

Identifying climate-resilient corridors for conservation in the Albertine Rift



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January 2013



MACARTHUR
The John D. and Catherine T. MacArthur Foundation



Acknowledgements

This report was supported by the John D. and Catherine T. MacArthur Foundation, the University of Queensland's School of Biological Sciences and the Wildlife Conservation Society. We are grateful to Grace Nangendo, Hamlet Mugabe, Ben Kirunda and Ken Fehling for helping us pull together the relevant data for the modeling in this report and grateful for advice and support for training from Antoine Guisan and Wilfried Thuiller. We are also grateful to Charles Foley, Sarah Durant and the Tanzania Mammal Atlas project for providing some mammal data for western Tanzania.

Suggested Citation:

Ayebare, S., Ponce-Reyes, R., Segan, D.B., Watson, J.E.M., Possingham, H.P., Seimon, A., and Plumptre, A.J. (2013) *Identifying climate resilient corridors for conservation in the Albertine Rift*. Unpublished Report by the Wildlife Conservation Society to MacArthur Foundation.

Executive Summary

The Albertine Rift region of Africa is one of the most species rich regions in Africa, and contains more threatened and endemic vertebrates than anywhere else on the continent. Many of these threatened and endemic species result from their isolation on mountain tops during the fluctuations in forest during previous ice ages and as a result are likely to be sensitive to climate change. The high human population density in this region will exacerbate the impacts of climate change and there is a need to assess where dispersal corridors need to be conserved before they are lost to other land uses. This report summarises the results of an assessment to identify where corridors should be located in the Albertine Rift to increase resilience to climate change.

Three approaches were used to determine where corridors should be located: a) Modeling the current and predicted (in 2080) distributions of 93 endemic and threatened large mammals, birds and plants; b) modeling five key vegetation types both currently and in 2080; and c) identifying gradients in abiotic conditions which are likely to support a diverse set of habitat types today and under future climate change. The approach builds upon work by Game *et al.* (2011) and is the first time that such a three-pronged approach has been used to identify corridors. Species and habitat models were developed using the Maxent software package and using 18 predictor variables that were selected from a larger set for their lower correlation coefficients with other variables. Potential corridor areas were identified as those areas of overlap between current and future distributions of species and vegetation types and for the geophysical features the areas of steepest gradients were identified that minimized the area of the Rift selected.

Results indicate that many endemic species are likely to need to move upslope on the mountains of the Albertine Rift. Threatened species are more widely distributed and although they will also tend to move upslope their distribution is less constrained by the mountains. A few endemic and threatened species may become more widespread given future climate predictions. Similarly the montane vegetation types (alpine, bamboo and montane forest) all are predicted to decline in area and need to move upslope. Only medium altitude forest and lowland forest look like they will expand or remain stable. Results of the geophysical assessment indicate that similar patterns of gradients can be in the Albertine Rift whether analysed on a 5x5km² or 10x10km² grid.

Results of the corridor analyses indicate that many of the geophysical corridor areas are already within protected areas in the Albertine Rift, indicating that these gradients may be linked in some way to areas of high biodiversity. Key overlap areas for both species and vegetation types include many of the protected areas also as well as areas west of Lake Kivu and Edward and also the Itombwe and Kabobo Massifs which are in the process of being gazetted as protected areas. These results also identified critical corridors outside protected areas. Some key areas are the forested area between Maiko/Tayna and Kahuzi Biega Parks in DR Congo and between Ugalla and Moyowosi /Kigozi Game Reserves in western Tanzania. However, we regard this analysis as preliminary in nature and over the coming year will include additional species and use the Marxan decision support tool to refine the corridor assessments in order to conserve viable targets for each species.

Table of Contents

Executive Summary.....	3
Table of Contents.....	4
The Albertine Rift.....	5
The importance of connectivity in a time of human-forced climate change	5
Aim of this report: the identification of corridors in the Albertine Rift.....	6
Modeling distributions of threatened and endemic species.....	7
Ecological modeling	9
Current distribution of endemic and threatened species	10
<i>Endemic species</i>	10
<i>Threatened species</i>	10
<i>Threatened and endemic species</i>	10
Future distribution of endemic and threatened species	14
<i>Endemic species</i>	14
<i>Threatened species</i>	14
<i>Threatened and endemic species</i>	14
Changes in vegetation types under future climate change	21
Methods used	21
Current distribution of vegetation types	23
Future distribution of habitat types.....	24
Future Distribution of habitats	25
Identification of abiotic gradients in the Albertine Rift	26
Methods.....	28
Conservation of climate-resilient corridors in the Albertine Rift	31
Identification of corridors with species and habitat models	31
Identification of corridor areas for species.....	32
Identification of corridors for vegetation types.....	39
Corridor identification for abiotic gradients	43
Climate Resilient corridors – combining all three methods	43
Future work.....	48
References	49
Appendix 1	55

The Albertine Rift

The Albertine Rift has been identified as one of the most species rich regions of Africa with more threatened and endemic vertebrates than anywhere else on the continent (Plumptre *et al.* 2007). It ranges in altitude from 600m to 5,100m above sea level (a.s.l.) and contains a wide variety of vegetation ranging from lowland rainforest, through medium altitude semi-deciduous rainforest, savanna grasslands and woodlands, Miombo woodland, papyrus wetlands, *Carex* wetlands, montane forest, *Sinarundinaria* bamboo, *Oxytenanthera* bamboo, *Hagenia-Hypericum* woodland, giant heather, giant *Senecio* and *Lobelia*, alpine moorland, bare rock and bare earth. It is this diversity of vegetation types, often determined by the changing climate that occurs with increasing altitude that has contributed to the high levels of diversity and endemism of this region. As a result it forms part of the Eastern Afromontane Hotspot (Brooks *et al.* 2004, Plumptre *et al.* 2004), it is an endemic bird area (Stattersfield *et al.* 1998) and one of the Global 200 Ecoregions (Olson and Dinerstein, 1998). Six core landscapes have been identified within the Albertine Rift (ARCOS 2004) as part of a regional strategic framework planning process and more detailed 10 year action plans have been developed for five of these landscapes. These landscapes were determined at the time by a compilation of the existing biodiversity information for 40 sites in the Albertine Rift by the Wildlife Conservation Society (WCS) and expert opinion on what may occur in the vicinity of other poorly surveyed sites. Since 2000 WCS has undertaken biodiversity surveys of all of these sites to provide consistent and comparable data across all 40 sites for mammals, birds and plants. In addition to this, WCS has been collaborating with Julian Kerbis Peterhans (Chicago Field Museum, USA) to build a comprehensive inventory of small mammal observations and with Michele Menegon and Fabio Pupin (Science Museum at Trento, Italy) to compile data for reptiles and amphibians. The collation of these data is still ongoing and is not reported on here.

During the 2004 regional strategic planning process little consideration was given to human-forced climate change and how it might affect the distribution of species in the future or what conservation actions would be required to secure them. This was primarily due because of an insufficient knowledge base around how the climate was going to change across the region and what impact these changes would have on species and habitats. The landscapes identified as part of the strategic planning process were intended to be large regions so that future planning processes that accounted for threats such as climate change, could refine areas for conservation action within the boundaries of each priority landscape. Work by WCS to model how the climate is likely to change within the Albertine Rift (Seimon, Picton-Phillipps and Plumptre, 2012; Seimon and Picton-Phillipps, 2010; Picton-Phillipps and Seimon, 2010) together with advances in methods to undertake species distribution modeling (Elith *et al.* 2009; 2011; Phillips, Dudik and Schapire, 2004; Phillips, Anderson and Schapire, 2006) over the past 10 years now makes this type of 'climate-resilient' assessment possible.

The importance of connectivity in a time of human-forced climate change

Climate change is likely to become one of the great environmental challenges we face. . While the long term survival of many species may depend on our ability to limit the extent to which the global climate changes, addressing global emissions is largely beyond the control of regional natural resource managers. Identifying regionally appropriate conservation responses to promote species and ecosystem adaption in the landscapes where we work is the major challenge for local managers.

Increasing connectivity between existing protected areas and intact, non-threatened patches of biologically important habitat is frequently advocated as a 'no-regrets' conservation action that can be employed to promote resilience to climate change (Heller & Zavaleta 2009; Lawler 2009; Hannah 2011; Watson et al. 2011). In fragmented landscapes, connectivity can be achieved through the creation or protection of corridors of intact vegetation. These corridors can be designed to achieve multiple objectives, including: connection of two or more sub-populations of a species across space, ensuring a population of a species can expand its current range through the protection of additional suitable habitat, or the connection of a population with habitat that is forecasted to become more suitable in the future.

Aim of this report: the identification of corridors in the Albertine Rift

This report assesses which areas in the Albertine Rift region are critical to conserve for the long-term conservation of endemic and threatened species located, factoring in future changes that may occur as a result of climate change. We use three different approaches to identify areas that are most suitable for establishment of conservation corridors to facilitate dispersal of species response to climate change. We used three Global Circulation Models (GCMs) for predicting the future climate and modeled changes in distribution under the A2 scenario of emissions as this seems to be the scenario that global climate is currently tracking (Seimon, Picton-Phillipps and Plumptre, 2012) (IPCC 2007).

The three approaches used to identify important areas for corridors were:

1. Modeling of endemic and threatened species distributions for large mammals, birds and plants to identify their distributions both under current climate and in the future under predicted climate change using the A2 GCM scenario. This is based on the methodology of Willis *et al.* (2009).
2. Modeling the distribution of the main vegetation types that form the specific habitat types of the Albertine Rift and predicting how these will change under future climate changes. This is based on the methodology of Ponce-Reyes *et al.* 2011.
3. An approach that identifies abiotic gradients in the Albertine Rift, particularly those that are relatively steep. This is based on the methodology of Game *et al.* 2011.

These three approaches are described in detail in the following sections of the report. We then describe the results of each approach. In the final section we undertake an analysis to combine the results to identify where corridors will be needed to conserve the potential for movement of species, vegetation types and gradients that may be important for evolution and maintenance of biodiversity.

Modeling distributions of threatened and endemic species

Here we describe how species distribution models were used to estimate the current and future spatial distribution of environments that are suitable for endemic and threatened bird (n=30), plant (n=46) and mammal (n=17) species across the Albertine Rift. We used species from these three taxonomic groups because they represent a diverse set of characteristics: sessile plants which often determine invertebrate diversity; wide ranging motile species such as some mammals and birds; taxa that are diverse and include many species (plants and birds) and also tending to have many threatened species (mammals and birds). They are also relatively easily identified to species level when surveyed, so the level of confidence in the presence records is higher. Threatened species were defined using the IUCN Redlist web site (IUCN 2012). In the case of plants we modeled timber species as surrogates for the threatened species given limited time as well as the endemic plants.

Species distribution models estimate the actual or potential geographic distribution of a species through quantifying the relationship of known species occurrence records and the environmental conditions at those sites (Elith *et al.* 2011; Pearson, 2007). Quantifying species-environmental relationship requires the visualization of species occurrence records in both geographical and environmental space. Geographical space represents the species' distribution as plotted on a map (defined as a species 'occupied niche') while environmental space is a conceptual space defined by environmental variables to which species responds (Pearson, 2007). A species distribution model identifies the species' niche in environmental space as described by species occurrence records in geographical space. When the model is projected back from environmental space to geographical space, the model fits parts of the actual and potential distribution (Pearson, 2007). Species distribution models have been used to support a variety of conservation ends including: conservation planning and reserve selection (Watson *et al.* 2010), projecting impacts of climate change on species (Willis *et al.* 2009), guiding field surveys to find new species (Pearson, 2007), predicting invasive species (Thuiller *et al.*, 2005a), and testing biogeographical, ecological and evolutionary hypotheses (Guisan and Thuiller, 2005).

Species occurrence data

Species occurrence data was obtained from various sources including Wildlife Conservation Society, Tanzania mammal data atlas and Global Biodiversity Information Facility (GBIF 2012: <http://www.gbif.org/>). A total of 70,000 occurrence records for birds, plants and mammals were used to fit distribution models using the Maxent algorithm. The number of presence records used for training the model varied from 15 to 3000 per species. The receiver operating characteristic (ROC) plots, were used for evaluating the predictive performance of our models (Freeman and Moisen, 2008; Manel *et al.* 2001). ROC plots provide a threshold independent measure of model accuracy of presence-absence models. The ROC plots area under curve (AUC) provides an effective indicator of model performance and AUC values ≥ 0.8 were selected for the final analysis (Manel *et al.* 2001). The list of species modeled is provided in Appendix 1.

Predictor variables

Predictor variables that are ecologically important for the distribution of birds, mammals and plants in the Albertine Rift were selected (Table 1). For current conditions, climate layers were obtained from the WorldClim database (<http://www.worldclim.org>) with a spatial resolution of $\sim 1 \text{ km}^2$. Additional predictor variables that were included in the model are: cloud mean, cloud max, lithology, digital elevation model, distance to rivers, slope, eastness, northness, drainage basin, aspect. Cloud mean and cloud max were derived from MOD09GA Surface Reflectance data which is provided in Hierarchical Data Format (HDF) at daily temporal resolution and was calculated by G. Picton-Phillipps.

Table 1: Predictor variables used for modeling the distribution of endemic and threatened species in the Albertine Rift.

