	Clutter	Least concern	48
Rhinolophus fumigatus	Clutter	Least concern	190
Rhinolophus guineensis	Clutter	Vulnerable	23
Rhinolophus hildebrandtii	Clutter	Least concern	214
Rhinolophus hillorum	Clutter	Near threatened	11
Rhinolophus hipposideros	Clutter	Least concern	5
Rhinolophus landeri	Clutter	Least concern	189
Rhinolophus maclaudi	Clutter	Endangered	8
Rhinolophus ruwenzorii	Clutter	Vulnerable	11
Rhinolophus simulator	Clutter	Least concern	120
Rhinolophus swinnyi	Clutter	Least concern	62
Rhinopoma cystops	Clutter	Least concern	20
Rhinopoma macinnesi	Open air	Data deficient	10
Rhinopoma microphyllum	Open air	Least concern	11
Rousettus aegyptiacus	Clutter	Least concern	245
Rousettus lanosus	Clutter	Least concern	45
Saccolaimus peli	Open air	Least concern	57
Sauromys petrophilus	Open air	Least concern	69
Scotoecus albofuscus	Clutter edge	Data deficient	17
Scotoecus hindei	Clutter edge	Least concern	54
Scotoecus hirundo	Clutter edge	Least concern	26
Scotonycteris ophiodon	Clutter	Near threatened	10
Scotonycteris zenkeri	Clutter	Least concern	44
Scotophilus damarensis	Clutter edge	Least concern	48
Scotophilus dinganii	Clutter edge	Least concern	464
Scotophilus leucogaster	Clutter edge	Least concern	96
Scotophilus nigrita	Clutter edge	Least concern	23
Scotophilus nucella	Clutter edge	Data deficient	5
Scotophilus nux	Clutter edge	Least concern	20
Scotophilus viridis	Clutter edge	Least concern	102
Tadarida aegyptiaca	Open air	Least concern	214
Tadarida fulminans	Open air	Least concern	33
Tadarida lobata	Open air	Least concern	9
Tadarida ventralis	Open air	Data deficient	20
Taphozous hamiltoni	Open air	Data deficient	11
Taphozous hildegardeae	Open air	Vulnerable	12
Taphozous mauritianus	Open air	Least concern	245

Taphozous nudiventris	Open air	Least concern	37
Taphozous perforatus	Open air	Least concern	79
Triaenops afer	Clutter edge	Least concern	50

Table A.2 AUC values indicate the discriminatory value of the models to predict the likelihood of a presence point being higher than the likelihood of a pseudo-absence point. The area under the curve (AUC) values for each climate change model used in the study. The climate change scenarios used were the current scenario, RCP2.6 (p26bi50), RCP4.5 (ip45bi50), RPC6.0 (ip60bi50), RPC8.5 (ip85bi50). Only models with values equal or higher than 0.7 were used in the study.

Species	AUC Current	AUC ip26bi50	AUC ip45bi50	AUC ip60bi50	AUC ip85bi50
Asellia tridens	0.86	0.86	0.86	0.86	0.86
Cardioderma cor	0.93	0.93	0.93	0.93	0.93
Casinycteris argynnis	0.96	0.96	0.96	0.96	0.96
Chaerephon aloysiisabaudiae	0.88	0.88	0.88	0.88	0.88
Chaerephon ansorgei	0.86	0.86	0.86	0.86	0.86
Chaerephon bemmeleni	0.89	0.89	0.89	0.89	0.89
Chaerephon bivittatus	0.88	0.88	0.88	0.88	0.88
Chaerephon chapini	0.82	0.82	0.82	0.82	0.82
Chaerephon major	0.87	0.87	0.87	0.87	0.87
Chaerephon nigeriae	0.85	0.85	0.85	0.85	0.85
Chaerephon pumilus	0.84	0.84	0.84	0.84	0.84
Cistugo lesueuri	0.99	0.99	0.99	0.99	0.99
Cistugo seabrae	0.95	0.95	0.95	0.95	0.95
Cloeotis percivali	0.93	0.93	0.93	0.93	0.93
Coleura afra	0.88	0.88	0.88	0.88	0.88
Eidolon helvum	0.80	0.80	0.80	0.80	0.80
Epomophorus angolensis	0.96	0.96	0.96	0.96	0.96
Epomophorus crypturus	0.94	0.94	0.94	0.94	0.94
Epomophorus gambianus	0.88	0.88	0.88	0.88	0.88
Epomophorus labiatus	0.92	0.92	0.92	0.92	0.92
Epomophorus minimus	0.92	0.92	0.92	0.92	0.92
Epomophorus wahlbergi	0.92	0.92	0.92	0.92	0.92
Epomops buettikoferi	0.98	0.98	0.98	0.98	0.98
Epomops dobsonii	0.97	0.97	0.97	0.97	0.97
Epomops franqueti	0.94	0.94	0.94	0.94	0.94
Eptesicus floweri	0.95	0.95	0.95	0.95	0.95
Eptesicus hottentotus	0.93	0.93	0.93	0.93	0.93

Glauconycteris alboguttata	0.92	0.92	0.92	0.92	0.92
Glauconycteris argentata	0.94	0.94	0.94	0.94	0.94
Glauconycteris beatrix	0.95	0.95	0.95	0.95	0.95
Glauconycteris humeralis	0.97	0.97	0.97	0.97	0.97
Glauconycteris poensis	0.95	0.95	0.95	0.95	0.95
Glauconycteris variegata	0.79	0.79	0.79	0.79	0.79
Hipposideros abae	0.95	0.95	0.95	0.95	0.95
Hipposideros beatus	0.95	0.95	0.95	0.95	0.95
Hipposideros caffer	0.83	0.83	0.83	0.83	0.83
Hipposideros cyclops	0.93	0.93	0.93	0.93	0.93
Hipposideros fuliginosus	0.94	0.94	0.94	0.94	0.94
Hipposideros gigas	0.90	0.90	0.90	0.90	0.90
Hipposideros jonesi	0.95	0.95	0.95	0.95	0.95
Hipposideros megalotis	0.97	0.97	0.97	0.97	0.97
Hipposideros ruber	0.87	0.87	0.87	0.87	0.87
Hipposideros vittatus	0.91	0.91	0.91	0.91	0.91
Hypsignathus monstrosus	0.93	0.93	0.93	0.93	0.93
Hypsugo anchietae	0.95	0.95	0.95	0.95	0.95
Hypsugo bellieri	0.95	0.95	0.95	0.95	0.95
Hypsugo crassulus	0.90	0.90	0.90	0.90	0.90
Hypsugo eisentrauti	0.91	0.91	0.91	0.91	0.91
Hypsugo musciculus	0.93	0.93	0.93	0.93	0.93
Kerivoula argentata	0.87	0.87	0.87	0.87	0.87
Kerivoula cuprosa	0.87	0.87	0.87	0.87	0.87
Kerivoula lanosa	0.88	0.88	0.88	0.88	0.88
Kerivoula phalaena	0.95	0.95	0.95	0.95	0.95
Kerivoula smithii	0.93	0.93	0.93	0.93	0.93
Laephotis angolensis	0.98	0.98	0.98	0.98	0.98
Laephotis botswanae	0.96	0.96	0.96	0.96	0.96
Laephotis namibensis	0.98	0.98	0.98	0.98	0.98
Laephotis wintoni	0.92	0.92	0.92	0.92	0.92
Lavia frons	0.89	0.89	0.89	0.89	0.89
Lissonycteris angolensis	0.92	0.92	0.92	0.92	0.92
Megaloglossus woermanni	0.95	0.95	0.95	0.95	0.95
Micropteropus pusillus	0.90	0.90	0.90	0.90	0.90
Mimetillus moloneyi	0.93	0.93	0.93	0.93	0.93
Mimetillus thomasi	0.86	0.86	0.86	0.86	0.86
Miniopterus fraterculus	0.98	0.98	0.98	0.98	0.98
Miniopterus inflatus	0.90	0.90	0.90	0.90	0.90
Miniopterus minor	0.91	0.91	0.91	0.91	0.91
Miniopterus natalensis	0.91	0.91	0.91	0.91	0.91