Name of Variable	Description of Variable
Bio2	Mean daily temperature range
Bio7	Temperature annual range
Bio6	Minimum temperature of coldest month
Bio5	Maximum temperature of warmest month
Bio12	Annual precipitation
Bio17	Precipitation of driest quarter
Bio16	Precipitation of wettest quarter
Cloud mean	Annual normal percent cloud cover
Cloud max	Maximum cloud cover for each pixel
Roads	Distance to nearest road
Lithology	Geologic parent material
DEM	Digital elevation model
Rivers	Distance to nearest river
Slope	Rate of maximum change in elevation
Easteness	Orientation East - West
Northness	Orientation North- South
Drainage basins	Topographically delineated area drained by a stream system
Aspect	Direction a slope is facing

Rivers and roads data layers were obtained from the African data sampler dataset (WRI 2010). Prior to inclusion in the model the euclidean distance was calculated from in each point in the Albertine Rift to the nearest road or river. The distance to roads and rivers was used as a surrogate for human access to an area. Lithology reflects key geological parent materials which are determinants in the distribution of vegetation (Source; U.S. Geological Survey/ The Nature Conservancy). Slope, aspect, eastness and northness were computed from the 90 metre digital elevation model (Source: <http://srtm.usgs.gov/>). Drainage basins were obtained from USGS Global data set of 2003. All predictor variables were clipped to the extent of the Albertine Rift and resampled to a 1 km^2 resolution using Arcgis 9.3. To remove multi-collinearity we ran a pairwise Pearson correlation using ENMTOOLS (Warren *et al.* 2010; a toolbox for comparative studies of environmental niche model; <http://purl.oclc.org/enmtools>) and only variables with less than (± 0.75) correlation were retained.

Future model projections for 2080 were calculated from three general circulation models (CCCMA: CGCM2, CSIRO: MK2 and HADCM3) and one (A2a) Intergovernmental Panel on Climate Change Special Report Emissions Scenario (IPCC 2007). We selected the A2a scenario/storyline that assumes a very heterogeneous world with high population growth, slow economic development that is regionally oriented and slow technological change that is slower and fragmented than other story lines (IPCC 2007).

Ecological modeling

Species distribution models were developed using a Maximum Entropy approach (hereafter 'Maxent', Maxent version 3.3.3e; Phillips & Dudík, 2008). Maxent is a program for modeling species distributions from presence-only occurrence records (Phillips *et al.* 2004, Phillips *et al.* 2006). The Maxent algorithm computes predictions or makes inferences from incomplete information (Phillips *et al.* 2006). We selected Maxent because it has been shown to consistently outperform other presence only methods (e.g. Bioclim, Domain) as well as presence-absence methods (e.g. GAM, GLM, GARP), (Elith *et al.* 2006). Maxent estimates the probability distribution with the maximum entropy (ie. that is most spread out, or closest to uniform), subject to constraints imposed by the information regarding presence records and the background information across the study area (Phillips *et al.* 2006; Elith *et al.* 2011). Default model parameters in Maxent were used for all species (Auto features, convergence threshold of 0.00001, maximum number of background points =10,000, regularization multiplier=1). We also ran Maxent just using Hinge features and compared the outputs with known distributions of the species. Hinge features are functions for piecewise linear splines and fit models closely related to GAMs (Elith *et al.* 2011). For about a third of the species modeled the 'Hinge features' model provided a more realistic result and these were selected for these species. A logistic format which provides an estimate between 0 and 1 of probability of presence of the species was the output.

In order to identify corridors for conservation of species a binary prediction of each species' presence or absence in an area was also required. The "maximum training sensitivity plus specificity" threshold rule was used to convert the continuous logistic output format from Maxent into binary (presence/absence) prediction of the distribution for each species (Freeman and Moisen, 2008; Manel *et al.* 2001). This threshold rule minimizes the mean error rate for positive observations and the error rate for negative observations (Freeman and Moisen, 2008). All areas with where the predicted probability of species presence was above the threshold were classified as "present" and areas with a predicted probability below the threshold were reclassified as "absent". A sampling bias layer was included in the Maxent runs for some taxa to account for the intensity of sampling. A bias layer was created in Arc Gis 9.3 by using a three by three smoothing window for the sampled areas. The predictions were extrapolated from the bias layer to outside the sampled areas to predict species presences throughout the Albertine Rift. Bootstrapping was used as a form of replication (10 runs), with the random test percentage set to 25. The training data are selected by sampling with replacement from the species occurrence points and the number of points in each run is equivalent to the total number of points available for training.

Current distribution of endemic and threatened species

The predicted extent of occurrence for each species included all areas in the region that are climatically suitable for that species. This extent is likely to overestimate the species current extent of occurrence because many of the areas identified as climatically suitable do not contain suitable habitat for the species. To correct for this model overestimation we used a recent map of land cover to remove areas no longer containing natural habitat. The GlobCover land cover was re-classified into three land cover classes; water, other, and natural vegetation (ESA 2008). The "other" class included all areas currently dominated by agriculture, forestry or urban development. The presence-absence model of each species distribution was clipped to the extent of the natural habitat layer to remove areas that do not contain natural habitat.

Endemic species

Figure 1 shows a map of the number of endemic species for birds, large mammals and plants separately and then combines the three maps together to provide an estimate for all three taxa. Because the number of plant species modeled is significantly larger than the number of mammal and bird species the combined assessment tends to be weighted strongly by the plant data. A future analysis will consider weighting taxa equally or species specific weightings that reflective relative importance for achieving conservation objectives. Grauer's gorilla was included as an endemic sub-species but occurs to the west of the Albertine Rift slightly. Whether the boundaries of the rift should be redefined to include this sub-species is something that needs consideration.

Threatened species

Similar maps were created for the threatened species in each taxon for which a reasonable number of observations ($n > 15$) were available to model the species distribution (figure 2). Timber species were mapped as a surrogate for threatened plants because many of these species are threatened also under the IUCN Redlist classification. In future we plan to model many of the additional 878 threatened plants species for which we have sufficient data.

Where species were both endemic and threatened they are only included once in the maps (usually the map with fewest species) because we intended to sum the number of endemic and threatened species and did not want to double count the same species. These results indicate that the northern part of the Albertine Rift, the region around the Okapi Wildlife Reserve in the northwest, and the wetland areas of Katanga in the south west contain large numbers of threatened species.

Threatened and endemic species

The results of both the threatened and endemic species analysis were then combined into one assessment to map the density of threatened and endemic species in the Albertine Rift (figure 3). This figure shows that the highest numbers of endemic and threatened species occur on the mountain tops and particularly in the Nyungwe-Kibira Landscape and in the Itombwe Massif. Most of the Albertine Rift region is predicted to contain at least one threatened or endemic species from the list that we modeled. It is unlikely that the whole region can be protected and it probably doesn't need to be. We plan in future to use the Marxan decision support tool to select areas where viable populations of all the species could be conserved while minimizing costs of doing so.

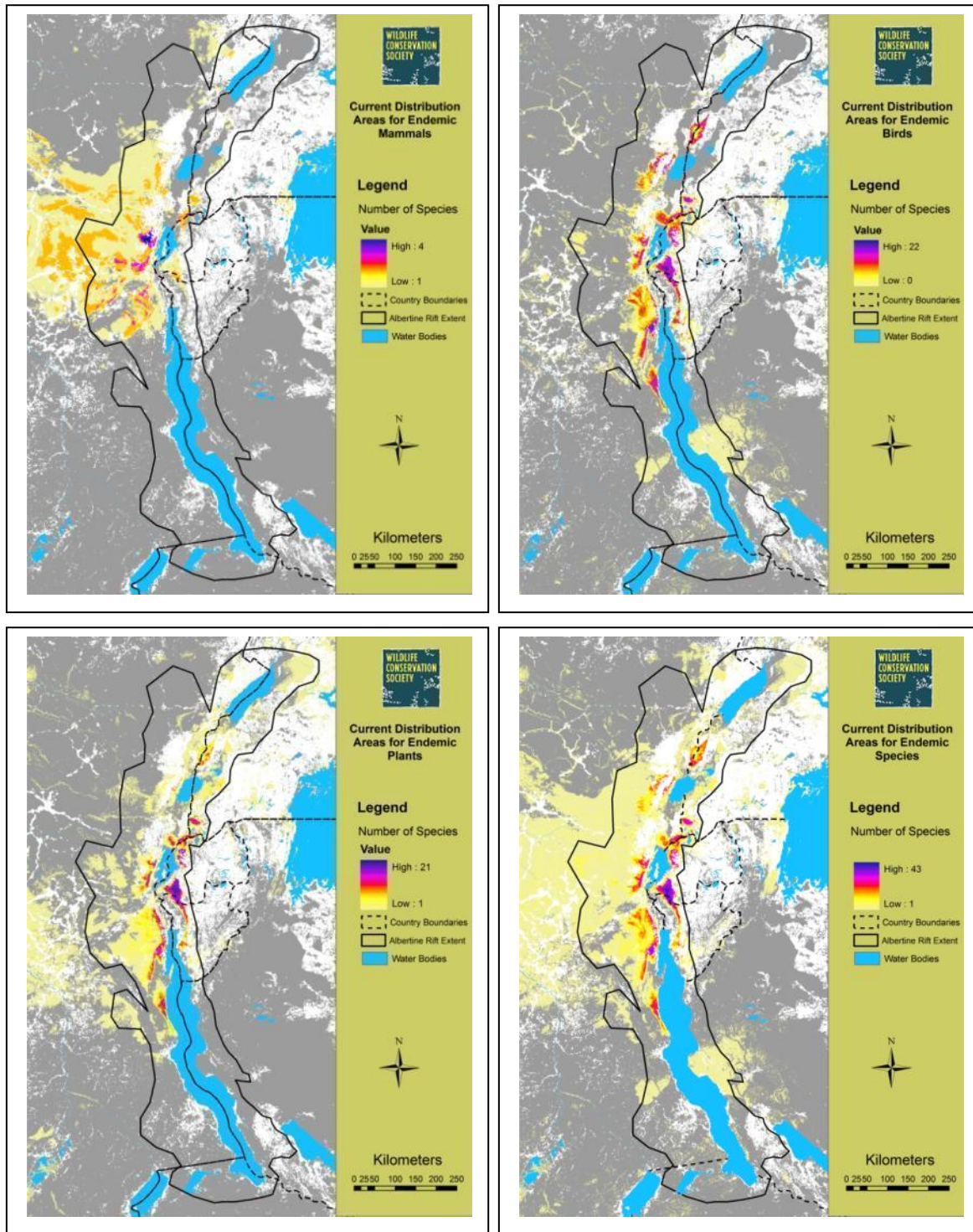


Figure 1. Current density of endemic large mammals (top left, n=6), endemic birds (top right, n=26), endemic plants (bottom left, n=36) and all endemic species (bottom right, n=68).

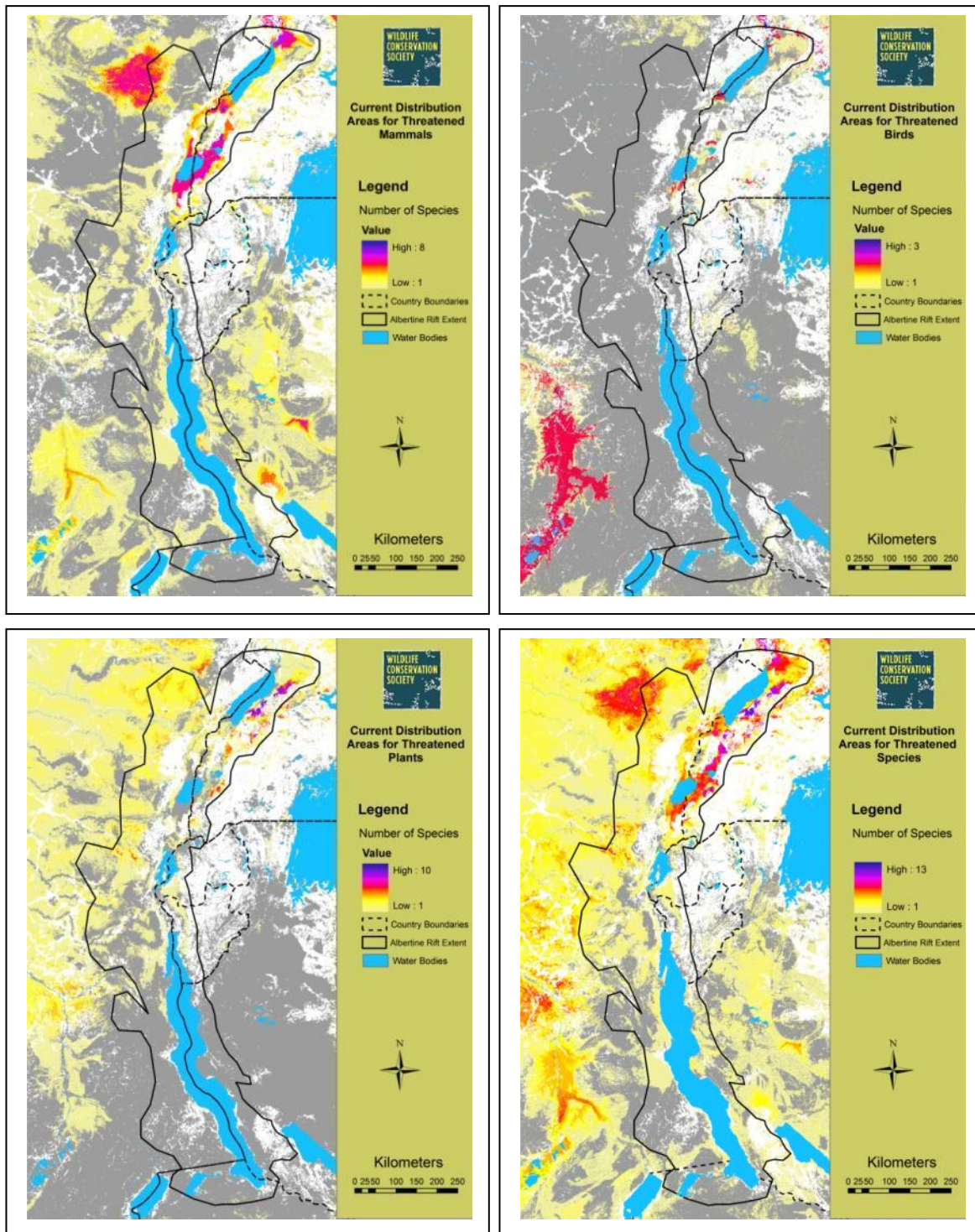


Figure 2. Distribution of threatened large mammals (top left, n=11), threatened birds (top right, n=4), timber species of tree (bottom left, n=10) and all threatened species (bottom right, n=25).

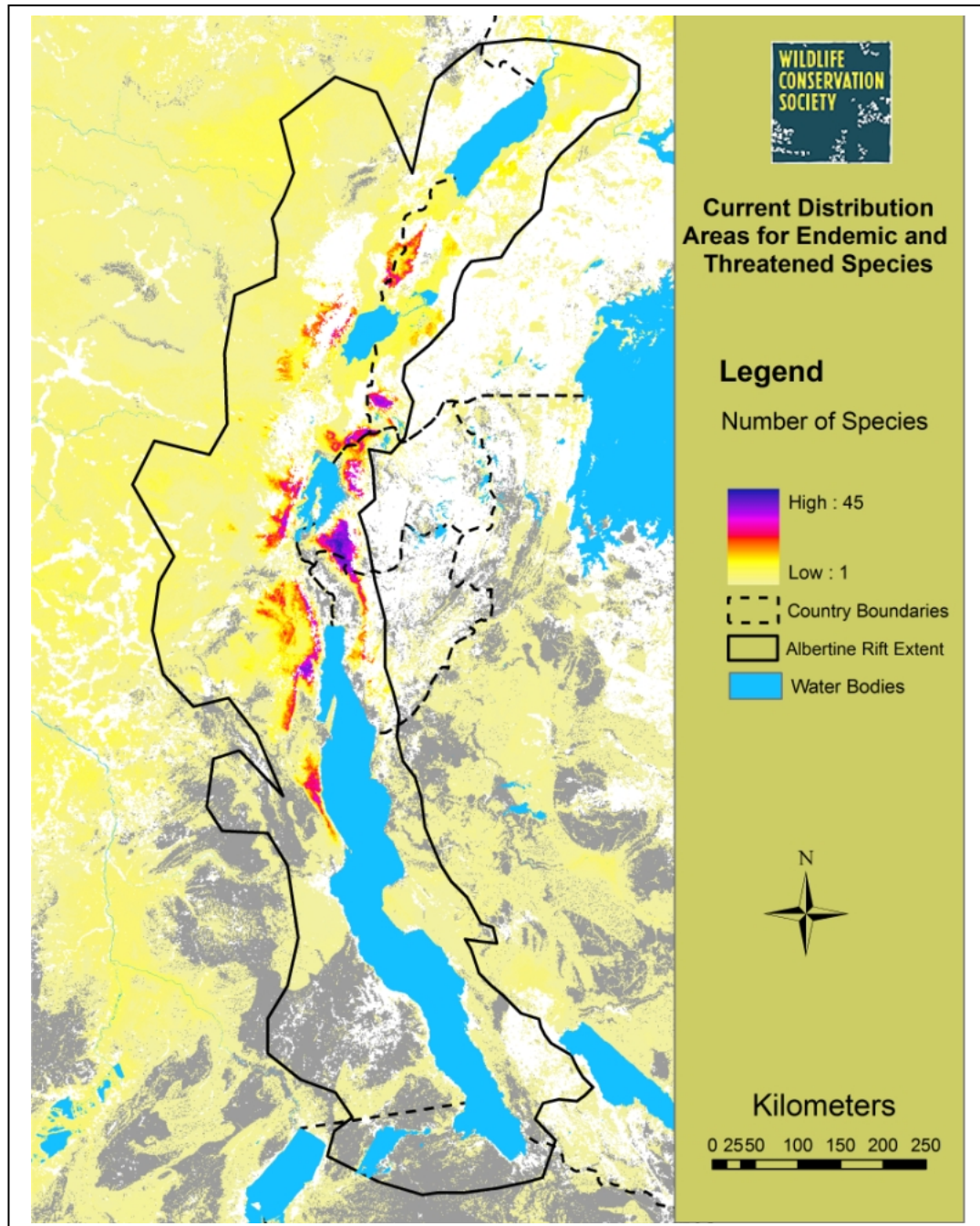


Figure 3. Density of threatened and endemic plants, birds and large mammals per 1 km² cell across the Albertine Rift. Based on the output of 93 species distribution models.

Future distribution of endemic and threatened species

The future distribution of each species was forecasted using the A2 emissions scenario and three GCMs (see above) to the year 2080. Different GCMs produced variable predictions about future suitability within the landscape. To combine the information garnered from modelling the future distribution with different GCMs into a single prediction, we first calculated a threshold for each species based with each GCM. The threshold was used to reclassify the model output from likelihood of occupancy to presence/absence. We considered two methods of combining the binary predictions of each model into an aggregate prediction of future presence: (i) *model consensus*, that is cells classified as suitable if all three models predict presence, and (ii) *model majority*, that is cells classified as suitable if two of the three models predict presence

The use of the "model consensus" approach is a more conservative approach to identifying viable future habitat for species, that addresses some of the uncertainty originating from different emission scenarios (Garcia *et al.*, 2012). To avoid underestimation of future habitat, we also considered the "model majority" approach for the identification of future habitat.

Endemic species

The same endemic species were modeled under future climate scenarios as the current distribution and plotted separately by taxon and then combined across all three taxa using the same methods as used for the current distributions (figure 4). This figure shows sites predicted by all three climate models (consensus model). If however we select sites where only two climate models out of the three agree in their 2080 predictions then we get a larger area of potential future distribution but the similar areas within the Rift are being selected (figure 7). Interestingly some endemic plants are predicted to expand in their distributions and to move to lower altitudes.

Threatened species

The threatened species modeled for the current distributions (figure 2) were modeled under the 2080 future climate distribution as described in the methods. The results are plotted for each taxon individually and then combined for all species modeled (figure 5). We also assessed how the results differ when only selecting predictions of two of the three climate models (figure 8). The results do not differ greatly within the Albertine Rift boundary but do outside this area where predictions are made in south west Uganda which may not be realized in practice.

Threatened and endemic species

Finally, the results of the modeling for both endemic and threatened taxa were combined into one map which summarises the predicted number of these species per 1km² cell across the Albertine Rift region in 2080 (figure 6). We also made the same assessment for potential sites where only two of the three climate models predicted a species (figure 9). Both of these results indicate that the mountain areas with highest peaks as well as the Greater Virunga Landscape are important areas for the future conservation of endemic and threatened species. The Greater Virunga Landscape becomes of greater importance in the model consensus scenario, but the maximum density of species in a single 1 km² cell drops from 36 to 19 species.

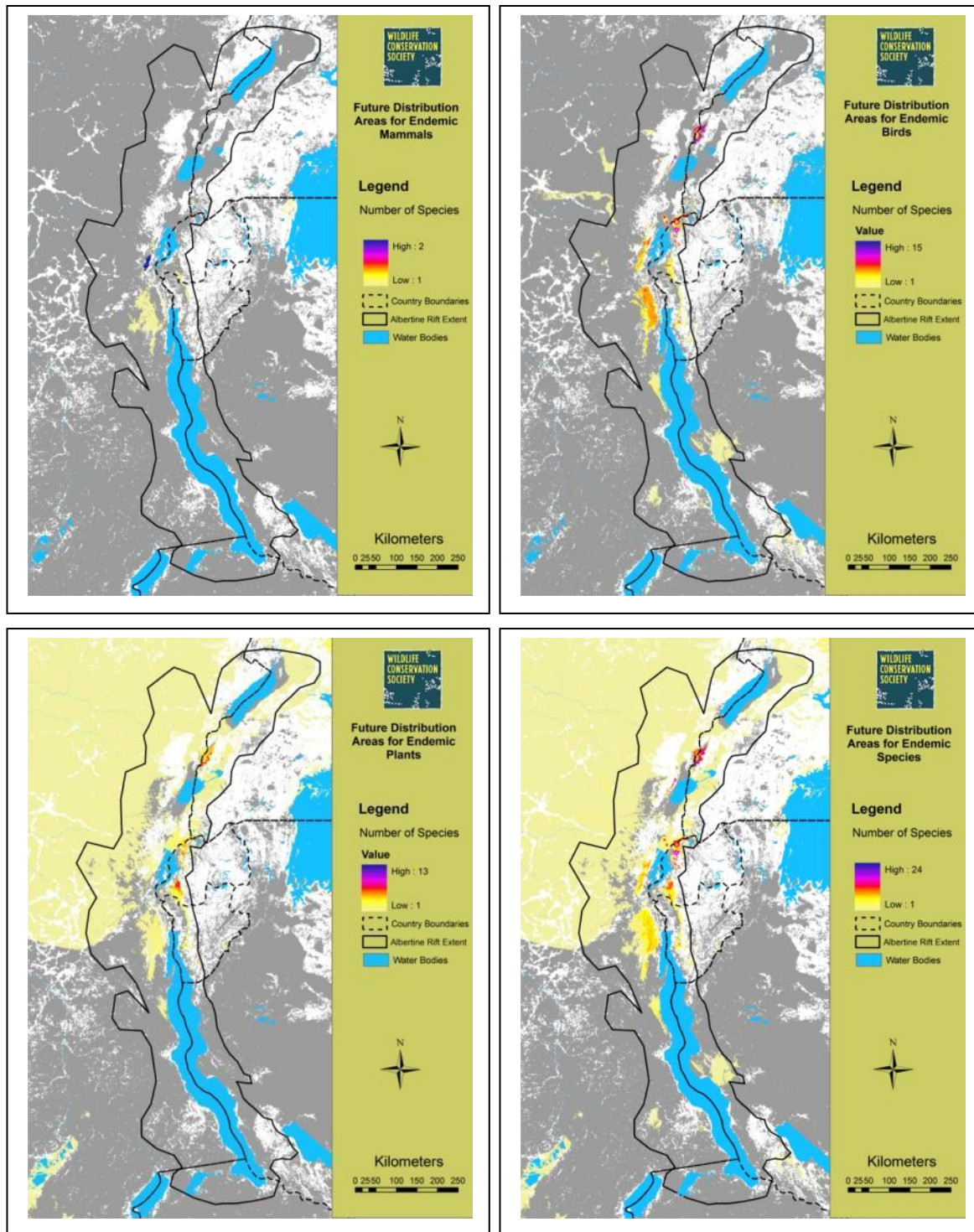


Figure 4. Consensus model results for the density of endemic species in 2080: large mammals (top left, n=6), endemic birds (top right, n=26), endemic plants (bottom left, n=36) and all endemic species (bottom right, n=68).

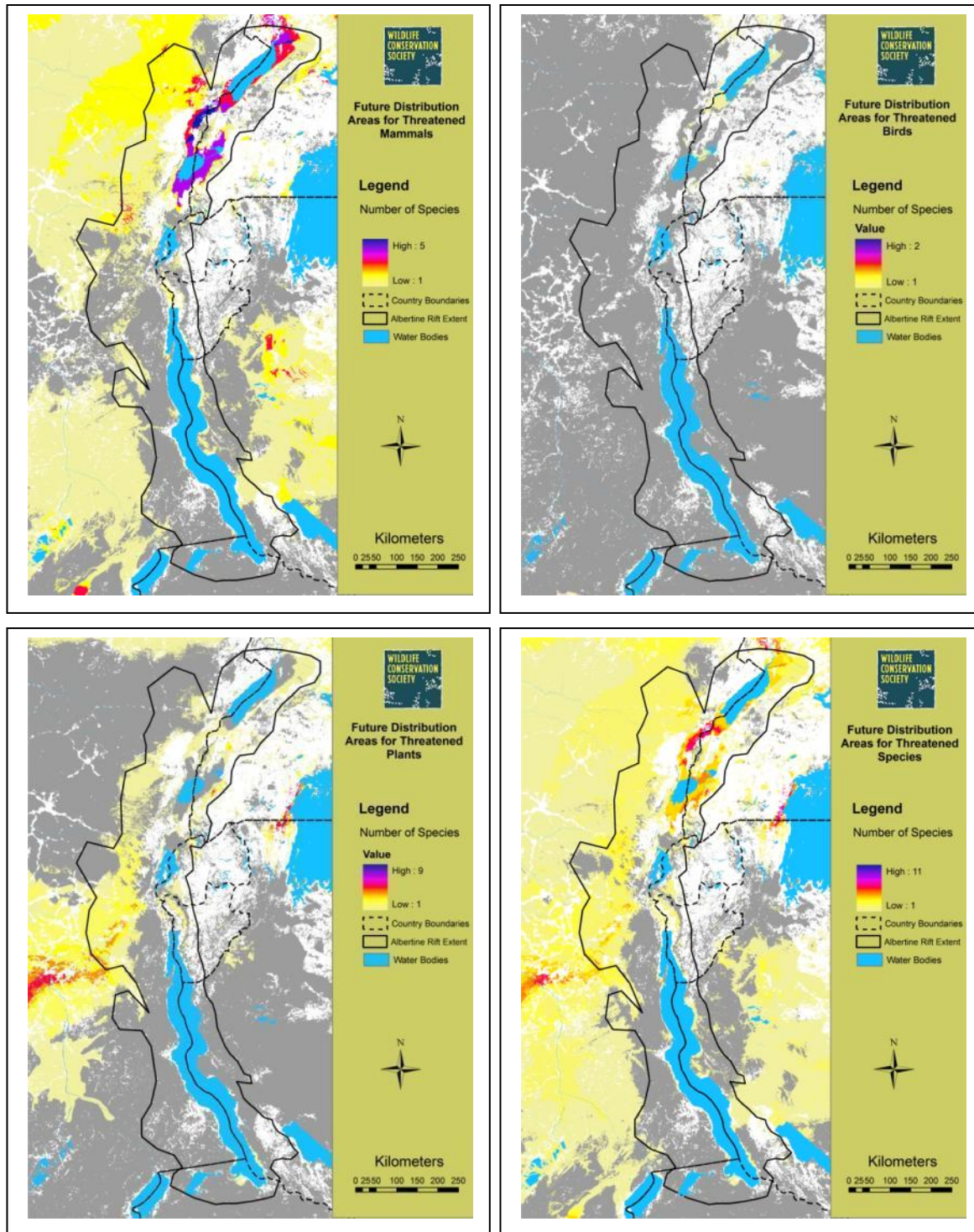


Figure 5. Consensus model results for the density of threatened species in 2080: large mammals (top left, $n=11$), threatened birds (top right, $n=4$), timber species of plant (bottom left, $n=10$) and all threatened species (bottom right, $n=25$).