Miniopterus villiersi	0.98	0.98	0.98	0.98	0.98
Mops brachypterus	0.87	0.87	0.87	0.87	0.87
Mops condylurus	0.97	0.97	0.97	0.97	0.97
Mops demonstrator	0.95	0.95	0.95	0.95	0.95
Mops leonis	0.84	0.84	0.84	0.84	0.84
Mops midas	0.91	0.91	0.91	0.91	0.91
Mops nanulus	0.94	0.94	0.94	0.94	0.94
Mops niveiventer	0.96	0.96	0.96	0.96	0.96
Mops spurrelli	0.94	0.94	0.94	0.94	0.94
Mops thersites	0.88	0.88	0.88	0.88	0.88
Mops trevori	0.70	0.70	0.70	0.70	0.70
Myonycteris relicta	0.95	0.95	0.95	0.95	0.95
Myonycteris torquata	0.82	0.82	0.82	0.82	0.82
Myopterus daubentonii	0.97	0.97	0.97	0.97	0.97
Myopterus whitleyi	0.85	0.85	0.85	0.85	0.85
Myotis bocagii	0.98	0.98	0.98	0.98	0.98
Myotis scotti	0.94	0.94	0.94	0.94	0.94
Myotis tricolor	0.93	0.93	0.93	0.93	0.93
Myotis welwitschii	0.96	0.96	0.96	0.96	0.96
Nanonycteris veldkampii	0.97	0.97	0.97	0.97	0.97
Neoromicia airuluensis	0.93	0.93	0.93	0.93	0.93
Neoromicia brunnea	0.89	0.89	0.89	0.89	0.89
Neoromicia capensis	0.95	0.94	0.95	0.95	0.95
Neoromicia cf. melckorum	0.85	0.85	0.85	0.85	0.85
Neoromicia guineensis	0.95	0.94	0.95	0.95	0.95
Neoromicia helios	0.84	0.84	0.84	0.84	0.84
Neoromicia nana	0.86	0.86	0.86	0.86	0.86
Neoromicia pusillus	0.79	0.78	0.79	0.79	0.79
Neoromicia rendalli	0.87	0.86	0.87	0.87	0.87
Neoromicia somalica	0.92	0.92	0.92	0.92	0.92
Neoromicia tenuipinnis	0.94	0.93	0.94	0.94	0.94
Nycteris arge	0.94	0.94	0.94	0.94	0.94
Nycteris aurita	0.92	0.92	0.92	0.92	0.92
Nycteris gambiensis	0.92	0.92	0.92	0.92	0.92
Nycteris grandis	0.83	0.82	0.83	0.83	0.83
Nycteris hispida	0.89	0.90	0.89	0.89	0.89
Nycteris intermedia	0.81	0.81	0.81	0.81	0.81
Nycteris macrotis	0.89	0.89	0.89	0.89	0.89
Nycteris major	0.95	0.95	0.95	0.95	0.95
Nycteris nana	0.84	0.84	0.84	0.84	0.84
Nycteris thebaica	0.96	0.96	0.96	0.96	0.96

Nycteris woodi	0.87	0.87	0.87	0.87	0.87
Nycticeinops schlieffeni	0.88	0.88	0.88	0.88	0.88
Otomops martiensseni	0.94	0.94	0.94	0.94	0.94
Pipistrellus aero	0.97	0.97	0.97	0.97	0.97
Pipistrellus grandidieri	0.74	0.71	0.74	0.74	0.74
Pipistrellus hesperidus	0.94	0.94	0.94	0.94	0.94
Pipistrellus inexspectatus	0.90	0.90	0.90	0.90	0.90
Pipistrellus nanulus	0.90	0.89	0.90	0.90	0.90
Pipistrellus rueppellii	0.74	0.76	0.74	0.74	0.74
Pipistrellus rusticus	0.87	0.87	0.87	0.87	0.87
Platymops setiger	0.95	0.95	0.95	0.95	0.95
Plerotes anchietae	0.98	0.98	0.98	0.98	0.98
Rhinolophus alcyone	0.94	0.94	0.94	0.94	0.94
Rhinolophus blasii	0.94	0.94	0.94	0.94	0.94
Rhinolophus capensis	0.99	0.99	0.99	0.99	0.99
Rhinolophus clivosus	0.93	0.93	0.93	0.93	0.93
Rhinolophus darlingi	0.94	0.94	0.94	0.94	0.94
Rhinolophus deckenii	0.91	0.91	0.91	0.91	0.91
Rhinolophus denti	0.94	0.93	0.94	0.94	0.94
Rhinolophus eloquens	0.96	0.96	0.96	0.96	0.96
Rhinolophus fumigatus	0.86	0.85	0.86	0.86	0.86
Rhinolophus guineensis	0.97	0.97	0.97	0.97	0.97
Rhinolophus hildebrandtii	0.92	0.92	0.92	0.92	0.92
Rhinolophus hillorum	0.99	0.99	0.99	0.99	0.99
Rhinolophus hipposideros	0.70	0.70	0.70	0.70	0.70
Rhinolophus landeri	0.79	0.79	0.79	0.79	0.79
Rhinolophus maclaudi	0.96	0.96	0.96	0.96	0.96
Rhinolophus ruwenzorii	0.99	0.99	0.99	0.99	0.99
Rhinolophus simulator	0.94	0.94	0.94	0.94	0.94
Rhinolophus swinnyi	0.95	0.95	0.95	0.95	0.95
Rhinopoma cystops	0.90	0.91	0.90	0.90	0.90
Rhinopoma macinnesi	0.90	0.90	0.90	0.90	0.90
Rhinopoma microphyllum	0.83	0.83	0.83	0.83	0.83
Rousettus aegyptiacus	0.89	0.89	0.89	0.89	0.89
Rousettus lanosus	0.98	0.98	0.98	0.98	0.98
Saccolaimus peli	0.95	0.95	0.95	0.95	0.95
Sauromys petrophilus	0.94	0.95	0.94	0.94	0.94
Scotoecus albofuscus	0.84	0.80	0.84	0.84	0.84
Scotoecus hindei	0.83	0.84	0.83	0.83	0.83
Scotoecus hirundo	0.87	0.88	0.87	0.87	0.87
Scotonycteris ophiodon	0.93	0.93	0.93	0.93	0.93

Scotonycteris zenkeri	0.96	0.96	0.96	0.96	0.96
Scotophilus damarensis	0.97	0.97	0.97	0.97	0.97
Scotophilus dinganii	0.86	0.86	0.86	0.86	0.86
Scotophilus leucogaster	0.88	0.88	0.88	0.88	0.88
Scotophilus nigrita	0.86	0.84	0.86	0.86	0.86
Scotophilus nucella	0.97	0.97	0.97	0.97	0.97
Scotophilus nux	0.97	0.97	0.97	0.97	0.97
Scotophilus viridis	0.90	0.90	0.90	0.90	0.90
Tadarida aegyptiaca	0.91	0.90	0.91	0.91	0.91
Tadarida fulminans	0.89	0.91	0.89	0.89	0.89
Tadarida lobata	0.73	0.73	0.73	0.73	0.73
Tadarida ventralis	0.81	0.81	0.81	0.81	0.81
Taphozous hamiltoni	0.99	0.99	0.99	0.99	0.99
Taphozous hildegardeae	0.93	0.93	0.93	0.93	0.93
Taphozous mauritianus	0.82	0.83	0.82	0.82	0.82
Taphozous nudiventris	0.85	0.86	0.85	0.85	0.85
Taphozous perforatus	0.79	0.80	0.79	0.79	0.79
Triaenops afer	0.84	0.84	0.84	0.84	0.84

Table A.3 The original land system category from van Asselen & Verburg, 2013) and the land use categories used in the analyses to simplify the data