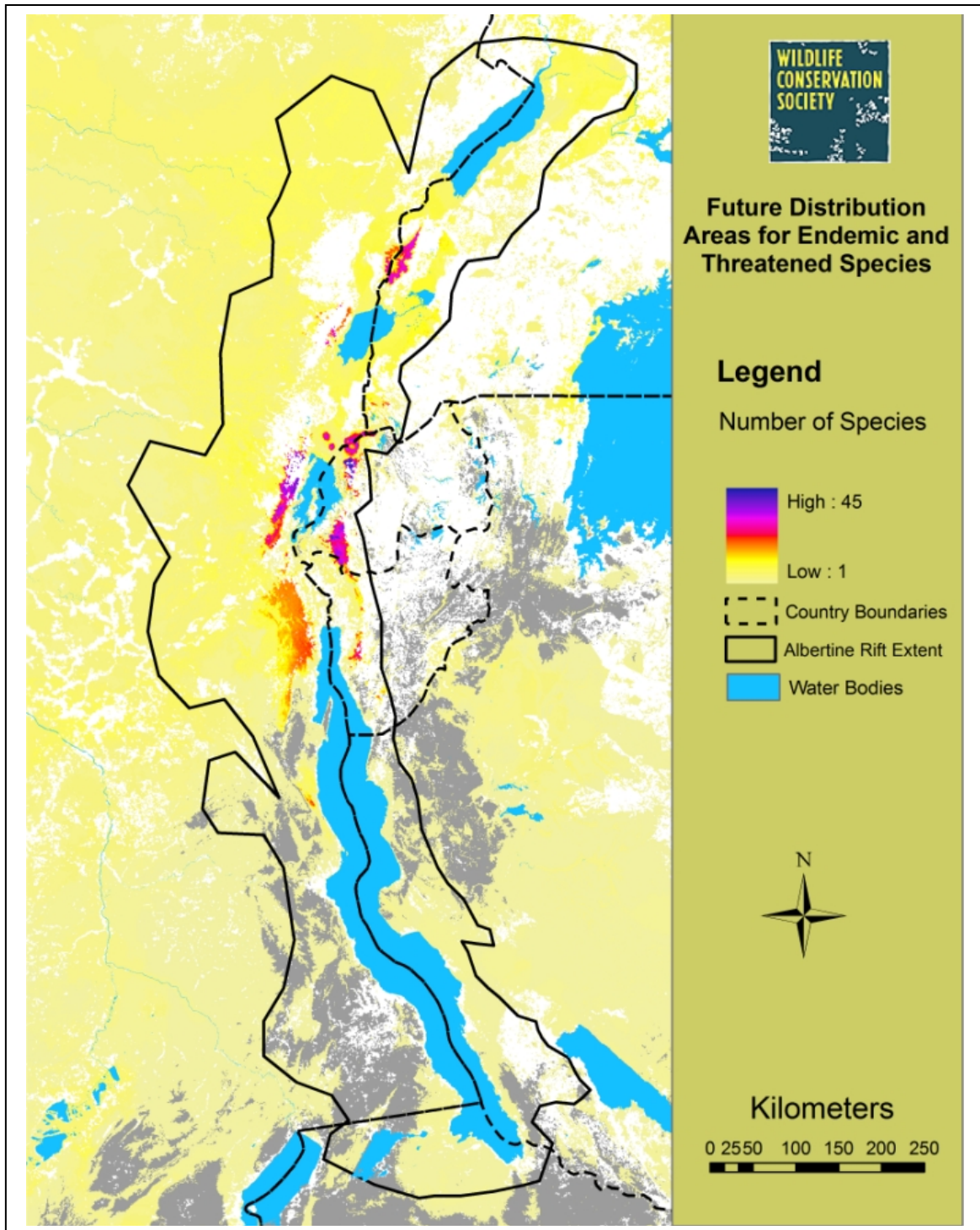


Figure 6. Consensus model results for density of threatened and endemic plants, birds and large mammals per 1 km² cell across the Albertine Rift from a total of 93 modeled species predicted in 2080.

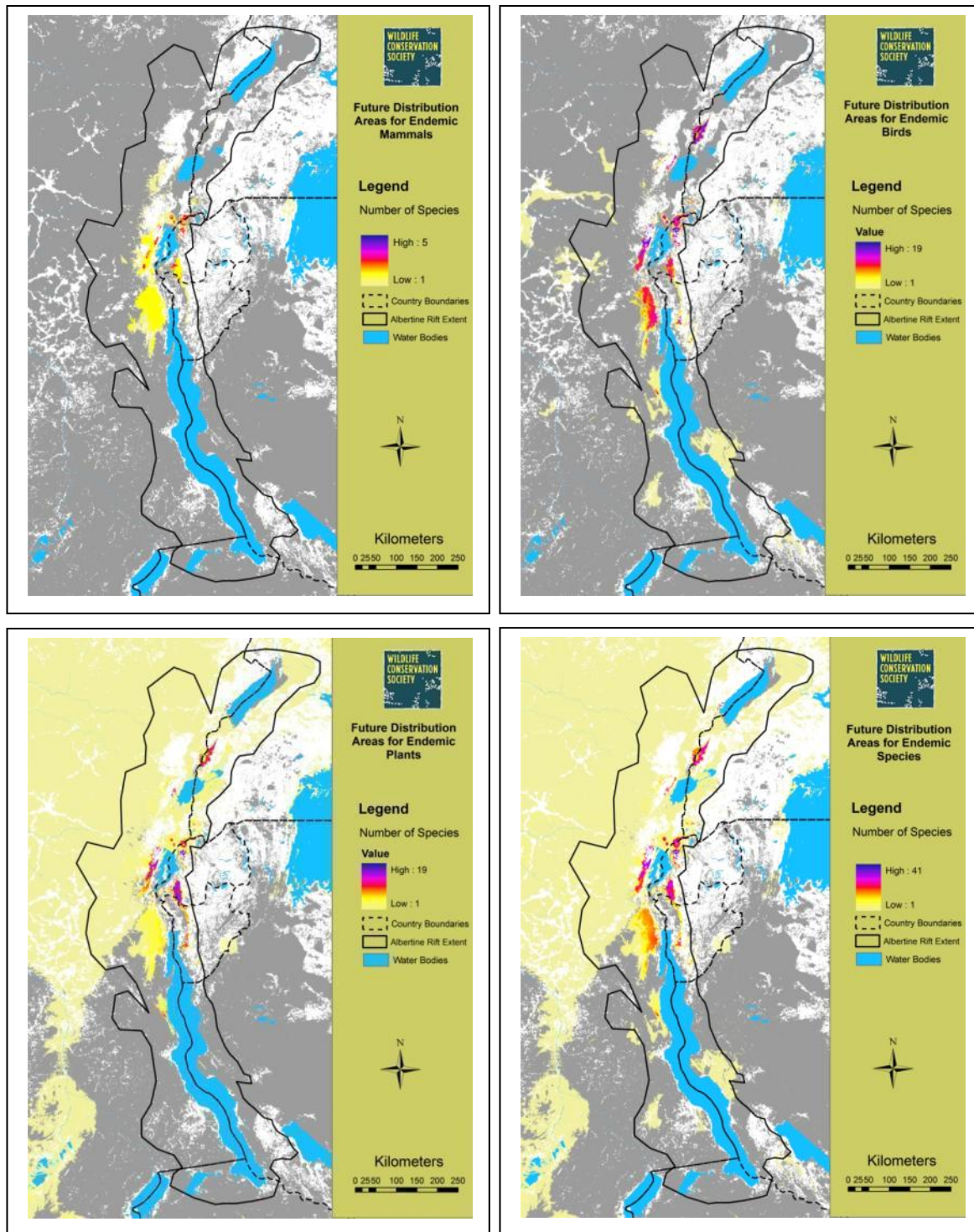


Figure 7. Model majority results for the density of endemic species in 2080: large mammals (top left, n=6), endemic birds (top right, n=26), endemic plants (bottom left, n=36) and all endemic species (bottom right, n=68).

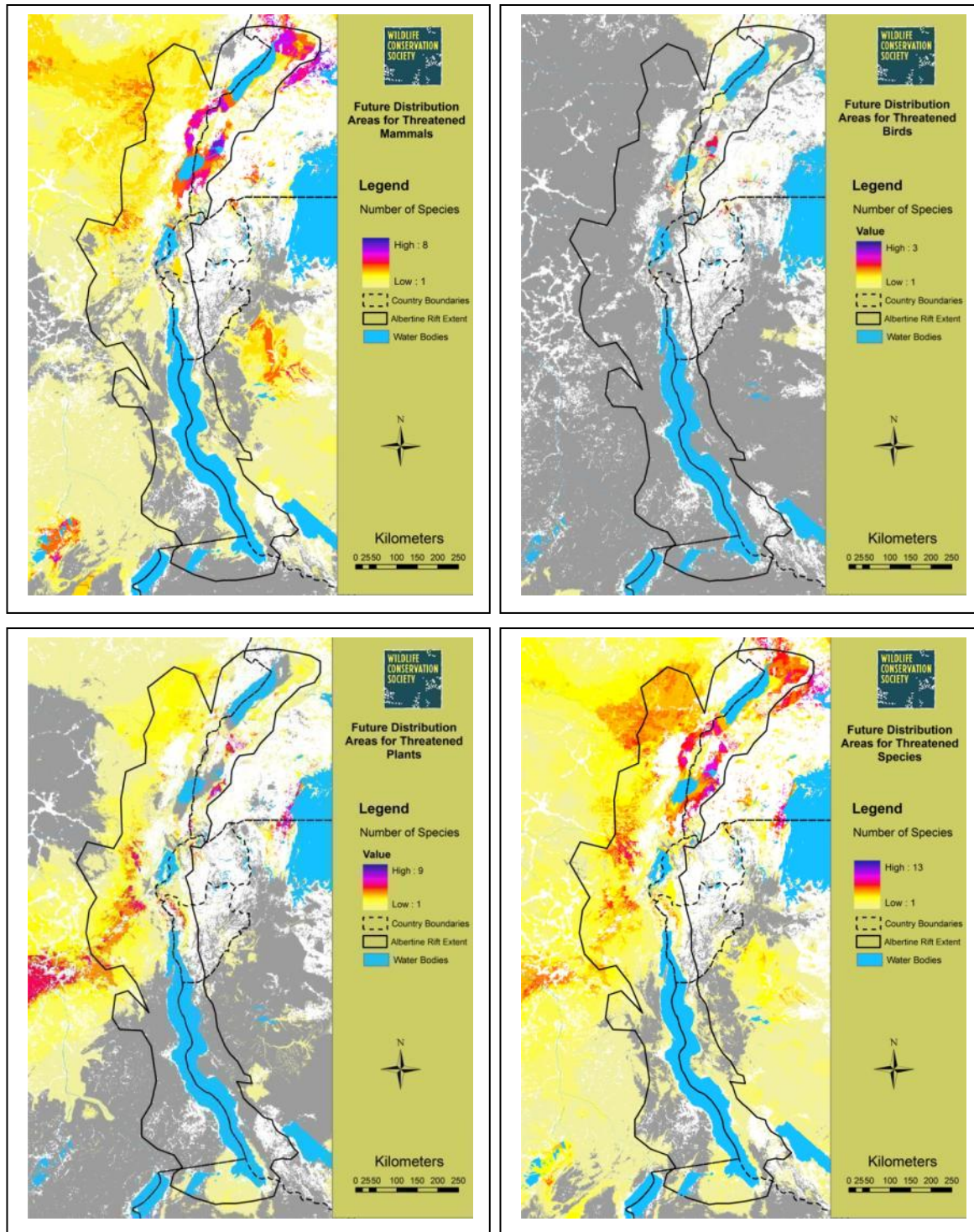


Figure 8. Model majority results for the density of threatened species in 2080: large mammals (top left, n=11), threatened birds (top right, n=4), timber species of plant (bottom left, n= 10) and all threatened species (bottom right, n=25).