Land System	Land Use Category
Cropland extensive, few livestock	Intensive and extensive agriculture
Cropland extensive, bovines, goats and sheep	Intensive and extensive agriculture
Cropland extensive, pigs and poultry	Intensive and extensive agriculture
Cropland medium intensive, few livestock	Intensive and extensive agriculture
Cropland medium intensive, bovines, goats and sheep	Intensive and extensive agriculture
Cropland medium intensive, pigs and poultry	Intensive and extensive agriculture
Cropland intensive, few livestock	Intensive and extensive agriculture
Cropland intensive, bovines, goats and sheep	Intensive and extensive agriculture
Cropland intensive, pigs and poultry	Intensive and extensive agriculture
Mosaic cropland and grassland, bovines, goats and sheep	Agricultural and natural mosaic
Mosaic cropland and grassland, pigs and poultry	Agricultural and natural mosaic
Mosaic cropland (ext.) and grassland, few livestock	Agricultural and natural mosaic
Mosaic cropland (med. Int.) and grassland, few livestock	Agricultural and natural mosaic
Mosaic cropland (int.) and grassland, few livestock	Agricultural and natural mosaic
Mosaic cropland and forest	Agricultural and natural mosaic
Mosaic cropland (ext.) and forest, few livestock	Agricultural and natural mosaic
Mosaic cropland (med. Int.) and forest, few livestock	Agricultural and natural mosaic
Mosaic cropland (int.) and forest, few livestock	Agricultural and natural mosaic
Dense forest	Forest and low intensity agriculture
Forest, few livestock	Forest and low intensity agriculture
Forest, pigs and poultry	Forest and low intensity agriculture
Mosaic grassland and forest	Grassland and low intensity agriculture
Mosaic grassland and bare	Grassland and low intensity agriculture
Grassland, natural	Grassland and low intensity agriculture
Grassland, few livestock	Grassland and low intensity agriculture
Grassland, bovines, goats and sheep	Grassland and low intensity agriculture
Bare	Bare ground
Bare, goats and sheep	Bare ground
Peri-urban and villages	Urban
Urban	Urban

Table A.4 Condition values for each land use used in the Zonation analysis under and optimistic and pessimistic scenarios

Optimistic		Bat Functional Group Open Air	Bat Functional Group Clutter Edge	Bat Functional Group Clutter
	Agricultural and natural mosaic	0.80	0.75	0.70
	Bare ground	0.19	0.04	0.13
	Forest and low intensity agriculture	1.00	1.00	1.00
	Grassland and low intensity agriculture	0.70	0.50	0.40
	Intensive and extensive agriculture	0.65	0.60	0.50
	Urban	0.60	0.55	0.50

Pessimistic		Bat Functional Group Open Air	Bat Functional Group Clutter Edge	Bat Functional Group Clutter
	Agricultural and natural mosaic	0.50	0.45	0.40
	Bare ground	0.19	0.04	0.13
	Forest and low intensity agriculture	1.00	1.00	1.00
	Grassland and low intensity agriculture	0.50	0.30	0.20
	Intensive and extensive agriculture	0.35	0.30	0.20
	Urban	0.40	0.35	0.30

Figure A.1 Points indicating the locations of bat records used in the analyses

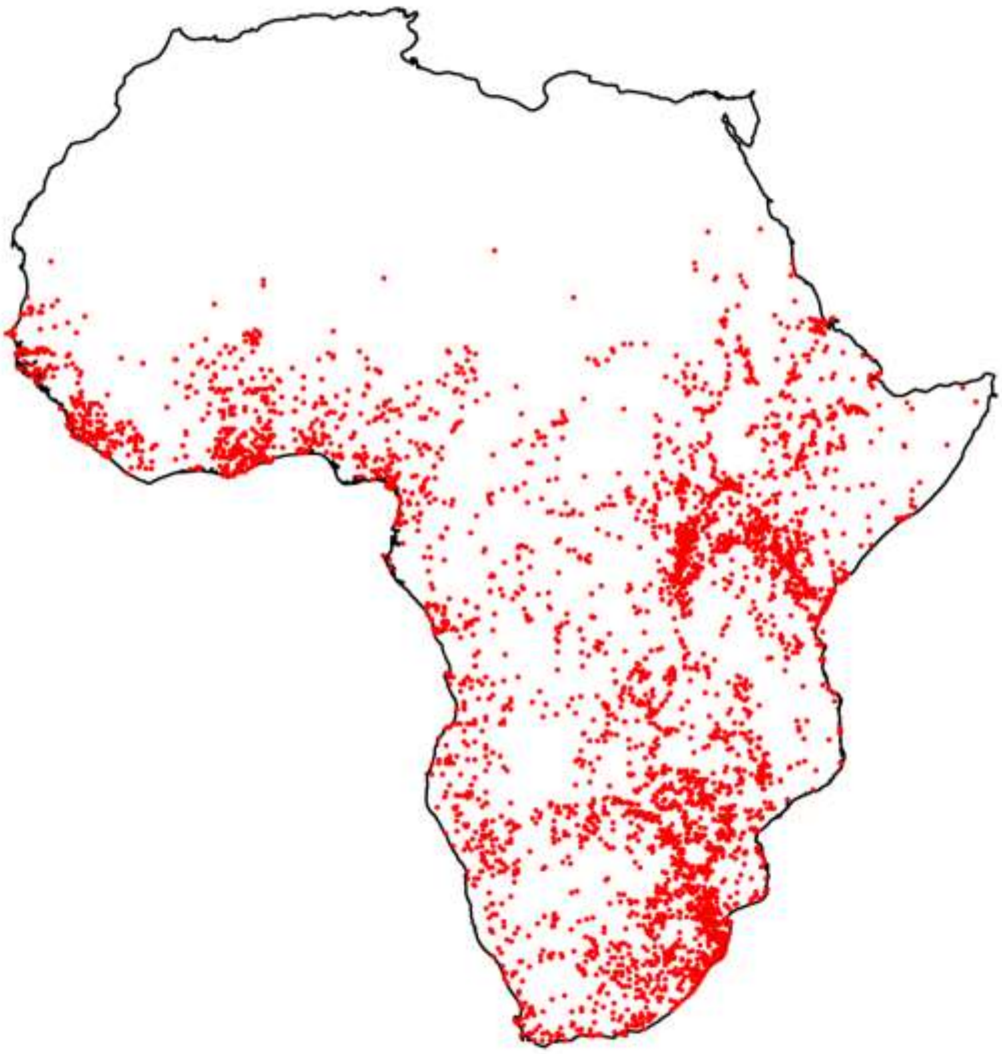


Figure A.2 Flow chart showing the order of analyses and inputs used in the Zonation prioritization analysis.

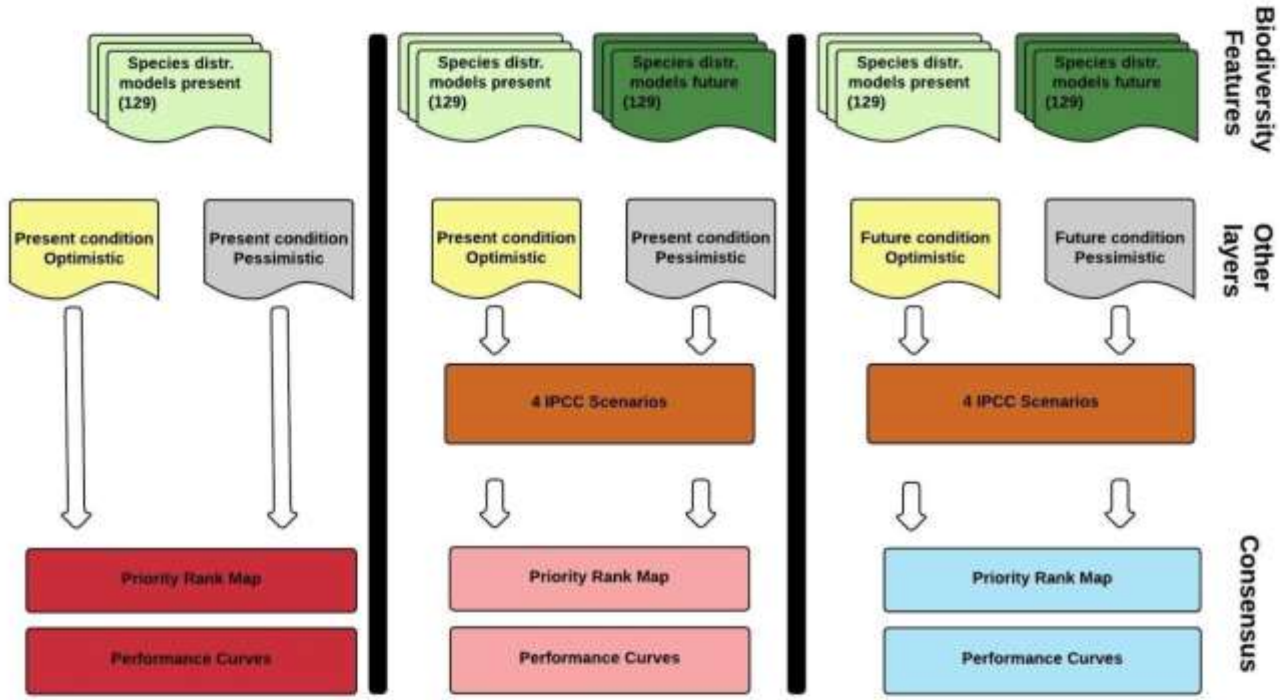


Figure A.3 The present and future land use coverages used in the analyses.

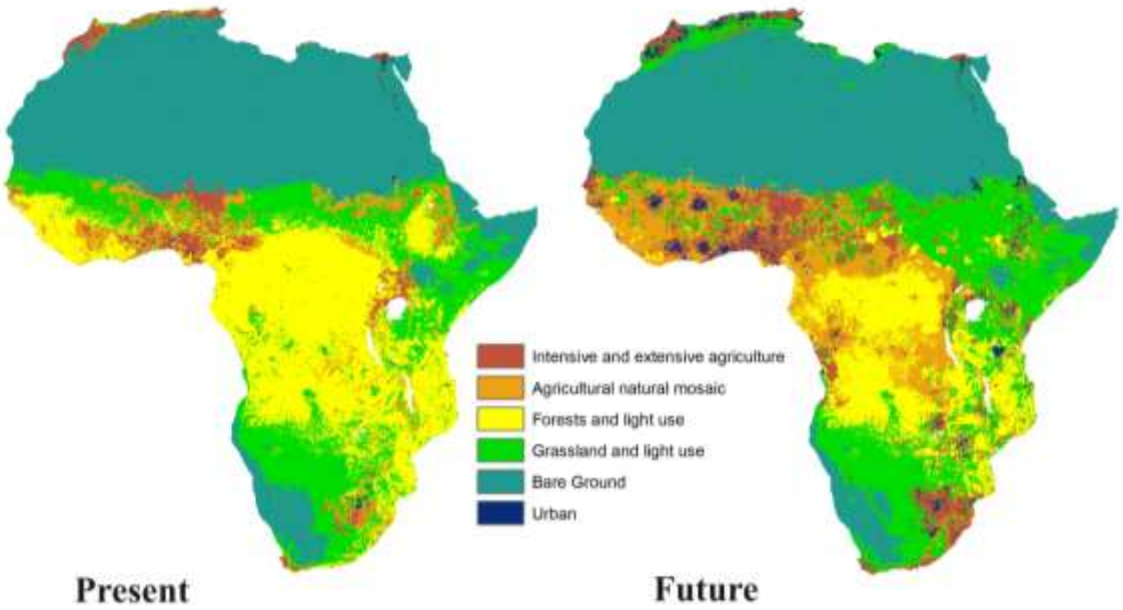
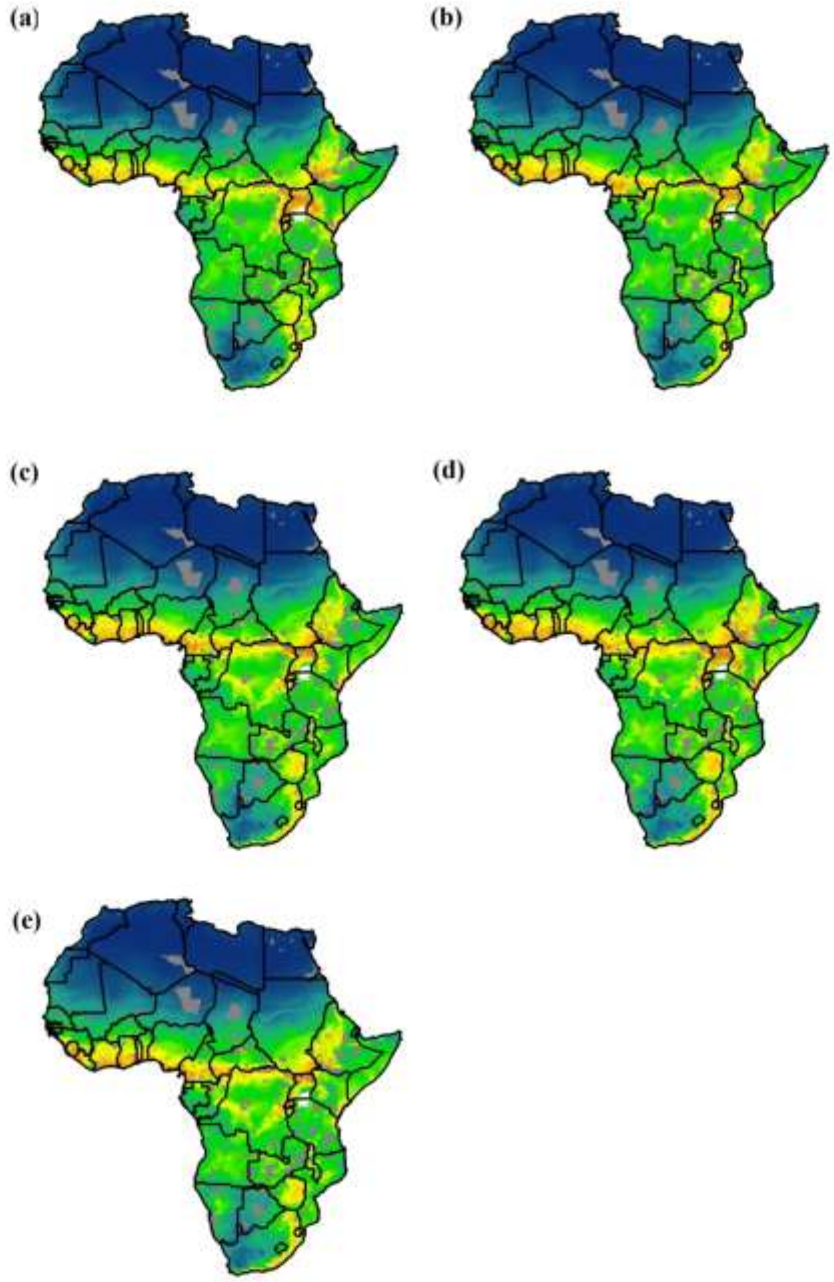


Figure A.4 The summed probabilities of MaxEnt predicted occurrence for species used in the analyses. Scenarios for current distribution: a. current prediction using current climatic conditions to predict distribution future distribution: b. predicted future distribution using RCP2.6, c. RCP4.5 d. RPC6.0 and e. RPC8.5 scenarios.



Appendix B

Supplementary Results

Table B.1 The percentage overlap between the 17 percent conservation core areas of each scenario used in the study. CCCO (Current climate and current optimistic), CCCP (Current climate and current pessimistic), FCCO (Future climate change current pessimistic land use), FCFO (Future climate and future optimistic land use), FCFP (Future climate and future pessimistic land use).

	CCCO	CCCP	FCCO	FCCP	FCFO	FCFP
CCCO	100	85	82	81	67	58
CCCP	85	100	80	82	67	59
FCCO	82	80	100	84	67	58
FCCP	81	82	84	100	68	59
FCFO	67	67	67	68	100	75
FCFP	58	59	58	59	75	100