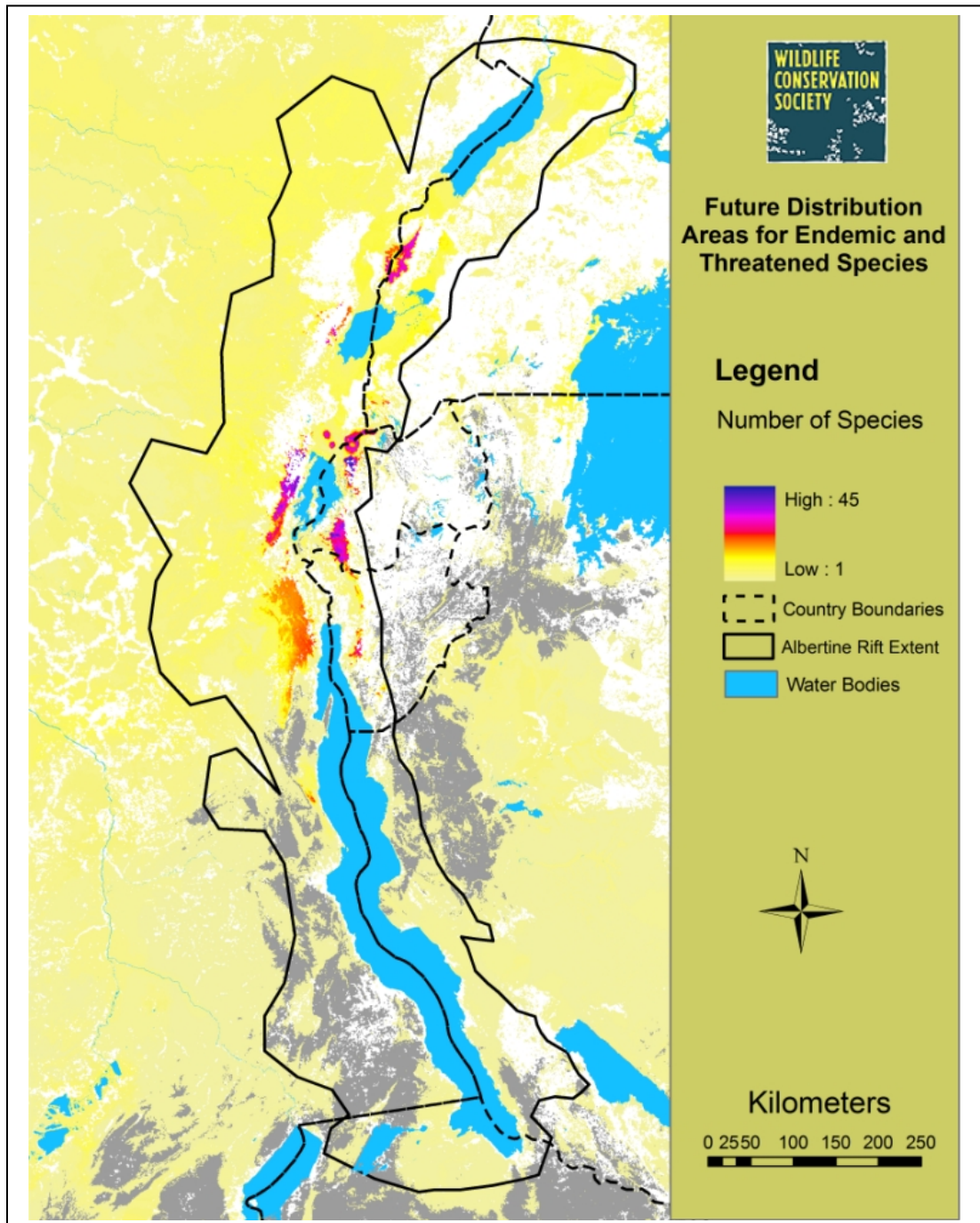


Figure 9. Model majority results for the density of threatened and endemic plants, birds and large mammals per 1 km² cell across the Albertine Rift from a total of 93 modeled species predicted in 2080.

Changes in vegetation types under future climate change

In this section we explore the use of species distribution models to understand how vegetative cover in the region may shift in response to changes in climatic conditions. For this analysis we considered five of the six main vegetation types of the Albertine Rift: alpine vegetation, montane forest vegetation, medium altitude forest, low altitude forest and bamboo forest. We used an altitude range to delimit the different tropical forests: montane forest (above 1500 m a.s.l.), medium altitude forest (between 1000-1499 m.a.s.l.) and low altitude forest (below 1000 m.a.s.l.). Even though savannahs occupy a large area in the Albertine Rift, we did not include them in our modeling because they often emerge when other vegetation types are altered by human activities. The role of humans in determining the distribution of savannah within the region means that application of niche based models to predict future extent would lead to inaccurate predictions if confounding influence of people was not accounted for. Detailed forecasting of the future activities of people within the region was beyond the scope of this project and thus a model of savannah was not included.

The application of species distribution models to predict shifts in environmentally suitable areas of entire vegetation types under future climate change scenarios is a relatively novel approach, that has not been leveraged much until recently (Carnaval & Moritz, 2008 and Ponce-Reyes et al 2012). The philosophy is similar to that used to identify climatically suitable space for individual species, and the approach can be used to identify areas that are likely to experience shifts in dominate vegetation type or vegetative communities that are most vulnerable areas to climate change.

Methods used

To model the current and future distribution of the vegetation types we followed the methodology of Ponce-Reyes *et al.* (2012) in which instead of modeling the distribution of single species, the extent of a vegetation type was modeled by extracting random points from within the current distribution of the vegetation type. The model is trained using the points drawn from the known current distribution and current environmental variables, before using future environmental variables to project future extent.

Species distribution models

For the reasons explained in the “Modeling distributions of threatened and endemic species” sections we used Maxent ver. 3.33 (Philips *et al.* 2006), a presence-only distribution modeling algorithm. We also used the default model parameters for modeling the distribution of each of the vegetation types (Auto features, convergence threshold of 0.00001, maximum number of background points =10,000, regularization multiplier=1).

We used the threshold value at which “equal training sensitivity and specificity” (Hoegh-Guldberg *et al.*, 2008) to convert the logistic output from Maxent into a binary (presence/absence) grid to calculate the extent of the suitable areas. This threshold value finds out where positive and negative observations have an equal chance of being correctly predicted (Fielding and Bell, 1997). To validate the model we used a 10-fold cross-validation, in which the presence data are partitioned to the number of folds

(replicates), in this case 10, and for each run one fold is excluded as test data and the rest are used for training.

We then calculated the mean area under the receiver operating characteristic curve (AUC; Hanley and McNeil, 1982). The AUC is a metric that compares models without using thresholds and it indicates the probability that a randomly chosen presence site will be ranked above a randomly chosen absence site (Philips and Dudik 2008). An AUC score above 0.7 is considered good model performance (Fielding and Bell 1997).

Vegetation type occurrence data were obtained from direct observations (field surveys made by WCS) and vegetation maps. The vegetation maps used for generating the points were: MODIS (https://lpdaac.usgs.gov/get_data), GLC2000 (<http://bioval.jrc.ec.europa.eu/products/glc2000/>), Globcover 2009 V2.3 (<http://ionia1.esrin.esa.int/>), and regional vegetation maps, including: forest change Democratic Republic of Congo (FACET 2010; <http://www.osfac.net>), Greater Virunga (WCS Unpublished data from aerial photograph interpretation), Kabobo (WCS Unpublished data from aerial photograph interpretation), Murchison-Semliki Landscape (WCS Unpublished data from aerial photograph interpretation), Greater Mahale (Jane Goodall Institute unpublished data), Uganda (National Biomass Study, NFA, Uganda). As the vegetation maps differed in their resolution, extent of coverage, and categorization of vegetation types, we extracted a random number of points from each of the five vegetation types. Using the R statistical software (R Development Core Team, 2009) we generated a random number between 1000- 10,000 for each vegetation type (due to the restricted distribution of alpine vegetation we only generated a number between 100 and 500). Then using all the layers for the vegetation type of interest and the points obtained from WCS field surveys we randomly sampled the selected number of points from all representations of each vegetation type. In this way we produced a dataset with randomly distributed points within each vegetation type separated by 1km². This combined dataset was used as the input dataset into the Maxent analysis to train the models. The total number of points used for developing each model for each vegetation type is shown in table 2.

Table 2. Number of presence points to develop Maxent models combining fieldwork observations and vegetation cover maps.

Vegetation type	Number of points
Alpine vegetation	326
Bamboo forest	1068
Low altitude forest	2760
Medium altitude forest	3932
Montane forest	7094

Current predictor variables

We selected variables of ecological importance for the distribution of the five main vegetation types in the Albertine Rift that were not autocorrelated (Table 3). To remove autocorrelated variables we ran a pairwise Pearson correlation in ENM Tools (Warren *et al.* 2010; <http://purl.oclc.org/enmtools>). We retained only those variables with less than +/- 0.75 correlation. The climatic variables dataset for the current conditions were obtained from the WorldClim website (Hijmans *et al.* 2005; <http://www.worldclim.org>) at a spatial resolution of 30m². The lithology data were obtained from U.S. Geological Survey/ The Nature Conservancy and soil data was sourced from the FAO Digital soil map of the world (FAO 2007). Each model was trained by masking predictor variables around a 10 km radius of the point locality for each of the vegetation types (except the low altitude forest). We did this for all the vegetation types, except for the low altitude forest, as they have restricted distributions. Finally we projected the distribution of each vegetation type to the whole Albertine Rift region.

Table 3. Predictor variables

Name of variables	Description of Variable
Bio2	Mean daily temperature range
Bio7	Temperature annual range
	Minimum temperature of coldest
Bio6	month
	Maximum temperature of warmest
Bio5	month
Bio12	Annual precipitation
Bio17	Precipitation of driest quarter
Bio16	Precipitation of wettest quarter
Soils	A map of the soils
Lithology	A map of parent materials

Current distribution of vegetation types

Resulting mean AUC values of all models were between 0.808-0.915 indicating excellent prediction of present-day Albertine Rift's vegetation types distribution and confirming the utility of these models for making projections of future forest distributions (figure 10). Savanna and woodland were modeled but we found that it was difficult to accurately predict these two vegetation types and this is likely to be because they are affected by anthropogenic factors such as fire.

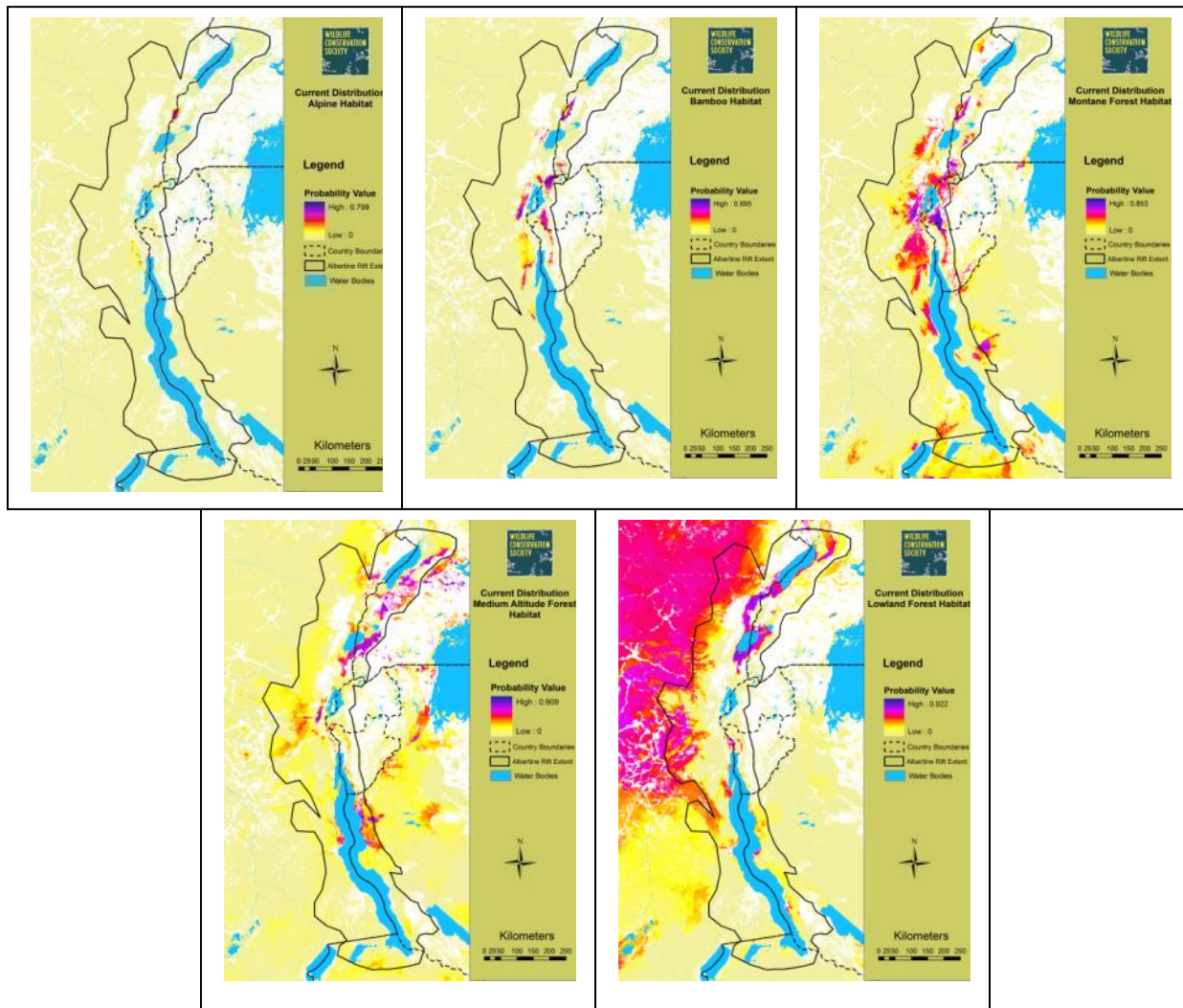


Figure 10. Current modeled distribution of five vegetation types in the Albertine Rift: Alpine (top left), bamboo (top centre), montane forest (top right), medium altitude Tropical forest (bottom left), low altitude tropical forest (bottom right). Values reflect the probability that the vegetation type will be present.