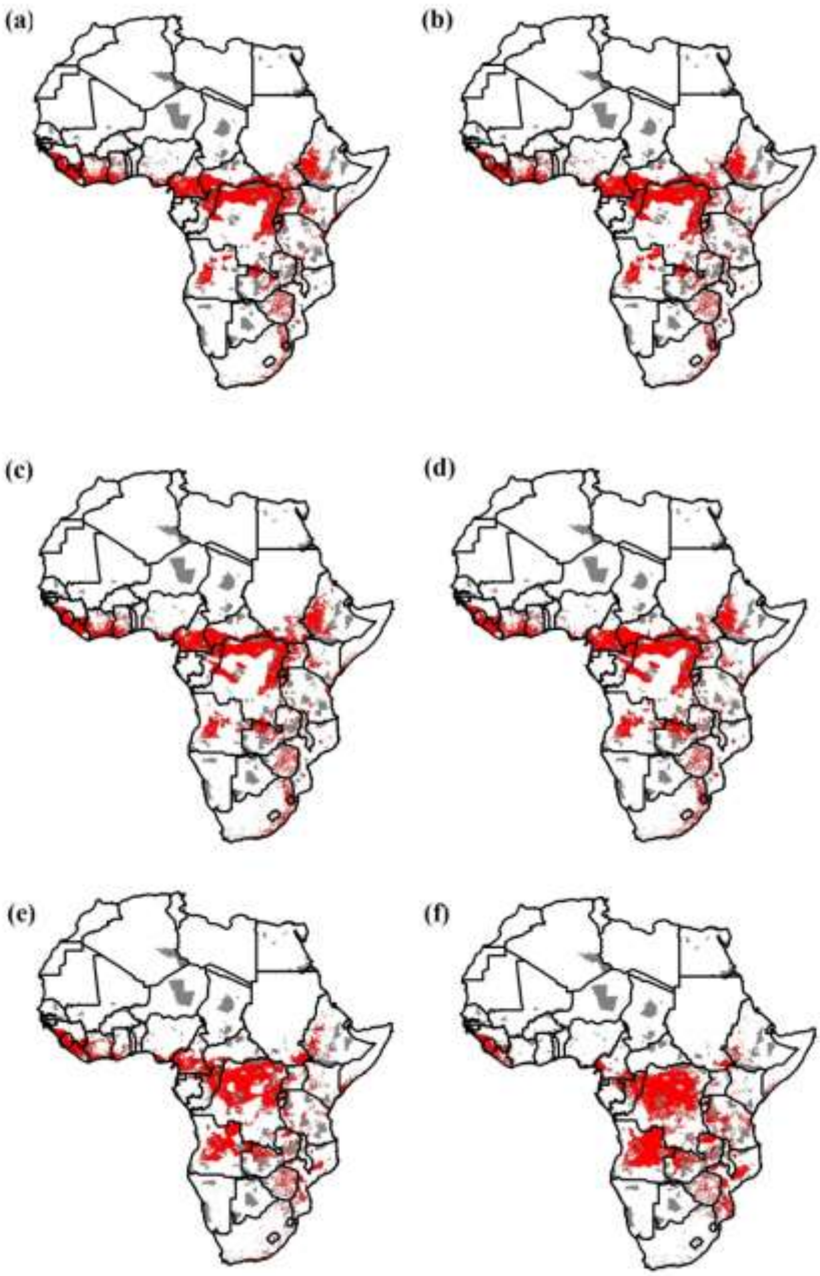
Table B.2 The average, minimum and maximum proportion of species ranges falling within current protected areas.

	Current	Future Climate Change Only	Future Climate Change and Land Use Change
Average Representation	0.069	0.068	0.065
Minimum Representation	0.02	0.015	0.019
Maximum Representation	0.12	0.13	0.12

Table B.3 Median representation for different IUCN categories of bats at the 17% priority areas. CCCO (current climate and current optimistic land use), CCCP (current climate and current pessimistic land use), FCCO (future climate and current optimistic land use), FCPO (future climate and current pessimistic land use), FCFO (future climate and future optimistic land use), FCFP (future climate future and pessimistic land use). None of the species included in the analysis is critically endangered.

	LC	TH	VU/DD
CCCO	0.283	0.306	0.299
CCCP	0.269	0.291	0.273
FCCO	0.328	0.352	0.349
FCCO	0.348	0.398	0.362
FCFO	0.295	0.329	0.333
FCFP	0.286	0.305	0.330

Figure B.1 Conservation priority areas within the 17 percent conservation target (red areas) and current conserved areas (grey); (a) current climate and current optimistic land use (b) current climate and current pessimistic land use (c) future climate and current optimistic land use (d) future climate and current pessimistic land use (e) future climate and future optimistic land use (f) future climate future and future pessimistic land use.



C References

Adam, F, V. Aellen, and M. Tranier. (1993) Nouvelles données sur le genre *Myopterus*. Le statut de *Myopterus daubentonii* Desmarest, 1820 (Chiroptera: Molossidae). *Revue Suisse de Zoologie,* **100**: 317-326.

Adam, F., and B. Hubert. (1972) Chiroptères nouveaux pour le Sénégal. *Mammalia*, **36**: 59 - 70.

Adam, F., and B. Hubert. (1976) Les Nycteridae (Chiroptera) du Sénégal: Distribution, biométrie et dimorphisme sexuel. *Mammalia*, **40**: 597-613.

Aellen, V. (1952) Contribution à l'étude des chiroptères du Cameroun. *Mémoire de la Société Neuchâteloise de Sciences Naturelles*, **8**: 1-121.

Aellen, V. (1956) Speologica africana. Chiroptères des grottes de Guinée. *Bulletin de l'I.F.A.N. Sér. A*, **18**(3):884-894.

Aellen, V. (1957) Les Chiroptères africains du Musée zoologique de Strasbourg. *Revue suisse de zoologie,* **64**: 189-214.

Aellen, V. (1963) La Reserve Naturelle Integrale du Mont Nimba. XXIX. *Chiropteres. Mémoires de l'Institut Francais d'Afrique Noire*, **66**: 629-638.

Aellen, V., and A. Brosset. (1968) Chiroptères du sud du Congo (Brazzaville*). Revue suisse de zoologie,* **75**: 435-458.

Aggundey, I.R., and D.A. Schlitter (1984) Annotated checklist of the mammals of Kenya. I. Chiroptera. *Annals of the Carnegie Museum*, **53**: 119-153.

Allen, J.A. Part I. Systematic list. In Allen, J.A., H. Lang and J.P. (1917) Chapin : The American Museum Congo Expedition Collection of Bats. *Bulletin of the American Museum of Natural History*, **37**: 405-496.

Anciaux De Faveaux, M. (1972) Répartition biogéographique et cycles annuels de Chiroptères d'Afrique centrale. *Thèse de doctorat, Univérsite de Paris*.

Ansell, W.F.H. (1974) Some mammals from Zambia and adjacent countries. *Occasional Papers of the National Parks and Wildlife Services, Zambia*, suppl **1**: 1-49.

Baeten, B., V. Van Cakenberghe, and F. De Vree. (1984) An annotated inventory of a collection of bats from Rwanda (Chiroptera). *Revue de zoologie africaine*, **98**: 183-196.

Benda, P., A. Kiefer, V. Hanák, and M. Veith. (2004) Systematic status of African populations of long-eared bats, genus *Plecotus* (Mammalia: Chiroptera). *Folia Zoologica: International journal of vertebratology*, **53**: 1 - 47.

Bergmans, W. (1988) Taxonomy and biogeography of African fruit bats (Mammalia, Megachiroptera). 1. *General introduction; Material and methods; Results: The genus Epomophorus Bennett, 1836*. Beaufortia, **38**: 75-146.

Bergmans, W. (1989) Taxonomy and biogeography of African fruit bats (Mammalia, Megachiroptera). 2. *The genera Micropteropus Matschie, 1899, Epomops Gray, 1870, Hypsignathus H. Allen, 1861, Nanonycteris Matschie, 1899, and Plerotes Andersen, 1910. Beaufortia*, **38**: 89–153.

Bergmans, W. (1990) Taxonomy and biogeography of African fruit bats (Mammalia, Megachiroptera). 3. The genera *Scotonycteris* Matschie, 1894, *Casinycteris Thomas, 1910, Pteropus Brisson, 1762, and Eidolon Rafinesque, 1815. Beaufortia*, **40**: 111-177.

Bergmans, W. (1974) Taxonomy and biogeography of African fruit bats (Mammalia, Megachiroptera). 5. The genera *Lissonycteris* Andersen, 1913, *Myonycteris* Matschie, 1899 and *Megaloglossus* Pagenstecher, 1885; *General remarks and conclusions; annex: Key to all species. Beaufortia* (, **47**: 11-90.

Bergmans, W., L. Bellier and J. Vissault. (1974) A taxonomical report on a collection of Megachiroptera (Mammalia) from the Ivory Coast. *Revue de zoologie africaine*, **88**: 18 - 48.

Böhme, W., and R. Hutterer. (1979) Kommentierte Liste einer Säugetier Aufsammlung aus dem Senegal. *Bonner zoologische Beitrage*, **29**: 303-322.

Brosset, A. (1966a) Contribution à la faune du Congo (Brazzaville). Mission A. Villiers et A. Descarpentries. XX. Chiroptères. *Bulletin de l'Institut fondamental d'Afrique noire: sciences naturelles*, **28**: 362-370.

Brosset, A. (1966b) Les chiroptères du Haut-Ivindo (Gabon). *Biologica Gabonica*, **2**: 47-86.

Clarke, L., Edmonds, J., Jacoby, H., Pitcher, H., Reilly, J. & Richels, R. (2007) Scenarios of greenhouse gas emissions and atmospheric concentrations. *US Department of Energy Publications*, 6.

Coe, M. (1975) Mammalian ecological studies at Mount Nimba, Liberia. *Mammalia*, **39**: 523–588.