Future distribution of vegetation types

Future predictor variables

Once we developed the models for the current distribution of each vegetation type, we projected the distribution of each in the year 2080 using the predicted climatic variables. To do so, we used the same three GCMs: CCCMA CGCM2; CSIRO MK2 and HADCM3 from the A2a Scenario (IPCC 2007) as were used for the species modeling. To predict the future distribution of each vegetation type we used the current version of the two static variables (soil and lithology) and the predicted version of seven climatic variables (table 3).

The binary vegetation type suitability layers were developed in the same way as the current vegetation type suitability layers, using the “equal training sensitivity and specificity” (Hoegh-Guldberg et al 2008). Once we developed the future distribution vegetation maps we estimated the extent of each one of those and compared the extent and overlap of each vegetation type today and in the year 2080. This provided us with estimates of how the distribution of five major vegetation types might shift within the Albertine Rift as a result of climate change.

Future Distribution of vegetation types

We also mapped the distribution of vegetation types as predicted for 2080 under the three climate models selecting those cells which were predicted by each of the three models (figure 11).

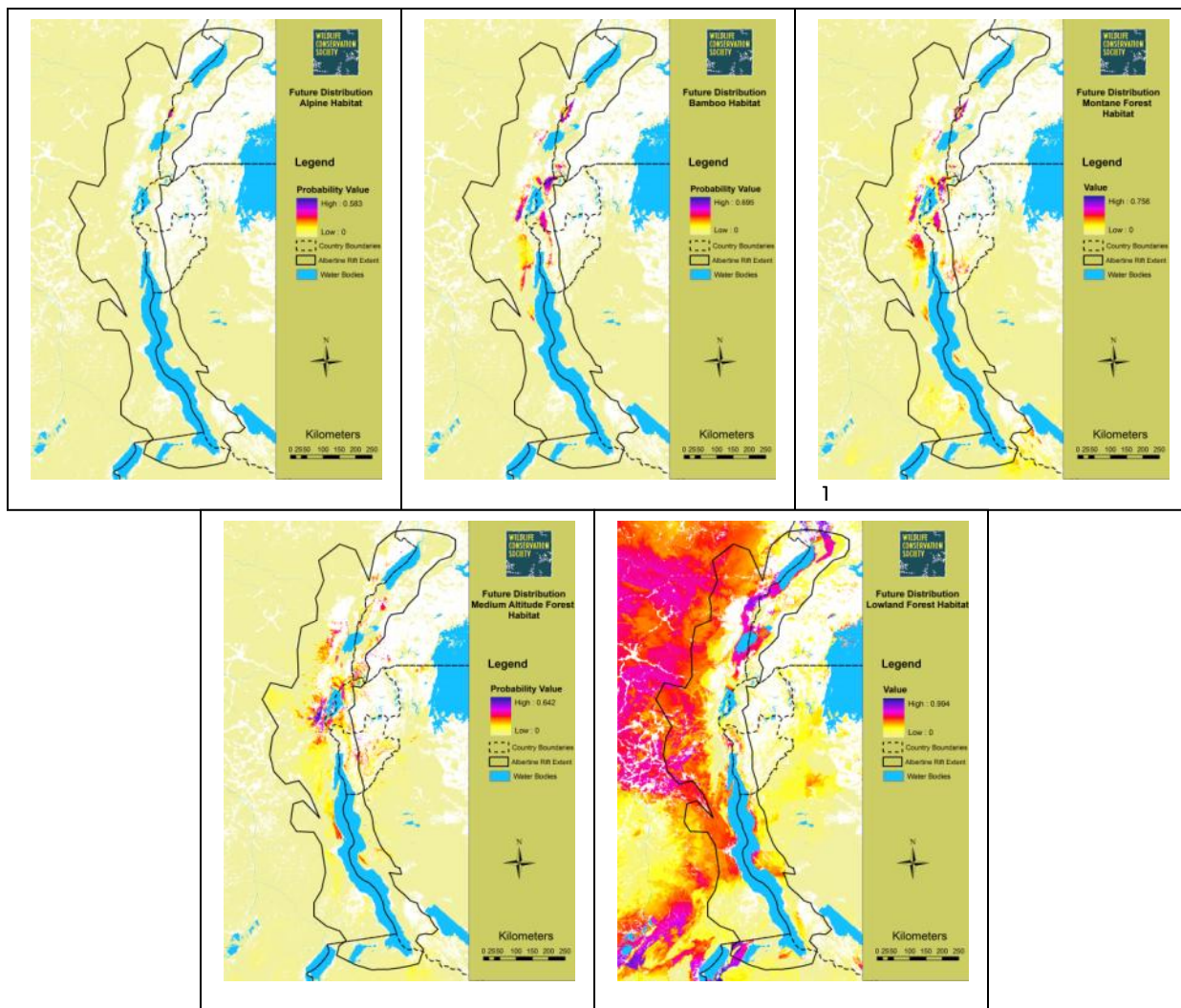


Figure 11. Future distribution of five vegetation types in the Albertine Rift modeled for 2080: Alpine (top left), bamboo (top centre), montane forest (top right), medium altitude Tropical forest (bottom left), low altitude tropical forest (bottom right). Values reflect the probability that the vegetation type will be present.

Our analyses suggests that the predicted extent of areas with suitable environmental conditions for four of the five vegetation types (alpine vegetation, bamboo forest, medium altitude forest and montane forest) will decrease significantly by 2080 (between 56-94% of their current extent, depending on the vegetation type- see Table 4). The lone vegetation type predicted to expand the area it occupies within the Rift was low altitude forest, which is predicted to increase coverage by almost 50%. In this analysis we are considering the areas with environmental suitability for five vegetation types (even though some of those areas have already been cleared for urban areas or agricultural zones). The general trend is that the extent of environmentally suitable areas for natural vegetation types will decrease about 22% in 2080.

Table 4. The change in extent of each vegetation type predicted from the current and future distributions. The totals vary because some vegetation types such as savanna grassland and woodland have not been included and also because there is some overlap in the predicted vegetation types.

Vegetation type	Extent in km ² 2010	Extent in km ² 2080
Alpine vegetation	1232	316
Bamboo forest	13,882	785
Montane forest	77,960	34,114
Medium altitude forest	308,937	66,376
Low altitude forest	302,373	444,828
Total vegetation cover	704,384	546,419

Identification of abiotic gradients in the Albertine Rift

The two previous approaches explored in this report focus on species specific or community level vegetation specific responses to climate change, and these are the standard methodologies used for identifying corridors (Watson *et al.*, 2011). The ability of species to persist in a changing climate will depend not only of the direct overlap between suitable conditions of today and suitable conditions of tomorrow, but also by the species ability to respond and adapt (Mackey *et al.* 2010). Species distribution models may not be accurate as they focus almost exclusively on exposure to climate change and do not incorporate other aspects of vulnerability such as acclimation, interspecific interactions, dispersal limitations and adaptive capacity (Dawson *et al.*, 2011, Rowland *et al.*, 2011).

The identification and protection of gradients in environmental space is seen as one way to overcome these limitations as this approach does not rely on species data but seeks to promote connectivity between heterogeneous habitats that will allow species to remain connected to a diverse suite of environmental resources or to transition quickly to more suitable conditions (Beier and Brost, 2010).

The identification of gradients in current environmental space also allows us to overcome uncertainty about the rate or extent of climate change within a region, or questions about the temporal aspects of future habitat availability (Game *et al.*, 2011).

Ecological analysis frequently involves dividing the landscape into habitat types, biomes, or ecoregions. Areas are grouped together based on the relative similarities in species composition or physical factors within a geography. An alternative to delineating classes is to utilize information available on the heterogeneity in the landscape and attempt to quantify the continuous change across the landscape. This change in the landscape, often referred to as an "ecological gradient", can be quantified based on the physical measures of change within the landscape. Temperature, elevation, and precipitation are commonly used physical variables that are used to quantify turnover along ecological gradients. These abiotic predictors have been leveraged widely in conservation to address known gaps in existing knowledge on the distribution of species and ecosystems (Hortal and Lobo, 2005).

The use of physical variables to measure landscape scale changes relies on the assumption that the physical variables chosen act as a surrogate for biodiversity within the landscape and that differences within the descriptor variables (eg. temperature, elevation) are correlated with differences in species composition. Reliance on physical characteristics of the landscape for conservation classifications is frequently driven by asymmetry in information availability between physical and biological data. Information on the distribution of species is often an order of magnitude more coarse than data on physical attributes of the landscape (Jetz *et al.*, 2012). Abiotic measures of environmental conditions are generally cheaper to acquire, provide more complete coverage, and are more readily available than detailed survey information on the location of species (Ferrier, 2002).

The use of environmental distance within climate change adaptation planning methodologies was suggested as a means to implement calls for maintaining connectivity to a variety of different habitat types and local resources (Game *et al.* 2011). The identification of areas with steep gradients (rapid rate of change) in environmental space is designed to minimize the distance that species will need to travel in order to reach different and potentially more favorable conditions, by ensuring that a wide variety of habitats are locally present. The objective is to retain connectivity between areas that contain dissimilar environmental conditions (eg. connecting high, cool and dry places with nearby low hot and wet places). The analysis does this by first quantifying the current condition at a site based on abiotic variables, and then assessing the similarity of each site to neighboring areas. By promoting connectivity between habitat types the analysis seeks to provide options in a time of climate change, by ensuring diversity in local habitat availability.

In addition to be useful for promoting the adaption by providing geographically proximate areas where conditions are different, they have also been suggested as areas of speciation and unique biological diversity (Kark, 2006). Gradient areas have also been suggested as potential areas where monitoring

efforts should be focused in times of climate change (Kark, 2006), as the regions may serve as a warning to changes happening elsewhere. The incorporation of environmental gradients within conservation planning has also been recognized as a method for promoting persistence of landscape level processes (Rouget *et al.*, 2006).

Environmental distance

The measurement of environmental distance provides a mechanism to quantify the observed differences in environment conditions across space. Methods for quantifying environmental distance can be broken down into two groups based on the type of input data used to quantify distance; 1) distance measures based on a species composition, and 2) distance measures based on abiotic conditions. Distance measures that use species composition directly rely on survey data that details species abundance or presence/absence and then quantifies the relative similarity of sites based on differences in species assemblages at a site. Measures that use abiotic predictors utilize information on abiotic factors like elevation, rainfall, and temperature to quantify differences between sites.

Environmental distance measures have been used to support a wide variety of conservation applications. They have been used to delineate biological domains (Mackey *et al.*, 2008), predict species composition (Ellis *et al.*, 2012; Pitcher *et al.*, 2012), identify regions at risk of climate change (Saxon *et al.*, 2005), inform survey design (Hortal and Lobo, 2005), explain genetic diversity in populations (Mendez *et al.*, 2010), to identify priority areas for the expansion of protected areas (Faith *et al.*, 1987), and to promote connectivity in national scale adaptation planning (Game *et al.* 2011).

Methods

Following the methods articulated by Game *et al.* (2011) we used fourteen variables to quantify abiotic environmental gradients within the Albertine Rift, to identify gradients in environmental space which could be used to facilitate species adaptation to climate change. Areas with high gradients are areas where environmental conditions change rapidly over relatively short geographic distances. Areas of high gradient are also referred to as ecotones. These are areas where either species composition or abiotic conditions change more rapidly than the surrounding environment.

The fourteen variables used in the analysis were first identified by Saxon *et al.* (2005), and selected to represent both stable (physical) and dynamic (climate) variables to delineate environmental domains and forecast risk during climate change. The variables identified were selected to include both process and distribution limiting variables in the identification of environmental domains (Saxon *et al.*, 2005). Seven variables represented physical diversity, and seven variables were climatic in nature (table 5).

Excluding water bodies and rivers, the area within the Albertine Rift was first divided into equal area grid cells for the analysis. To control for potential bias introduced by scale of analysis, three cell sizes were considered in the analysis. Cell resolutions considered were 100 km², 50 km² and 25 km², which

respectively meant the landscape was divided into 9885, 18532, and 39294 square cells. The processing for the three resolutions varied only in size of the cell considered.

Within each cell, the mean value of each of the fourteen variables was calculated based on the weighted area within the cell. The mean value for each variable within each cell was then normalized to a value between 0-1. The normalized value was calculated by dividing the value within the cell by the maximum value for the variable in any cell in the Albertine Rift (equation 1).

Table 5. Variables used to quantify environmental distance in the Albertine Rift. Fourteen variables were used in total, seven climate variables and seven physical variables.