Cotterill, F.P.D. (2001a) The first specimen of Thomas's flat-headed bat, *Mimetillus moloneyi thomasi* (Microchiroptera: Mammalia) in Southern Africa from Mozambique. *Arnoldia Zimbabwe*, **10**: 211-218.

Cotterill, F.P.D. (2001b) New specimens of lesser house bats (Vespertilionidae: *Scotoecus*) from Mozambique and Zambia. *Arnoldia Zimbabwe*, **10**: 219-223.

Crawford-Cabral, J. (1989) A list of Angolan Chiroptera with notes on their distributions. *Garcia de Orta, Ser. Zool.*, **13**: 7–48.

Csorba, G., P. UJhelyi, and N. Thomas. (2003) Horseshoe Bats of the World (Chiroptera: Rhinolophidae). *Alana Books – Shropshire*.

Curran, M., M. Kopp, J. Beck, and J. Fahr. (2012) Species diversity of bats along an altitudinal gradient on Mount Mulanje, southern Malawi. *Journal of Tropical Ecology*, **28**: 243-253.

Decher, J., and J. Fahr. (2007) A conservation assessment of bats (Chiroptera) of Draw River, Boi-Tano, and Krokosua Hills Forest Reserves in the Western Region of Ghana. *Myotis,* **43**: 5-30.

Decher, J., R.W. Norris, and J. Fahr. (2010) Small mammal survey in the upper Seli River valley, Sierra Leone. *Mammalia*, **74**: 163-176.

Denys, C., B. Kadjo, A.D. Missoup, A. Monadjem, and V. Aniskine. (2013) New records of bats (Chiroptera) and karyotypes from Guinean Mount Nimba (West Africa). *Italian Journal of Zoology*, DOI:10.1080/11250003.2013.775367.

De Vree, F. (1971) Notes sur une collection de Chiroptères ouest africains, principalement de la Côte d'Ivoire. *Revue de zoologie et botanique africaines,* **83**: 31-49.

Dorst, J. (1963) Présence de *Pipistrellus rüppelli* au Tchad. *Mammalia,* **27**: 443.

Dowsett, R.J., D.L. Harrison, and L. (1991) Granjon. Bats (Chiroptera) from the Mayombe and lower Kouilou (with a checklist for Congo). *Tauraco Research Report*, **4**: 251-263.

Duckworth, J.W., D.L. Harrison, and R J. Timmins. (1993) Notes on a collection of small mammals from the Ethiopian Rift Valley. *Mammalia,* **57**: 278-282.

Eger, J. L., and D. A. Schlitter. (2001) A new species of *Glauconycteris* from West Africa (Chiroptera: Vespertilionidae). *Acta Chiropterologica,* **3**: 1-10.

Eisentraut, M. (1956) Beitrag zur Chiropteren-Fauna Von Kamerun (Westafrika). *Zoologische Jahrbücher: Abteilung für Systematik*, **84**: 505-540.

Eisentraut, M., and H. Knorr. (1957) Les chauves-souris cavernicoles de la Guinee Francaise. *Mammalia,* **4**: 321-340.

Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E. & Yates, C.J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*, **17**, 43-57.

Estrada, A., Coates-Estrada, R. & Meritt, D. (1993) Bat species richness and abundance in tropical rain forest fragments and in agricultural habitats at Los Tuxtlas, Mexico. *Ecography*, **16**, 309-318.

Fahr, J., B.A. Djossa, H. VIerhaus. (2006) Rapid assessment of bats (Chiroptera) in Déré, Diécké and Mt. Béro classified forests, southeastern Guinea; including a review of the distribution of bats in Guinée Forestière. In: Wright, H.E., McCullough, J., Alonso, L.E., Diallo, M.S., eds. A rapid biological assessment of three classified forests in Southeastern Guinea. Washington, DC: Conservation International, *RAP Bulletin of Biological Assessment*, **40**: 168–180, 245–247.

Fahr, J., and N.M. Ebigbo. (2003) A conservation assessment of the bats of the Simandou Range, Guinea, with the first record of *Myotis welwitschii* (Gray, 1866) from West Africa. *Acta Chiropterologica*, **5**: 125–141.

Fahr, J., H. Vierhaus, R. Hutterer, and D. Kock. (2002) A revision of the *Rhinolophus maclaudi* species group with the description of a new species from West Africa (Chiroptera: Rhinolophidae). *Myotis*, **40**: 95–126.

Fahr, J., and E.K.V. Kalko. (2011) Biome transitions as centers of diversity: habitat heterogeneity and diversity patterns of West African bat assemblages across spatial scales. *Ecography*, **34**: 177-195.

Fairon, J. (1980) Deux nouvelles espèces de cheiroptères pour la faune du massif de l'Air (Niger): *Otonycteris hemprichi* Peters, 1859 et *Pipistrellus nanus* (Peters, 1852*).* *Bulletin - Koninklijk Belgisch Instituut voor Natuurwetenschappen, Biologie*, **52**: 1-7.

Fenton, M.B., and J.L. Eger. (2002) *Chaerephon chapini*. *Mammalian Species*, **692**: 1 - 2, Fjeldså, J. and R.C.K. Bowie. (2008) New perspectives on the origin and diversification of Africa's forest avifauna. *African Journal of Ecology*, **46**: 235–247.

Fujino, J., Nair, R., Kainuma, M., Masui, T. & Matsuoka, Y. (2006) Multi-gas mitigation analysis on stabilization scenarios using AIM global model. Multigas Mitigation and Climate Policy. *The Energy Journal*, 343-353

Funaioli, U., and B. Lanza. (1968) On some bats from Somalia. *Monitore zoologico Italiana, suppl*. **2**: 199-202.

GarcÍA-Morales, R., Badano, E.I. & Moreno, C.E. (2013) Response of Neotropical Bat Assemblages to Human Land Use. *Conservation Biology*, **27**, 1096-1106.

Garcia, R.A., Burgess, N.D., Cabeza, M., Rahbek, C. & Araújo, M.B. (2012) Exploring consensus in 21st century projections of climatically suitable areas for African vertebrates. *Global Change Biology*, **18**, 1253-1269.

Gallagher, M.D., and D.L. Harrison. (1968) Report on the bats (Chiroptera) obtained by the Zaire River Expedition. *Bonner Zoologische Beitrage*, **28**: 19-32.

Green, A.A. (1983) Rodents and bats of Arli and Pendjari National Parks, Upper Volta and Benin. *Nigerian Field*, **47**: 185-194.

Grubb, P. (1982) Refuges and dispersal in the speciation of African forest mammals. Biological diversification in the tropics (ed. by G.T. Prance*). Columbia University Press, New York*. 537–553.

Grubb, P., T.S. Jones, A.G. Davies, E. Edberg, E.D. Starin, and J.E. Hill. (1999) Mammals of Ghana, Sierra Leone, and The Gambia. *The Trendine Press. Zennor*, St. Ives.

Happold, D.C.D. (1987) The mammals of Nigeria. *Clarendon Press, Oxford*.

Happold, M. and Happold, H.D.C. (2013) Mammals of Africa Vol. IV. *Bloomsbury Publishing, London*.

Harrison, D.L. (1975) A new species of African Free-tailed bat (Chiroptera: Molossidae) obtained by the Zaire River Expedition. *Mammalia*, **39**: 313-318.

Hastie, T., Tibshirani, R., Friedman, J. & Franklin, J. (2005) The elements of statistical learning: data mining, inference and prediction. *The Mathematical Intelligencer*, **27**, 83-85

Hayman, R.W., X. Misonne, and W.N. VErheyen. (1966) The bats of the Congo and of Rwanda and Burundi. *Annals Royal Museum African Center Zoology Ser.*, **154**: 1–191.

Heller, K.G., M. Volleth, and D. Kock. (1994) Notes on some vespertilionid bats from the Kivu region, Central Africa (Mammalia: Chiroptera). *Senckenbergiana biologica*, **74**: 1-8.

Hill, J.E. (1968) Bats from the Cameroons, with the description of a new species of *Pipistrellus*. *Bonner Zoologische Beitrage*, **19**: 43-48.

Hill, J.E. (1975) Occurrence of *Nycteris parisii* (de Beaux, 1923) (Chiroptera: Nycteridae) in Ethiopia. *Mammalia*, **39**: 506-508.

Hill, J.E. (1982) Records of bats from Mount Nimba, Liberia. *Mammalia*, **46**: 116-120.