	Variable	Type	Reference
1	Potential evapo-transpiration	Climate	(Willmott & Matsuura 2001)
2	Precipitation/potential evapo-transpiration	Climate	(Willmott & Matsuura 2001)
3	Precipitation coldest quarter	Climate	(Hijmans et al. 2005)
4	Precipitation warmest quarter	Climate	(Hijmans et al. 2005)
5	Mean temperature coldest quarter	Climate	(Hijmans et al. 2005)
6	Mean temperature warmest quarter	Climate	(Hijmans et al. 2005)
7	Average monthly temperature	Climate	(Hijmans et al. 2005)
8	Elevation (m)	Physical	DEM (SRTM 90m data; USGS)
9	Compound topographic index	Physical	Using tool provided by (Evans 2011)
10	Potential solar radiation	Physical	Using Area solar radiation tool (ESRI 2010)
11	Profile available water capacity (mm)	Physical	(Global Soil Data Task Group 2000)
12	Soil bulk density (g/cm)	Physical	(Global Soil Data Task Group 2000)
13	Soil carbon density (kg/m2)	Physical	(Global Soil Data Task Group 2000)
14	Total soil nitrogen (g/m2)	Physical	(Global Soil Data Task Group 2000)

$$nv_{ji} = v_{ji} / \max_i v_j(i) \quad [\text{Equation 1}]$$

Where nv_{ji} is the normalized value for variable j in cell i , and v_{ji} is the mean value of variable j in cell i , and $\max_i v_j(i)$ is the maximum value of variable j in any of the i cells in the Albertine Rift.

Using the normalized value for each variable, and placing equal weight on each variable, we calculated the Euclidean distance in environmental space, between each cell and every other cell in the Albertine Rift. We then calculated the mean distance between each cell and all adjacent cells. The mean distance of a cell to its neighbors was considered as the similarity to its neighbors. Plotting these results indicate sites where gradients are steep (figure 12).

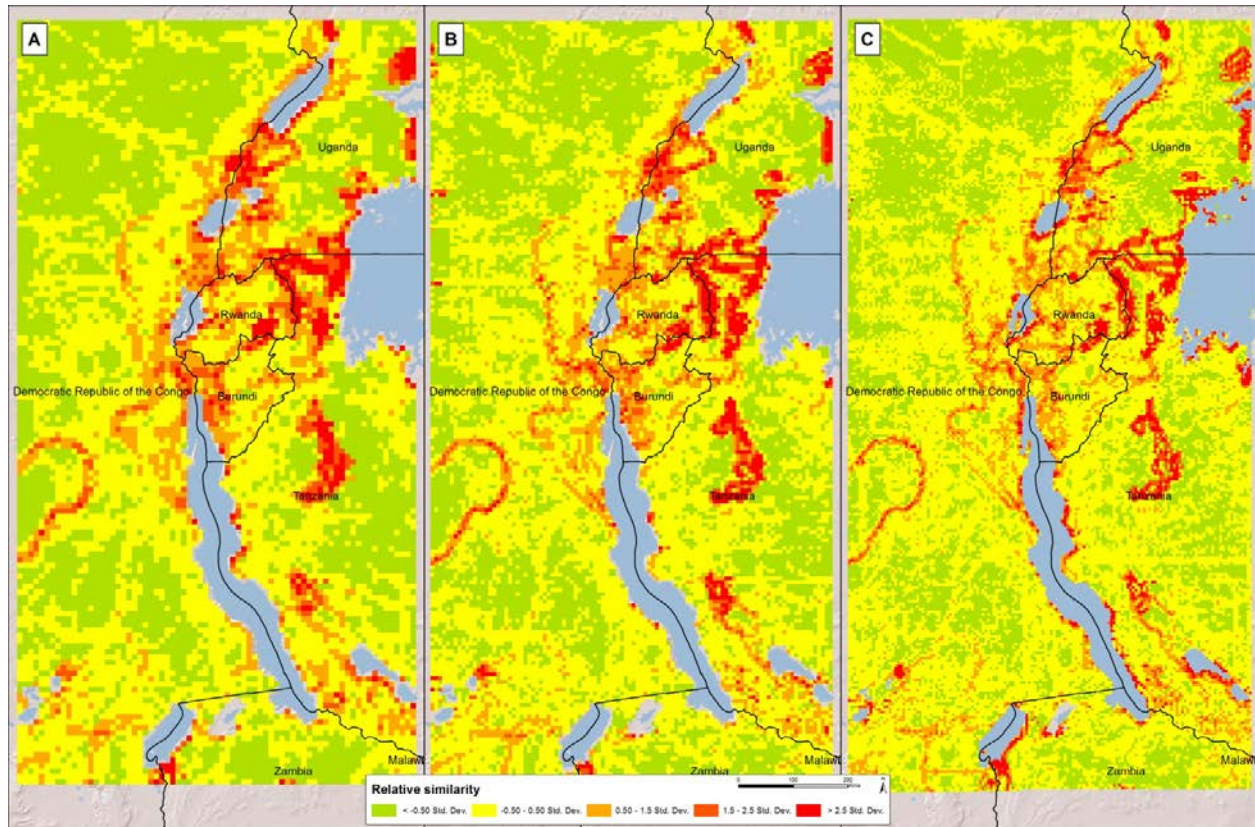


Figure 12. Relative similarity of environmental conditions measured with three different cells sizes. A) 100 km², B) 50 km² and C) 25 km². Relative similarity is calculated as the slope in environmental space of each cell to neighboring cells. The steepest gradients in environmental space (areas that are most dissimilar) are displayed in red, and areas that are most similar appear in green. The same general patterns of landscape heterogeneity emerged from all three analysis.

The exploration of environmental gradients within the region differs from the other approaches used to identify corridors in this report in that it does not leverage forecasts of future climatic conditions to identify areas of importance. This analysis identifies areas where heterogeneous conditions exist in close proximity to each other today. Because the information used reflects current conditions within the region the gradients identified represent differences today to which species can move between to seek out different environmental conditions. Three of the physical variables are topographic and thus not responsive to climate change, and four are edaphic and thus likely to have longer lags in their response time to a changing climate. The relative stability of half the variables used in the analysis means that some of the gradients identified are likely to persist into future.

Conservation of climate-resilient corridors in the Albertine Rift

The primary aim of this analysis is the identification of areas in the Albertine Rift that are likely to be important corridors for the conservation of the endemic and threatened species under future climate change. In the previous sections we explored three methods for assigning value to the landscape for the identification of corridors: 1) a species approach, 2) a vegetation type approach and 3) an abiotic approach. Here we use the information derived from each analysis to identify a set of corridors based solely on that analysis. We constrain corridor identification with each method to only those areas of the landscape that are not already transformed to facilitate comparison between methods. Then we integrate corridors identified with the individual methods to identify "no-regrets" corridors areas, areas that are likely to provide benefits today and tomorrow, and methodologically robust corridors or areas that are identified as important for conservation under future climate change by multiple analytic methods.

Identification of corridors with species and vegetation type models

For each species or vegetation type a threshold (1 or 0) layer was produced under the baseline mapping described above for both the predicted current distribution and predicted future distribution. As we modeled future distributions under three climate models we assessed how the predicted distributions and corridors were affected under two scenarios: 1. Model consensus: Select 1km² cells where all three climate models predict a threshold value for a species/vegetation type 2: Model Majority: Select 1km² cells where two of the three climate models predict a threshold value for a species/vegetation type.

We then combined the current and future distributions to produce a map with four values:

1. 0 – no predicted occurrence of a species/vegetation type currently or in 2080
2. 1 – Predicted currently but not in the future
3. 2 – Predicted in 2080 but not currently
4. 3 – Predicted both currently and in the future.

The areas of overlap (value=3) are "no-regrets" corridor areas. These are areas that will be suitable both today and in the future for a species or vegetation type. They include two scenarios: firstly, polygons where a species or vegetation type is confined to a smaller area within the current polygon of distribution (eg. a species/vegetation has to move upslope on a mountain); and secondly areas that will act as corridors, linking current and future distributions (figure 13). A third scenario where current and future polygons are completely separate were not evaluated here because of time constraints and also because most species or vegetation types showed overlaps occurred except for very small polygons which are unlikely to be important for the viability of the species/vegetation type. This assessment is ongoing and we will ideally also assess the third scenario if we identify any important separated distributions once we have modeled amphibian, reptiles and small mammals.

We therefore plotted overlap areas as defined in figure 13 for the endemic and threatened species and for the vegetation types to assess whether areas of overlap tended to coincide or whether they were very different for different taxa and vegetation.

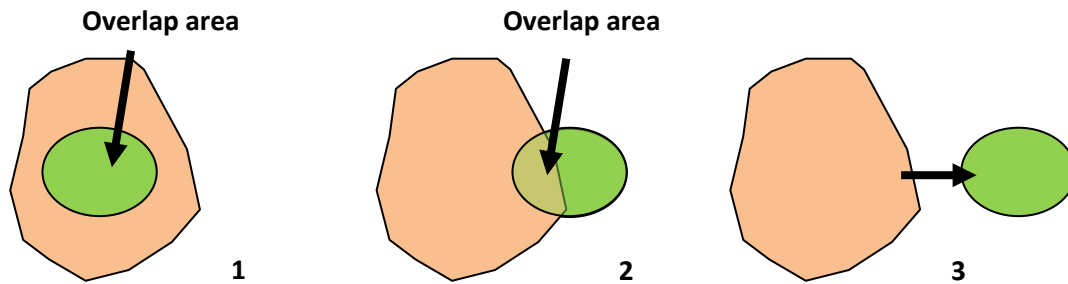


Figure 13. Three scenarios detailing the possible configurations current (orange) and future (green) distribution of a species or vegetation type. In scenario one the entire future distribution is contained inside the area currently occupied. In the second scenario the current area and future distribution overlap but each contain some area not included in the other. In the third scenario there is no overlap between the current and future distribution.

Identification of corridor areas for species

Endemic species

The results of the species corridor analysis are plotted in figure 14 for endemic large mammals, birds and plants respectively and for all three taxa combined. For large mammals there are very few predicted overlap areas because of the small number of species and relatively small areas of predicted future distribution. Given the low level of predicted overlap using the model consensus approach, we also examined areas of overlap forecasted by model majority forecast (figure 17). This shows more area in eastern DRC that may be important for conservation but the key areas where most species would be conserved are the mountain areas.

Threatened species

The same analysis was performed for each taxon of threatened species and for the three taxa combined for the scenario where future predictions were made by all three models (figure 15) and where only two of the three models agree (figure 18). Here the Greater Virunga Landscape is shown to be important for conserving most numbers of threatened species in both scenarios.

Threatened and endemic species

Finally the results were combined for both the threatened and endemic species across all taxa for the three model (figure 16), and the two out of the three model agreement (figure 19). Again the Greater Virunga Landscape and mountain tops contain most numbers of species. In DR Congo areas west of Lake Edward, Kivu and northern Tanganyika are important as well as the Okapi Reserve region west of Lake Albert under both scenarios.

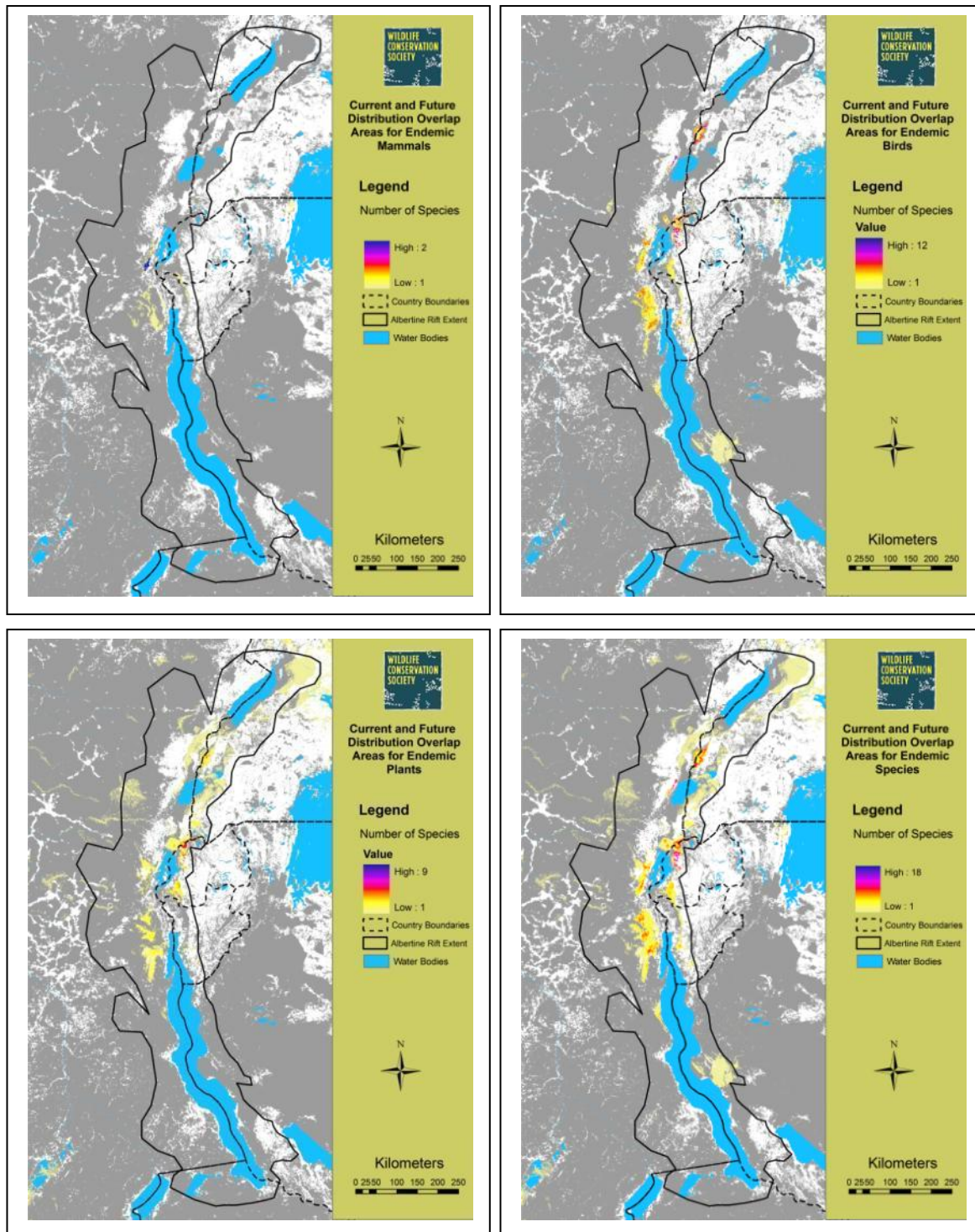


Figure 14. Distribution of overlap areas for endemic large mammals (top left, n=6), endemic birds (top right, n=26), endemic plants (bottom left, n=36) and all endemic species (bottom right, n=68), based on model consensus.