Hill, J.E. (1983) Further records of bats from the Central African Republic (Mammalia: Chiroptera). *Annals of the Carnegie Museum*, **52**: 55-58.

Hill, J.E., D.L. Harrison, and T.S. Jones. (1988) New records of bats (Microchiroptera) from Nigeria. *Mammalia*, **52**: 590-592.

Hijioka, Y., Matsuoka, Y., Nishimoto, H., Masui, M. & Kainuma, M. (2008) Global GHG emissions scenarios under GHG concentration stabilization targets. *Journal of Global Environmental Engineering*, **13**, 97-108.

Hutterer, R., and U. Joger. (1982) Kleinsäuger aus dem Hochland von Adamaoua, Kamerun. *Bonner zoologische Beitrage*, **33**: 119-132.

Hutterer, R., F. Dieterlen, and G. Nikolaus. (1992) Small mammals from forest islands of eastern Nigeria and adjacent Cameroon, with systematical and biogeographical notes. *Bonner zoologische Beitrage*, **43**: 393 - 414.

Johansson, M. & De Jong, J. (1996) Bat species diversity in a lake archipelago in central Sweden. *Biodiversity & Conservation*, **5**, 1221-1229.

Jones, C. (1971) The bats of Rio Muni, West Africa. *Journal of Mammalogy*, **52**: 121-140.

Kearney, T.C. & Seamark, E.C. (2005) Morphometric analysis of cranial and external characters of Laephotis Thomas, 1901 (Mammalia: Chiroptera: Vespertilionidae) from southern Africa. *Annals of the Transvaal Museum*, **42**, 71-87.

Koch-Weser, S. (1984) Fledermause aus Obervolta, W-Afrika. Senckenbergiana Biologica, **64**: 255-311.

Kock, D. (1969) Die Fledermaus-Fauna des Sudan (Mammalia, Chiroptera). *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft*, 521: 1-238.

Kock, D. (1981) Vergleichende untersuchung einiger Säugetiere im sűdlichen Niger (Mammalia: Insectivora, Chiroptera, Lagomorpha, Rodentia). *Senckenbergiana biologica* (, **58**: 113-136.

Kock, D. (1981) Zur Chiropteren-Fauna von Burundi (Mammalia). *Senckenbergiana biologica*, **61**: 329-336.

Kock, D., L. Barnett, J. Fahr, and C. Emms. (2002) On a collection of bats (Mammalia: Chiroptera) from The Gambia. *Acta Chiropterologica,* **4**: 77–97.

Kock, D., G. Csorba, and K.M. Howell. (2000) *Rhinolophus maendeleo* n. sp. from Tanzania, a horseshoe bat noteworthy for its systematics and biogeography (Mammalia, Chiroptera, Rhinolophidae). *Senckenbergiana biologica*, **80**: 233-239.

Kock, D., and K.M. Howell. (1988) Three bats new for mainland Tanzania (Mammalia: Chiroptera). *Senckenbergiana biologica*, **68**: 223-239.

Kock, D., and W.T. Stanley. (2009) Mammals of Mafia Island, Tanzania. *Mammalia*, **73**: 339-352.

Konstantinov, O.K., A.I. Pema, V.V. Labzin, G.V. (2000) Farafonova. Records of bats from Middle Guinea, with remarks on their natural history. *Plecotus*, **3**: 129-148.

Koopman, K.F. (1975) Bats of the Sudan. *Bulletin of the American Museum of Natural History*, **154**: 353-444.

Koopman, K.F. (1989) Systematic notes on Liberian bats. *American Museum Novitiates*, **2946**: 1–11.

Koopman, K.F., C.P. Kofron, and A. Chapman. (1995) The bats of Liberia: Systematics, ecology, and distribution. *American Museum Novitiates*, **3148**: 1–24.

Koopman, K.L., R.E. Mumford, J.F. Heisterberg. (1978) Bat records from Upper Volta, West Africa. *American Museum Novitiates*, **2643**: 1-6.

Kruskop, S.V., and L.A. Lavrenchenko. (2000) A new species of long-eared bat (*Plecotus*; Vespertilionidae, Mammalia) from Ethiopia. *Myotis*, **38**: 5-17.

Kruskop, S.V., and L.A. Lavrenchenko. (2006) First bat records in the Simien Mountains (Northern Ethiopia). *Russian Journal of Theriology*, **5**: 59 - 62.

Kuhn, H.-J. (1965) A provisional checklist of the mammals of Liberia. (With notes on the status and distribution of some species). *Senckenbergiana Biologica*, **46**: 321–340.

Largen, M.J., D. Kock, and D.W. Yalden. (1974) Catalogue of the mammals of Ethiopia. 1. Chiroptera. *Monitore zoologico Italiana, suppl*. **5**: 221 - 298.

Lavrenchenko, L.A., S.V. Kruskop, and P.N. Morozov.(2004) Notes on the bats (Chiroptera) collected by the joint Ethiopian-Russian biological expedition, with remarks on their systematics, distribution, and ecology. *Bonner zoologische Beitrage*, **52**: 127 - 147.

Lim, B.K., and M.D. Engstrom. (2001) Species diversity of bats (Mammalia: Chiroptera) in Iwokrama Forest, Guyana, and the Guianan subregion: implications for conservation. *Biodiversity and Conservation*, **10**: 613-657.

Lim, B.K., and P.J. Van Coeverden De Groot. (1997) Taxonomic report of small mammals from Côte d'Ivoire. *Journal of African Zoology*, **111**: 261-279.

Lopes, F.J., and J. Crawford-Cabral. (1990) Catalogo dos Chiroptera em coleccao no centro de Zoologia. *Garcia de Orta, ser. Zool.*, **17**:1-20.

Lunde, D.P., and P. Beresford. (1997) Noteworthy records of bats from the Central African Republic. *Bat Research News*, **38**: 19-20.

Lunde, D.P., T.M. Conway, and P. Beresford. (2001) Notes on a collection of bats (Chiroptera) from Dzanga-Sangha, Central African Republic. *Mammalia*, **65**: 535-540.

Malbrant, R., and A. Maclatchy. (1949) Faune de l'Equateur Africain français. II. Mammifères. *Encyclopédie Biologique, Paris*.

Mclellan, L.J. (1986) Notes on bats of Sudan. *American Museum Novitiates*, **2839**: 1-12.

Mehr, M., Brandl, R., Hothorn, T., Dziock, F., Förster, B. & Müller, J. (2011) Land use is more important than climate for species richness and composition of bat assemblages on a regional scale. *Mammalian Biology - Zeitschrift für Säugetierkunde*, **76**, 451-460.

Meinig, H. (2000) Notes on the mammal fauna of the southern part of the Republic of Mali, West Africa. *Bonner zoologische Beitrage*, **49**: 101-114.

Monadjem, A. & Fahr, J. (2007) Rapid survey of bats of North Lorma, Gola and Grebo National Forests, with notes on shrews and rodents. *A rapid biological assessment of North Lorma, Gola and Grebo National Forests, Liberia. Arlington, VA: Conservation International*, 47-58.

Monadjem, A., P.J. Taylor, F.P.D. Cotterill, and M.C. Schoeman. (2010) Bats of Southern and Central Africa: A Biogeographic and Taxonomic Synthesis. *University of the Witwatersrand, Johannesburg, South Africa*.

Monadjem, A., L. Richards, P.J. Taylor, and S. Stoffberg. (2013) High diversity of pipistrelloid bats (Vespertilionidae: *Hypsugo*, *Neoromicia*, and *Pipistrellus*) in a West African rainforest with the description of a new species. *Zoological Journal of the Linnean Society*, **167**: 191-207.

Monadjem, A., Richards, L., Taylor, P.J., Denys, C., Dower, A. & Stoffberg, S. (2013) Diversity of Hipposideridae in the Mount Nimba massif, West Africa, and the taxonomic status of Hipposideros lamottei. *Acta Chiropterologica*, **15**, 341-35

Monard, A. (1939) Resultats de la mission scientifique du Dr. Monard en Guinee Portugaise, 1937-1938. *Arquivos do Museu Bocage*, **10**: 50-80.

Montfort, A. (1992) Première liste commentée des mammifères du Rwanda. *Revue de zoologie africaine*, **106**: 141-151.

Niort, P.L. (1970) Contribution à la connaissance des chiroptères du Burundi (Afrique Centrale). *Annalen van de Koninklijke Vereniging voor Dierkunde*, **100**: 247-274.

Patterson, B.D., and P.W. Webala. (2012) Key to the bats (Mammalia: Chiroptera) of East Africa. Fieldiana Life and Earth Sciences, No. 6. *Field Museum of National History, Chicago*.

Pearch, M.J., P.J.J. Bates, and C. Magin. (2001) A review of the small mammal fauna of Djibouti and the results of a recent survey. *Mammalia*, **65**: 387-409.

Peterson, R.L., and D.A. Smith. (1973) A new species of *Glauconycteris* (Vesptertilionidae, Chiroptera). *Life Science Occasional Papers - Royal Ontario Museum*, **22**: 1-9.

Phillips, S. (2006) A brief tutorial on Maxent .AT&T Research. Available at: http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc.

Phillips, S.J. & Dudík, M. (2008) Modeling of species distributions with Maxent : new extensions and a comprehensive evaluation. *Ecography*, **31**, 161-175.

Poché, R.M. (1975) The bats of the National Park W, Niger, Africa. *Mammalia*, **39**: 39-50.

Poulet, A.R. (1972) Recherches écologiques sur une savane sahelienne du Ferlo Septentrional, Senegal: Les mammifères. *Terre at la vie: revue d'écologie appliqué*, **26**: 440-472.

Qumsiyeh, M.B., and D.A. Schlitter. (1981) Bat records from Mauritania, Africa (Mammalia: Chiroptera). *Annals of the Carnegie Museum*, **50**: 345-351.

Riahi, K., Grübler, A. & Nakicenovic, N. (2007) Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological Forecasting and Social Change*, **74**, 887-935.

Robbins, C.B. (1980) Small mammals of Togo and Benin. I. Chiroptera. *Mammalia*, **44**: 83-88.

Rovero, F., and D.W. De Luca. (2007) Checklist of mammals of the Udzungwa Mountains of Tanzania. *Mammalia*, 47-55.

Schlitter, D.A., and I.R. Aggundey. (1986) Systematics of African bats of the genus *Eptesicus* (Mammalia: Vespertilionidae). 1. Taxonomic status of the large serotines of Eastern and southern Africa. *Cimbebasia*, **8**: 167-174.

Schlitter, D.A., L.W. Robbins, and S.A. Buchanan. (1982) Bats of the Central African Republic (Mammalia: Chiroptera). *Annals of the Carnegie Museum*, **51**: 133-155.

Schoeman, M.C., F.P.D. Cotterill, P.J. Taylor, and A. Monadjem. (2013) Using potential distributions to explore environmental correlates of bat species richness in southern Africa: Effects of model selection and taxonomy. *Current Zoology*, **59**: 279-293.

Schouteden, D.H. De zoogdieren van Belgisch. (1947) Congo en van Ruanda-Urundi. *Ann. Mus. Congo Belge*, *Tervuren*, **I**: 1–576.

Seamark, E.C.J. and V. Van Cakenberghe. (2012) African Chiroptera Report 2012. *African Chiroptera Report, Pretoria*. www.africanbats.org.

Sidiyène, E. A., and M. Tranier. (1990) Données récentes sur les Mammifères de l'Adrar des Iforas (Mali). *Mammalia*, **54**: 471-477.

Smith, S.J. & Wigley, T.M.L. (2006) Multi-Gas Forcing Stabilization with the MiniCAM. *Energy Journal*, **3**, 373-391.

Stanley, W.T. (2009) A new species of *Mops* (Molossidae) from Pemba Island, Tanzania. *Acta Chiropterologica*, **10**: 183-192.

Stanley, W.T., and C.A.H. Foley. (2008) A survey of the small mammals of Minziro Forest, Tanzania, with several additions to the known fauna of the country. *Mammalia*, **72**: 116-122.

Stanley, W.T., and D. Kock. (2004) New records and notes on *Laephotis* Thomas, 1901 (Chiroptera: Vespertilionidae). *Mammalian biology*, **69**: 173-181.

Stanley, W.T., J. Gunn and P.M. Kihaule. (2005a) Results of a preliminary small mammal survey of Malundwe Mountain, Mikumi National Park, Tanzania. *Journal of East African Natural History*, **94**: 213-222.

Stanley, W.T., A.M. Nikundiwe, F.A. Mturi, P.M. Kihaule, and P.D. Moehlman. (2005b) Small mammals collected in the Udzungwa mountains national park, Tanzania. *Journal of East African Natural History*, **94**: 203 - 212.

Stanley, W.T., M.A. Rogers, K.M. Howell, and C.A. Msuya. (2005c) Results of a survey of small mammals in the Kwamgumi Forest Reserve, East Usambara Mountains, Tanzania. *Journal of East African Natural History*, **94**: 223-230.

Stanley, W.T., J.C. Kerbis Peterhans, R.M. Kityo, and L. Davenport. (1996) New records of bats for Uganda and Burundi. *African Journal of Ecology*, **34**: 196-201.

Swynnerton, G.H., and R.W. Hayman. (1951) A checklist of the land mammals of the Tanganyika Territory and the Zanzibar Protectorate. *Journal of the East African Natural History Society and National Museum*, **20**: 274-392.

Thorn, E., D. Kock, J. Cuisin. (2007) Status of the African bats *Vesperugo grandidieri* Dobson 1876 and *Vesperugo flavescens* Seabra 1900 (Chiroptera, Vespertilionidae), with description of a new subgenus. *Mammalia*, **71**: 70–79.

Thorn, E., J. C. Kerbis Peterhans. and J. Baranga. (2009) Chiroptera, pp. 12–75. In Thorn, E., and J. C. Kerbis Peterhans, eds., Small Mammals of Uganda. *Bonner Zoologische Monographien 55. Museum Alexander Koenig, Bonn*.

Van Cakenberghe, V., and F. De Vree. (1985) Systematics of African *Nycteris* (Mammalia: Chiroptera). *Proceedings of the International Symposium on African Vertebrates, Bonn*. 53 - 90.

Van Cakenberghe, V., F. De Vree, and H. Leirs. (1999) On a collection of bats (Chiroptera) from Kikwit, Democratic Republic of the Congo. *Mammalia.* **63**: 291-322.

Van Vuuren, D.P., Den Elzen, M.G., Lucas, P.L., Eickhout, B., Strengers, B.J., van Ruijven, B., Wonink, S. & van Houdt, R. (2007) Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Climatic Change*, **81**, 119-159.

Varty, N., and J.E. Hill. (1988) Notes on a collection of bats from the riverine forests of the Jubba Valley, southern Somalia, including two species new to Somalia. *Mammalia*, **52**: 533-540.

Verschuren, J. Exploration du Parc National Albert. Mission F. Bourlière et J. (1967) Verschuren (1957 - 1961). Fasc. 2. Introduction a l'écologie et la biologie des cheiroptères. Instituut der Nationale Parken van Belgisch Kongo. 25 - 65.

Verschuren J. (1977) Les chiropteres du Mont Nimba (Liberia). *Mammalia*. **40**: 615–632.

Verschuren, J. (1980) Notes sur les cheiroptères du Burundi. Bulletin - Koninklijk Belgisch Instituut voor Natuurwetenschappen. *Biologie*. **52**: 2 - 9.

Vielliard, J. Les chiroptères du Tchad. (1974) *Revue suisse de zoologie*. **81**: 975-991.

Wise, M., Calvin, K., Thomson, A., Clarke, L., Bond-Lamberty, B., Sands, R., Smith, S.J., Janetos, A. & Edmonds, J. (2009) Implications of limiting CO2 concentrations for land use and energy. *Science*, **324**, 1183-1186.

Wolton, R.J., P.A. Arak, H.C.J. Godfray, and R.P. Wilson. (1982) Ecological and behavioural studies of the Megachiroptera at Mount Nimba, Liberia, with notes on Microchiroptera. *Mammalia*. **46**: 419-448.

Yackulic, C.B., Chandler, R., Zipkin, E.F., Royle, J.A., Nichols, J.D., Campbell Grant, E.H. & Veran, S. (2013) Presence-only modelling using MAXENT: when can we trust the inferences? *Methods in Ecology and Evolution*, **4**, 236-243.

Yalden, D.W., M.J. Lsrgen, D. Kock, and J.C. Hillman. (1996) Catalogue of the mammals of Ethiopia and Eritrea. 7. Revised checklist, zoogeography and conservation. *Tropical Zoology*. **9**: 73-164.