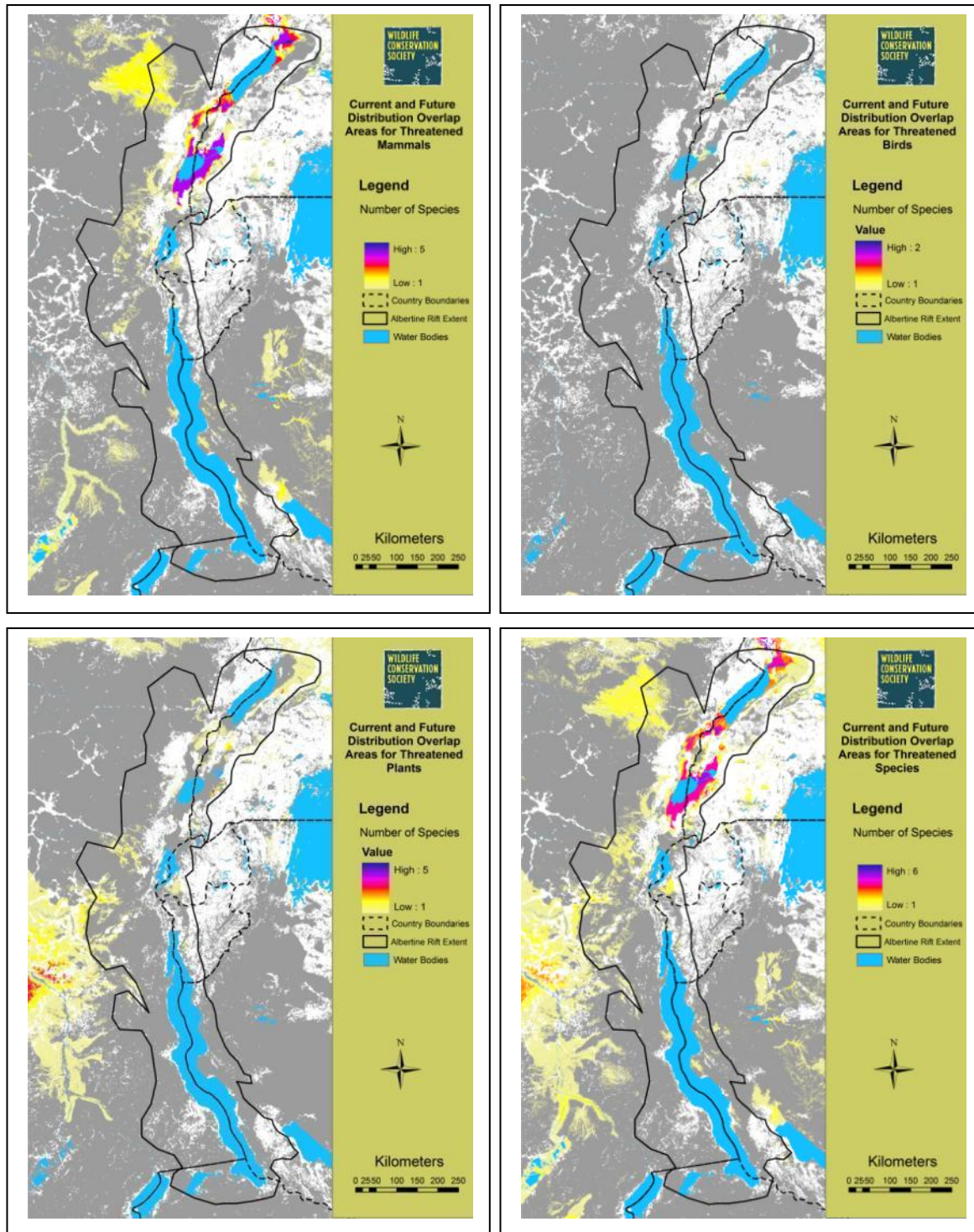


Figure 15. Species density in overlap areas for threatened large mammals (top left, n=11), threatened birds (top right, n=4), timber species of plant (bottom left, n= 10) and all threatened species (bottom right, n=25), based on model consensus.

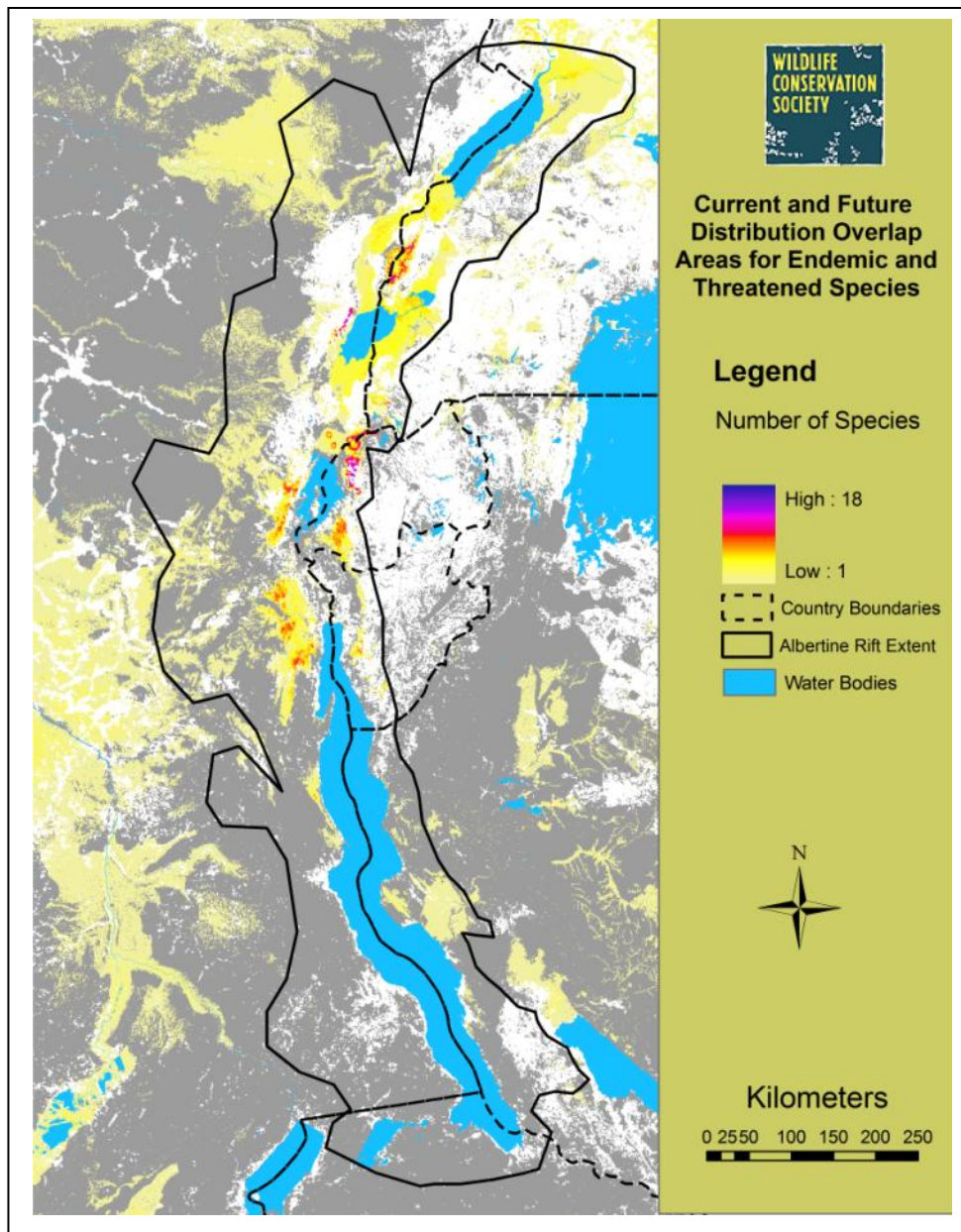


Figure 16. Species density in overlap areas for threatened and endemic plants, birds and large mammals per 1 km² cell in the Albertine Rift from a total of 93 modeled species. Overlap areas based on model consensus.

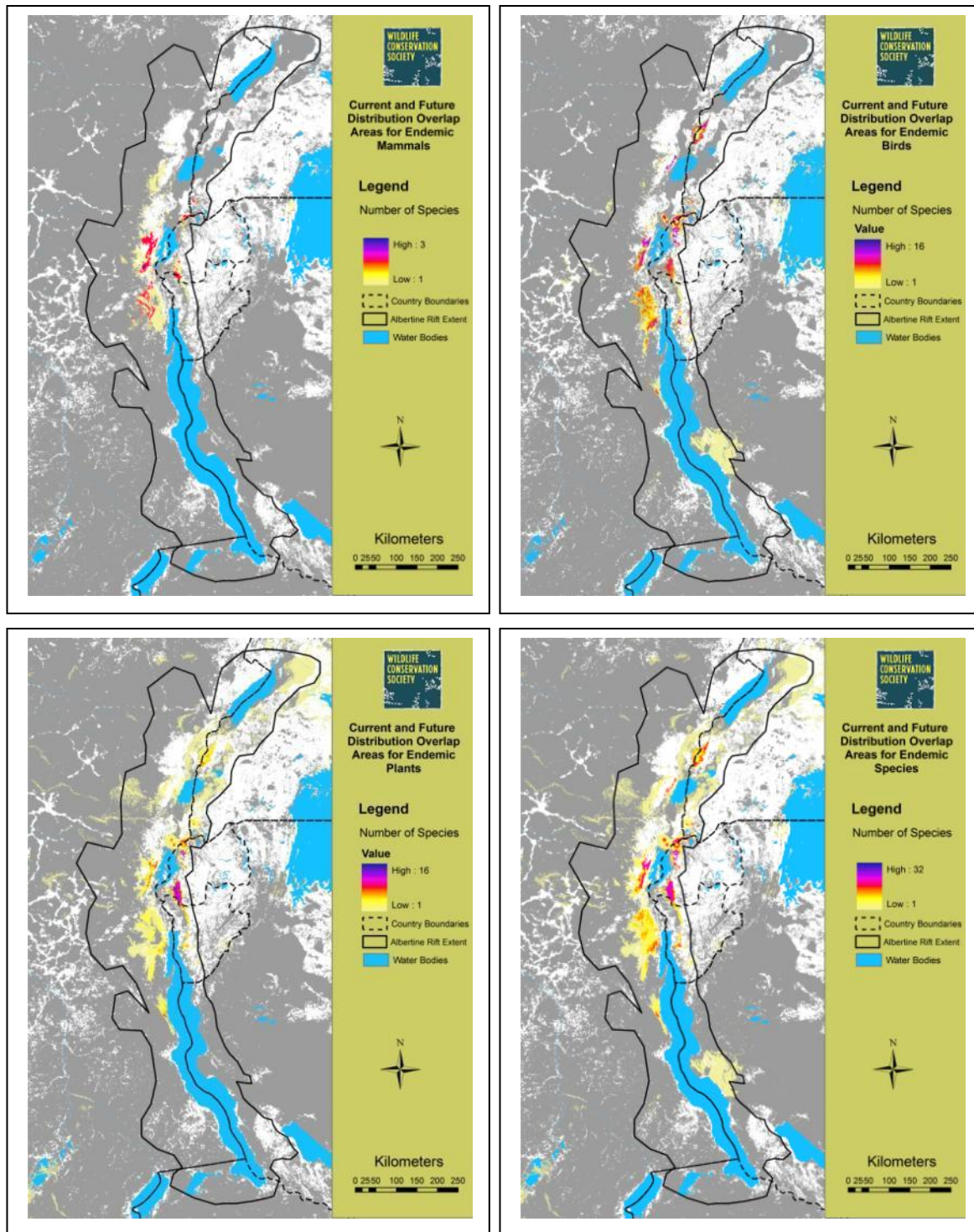


Figure 17. Species density in overlap areas for endemic large mammals (top left, $n=6$), endemic birds (top right, $n=26$), endemic plants (bottom left, $n=36$) and all endemic species (bottom right, $n=68$). Overlap areas based on model majority.

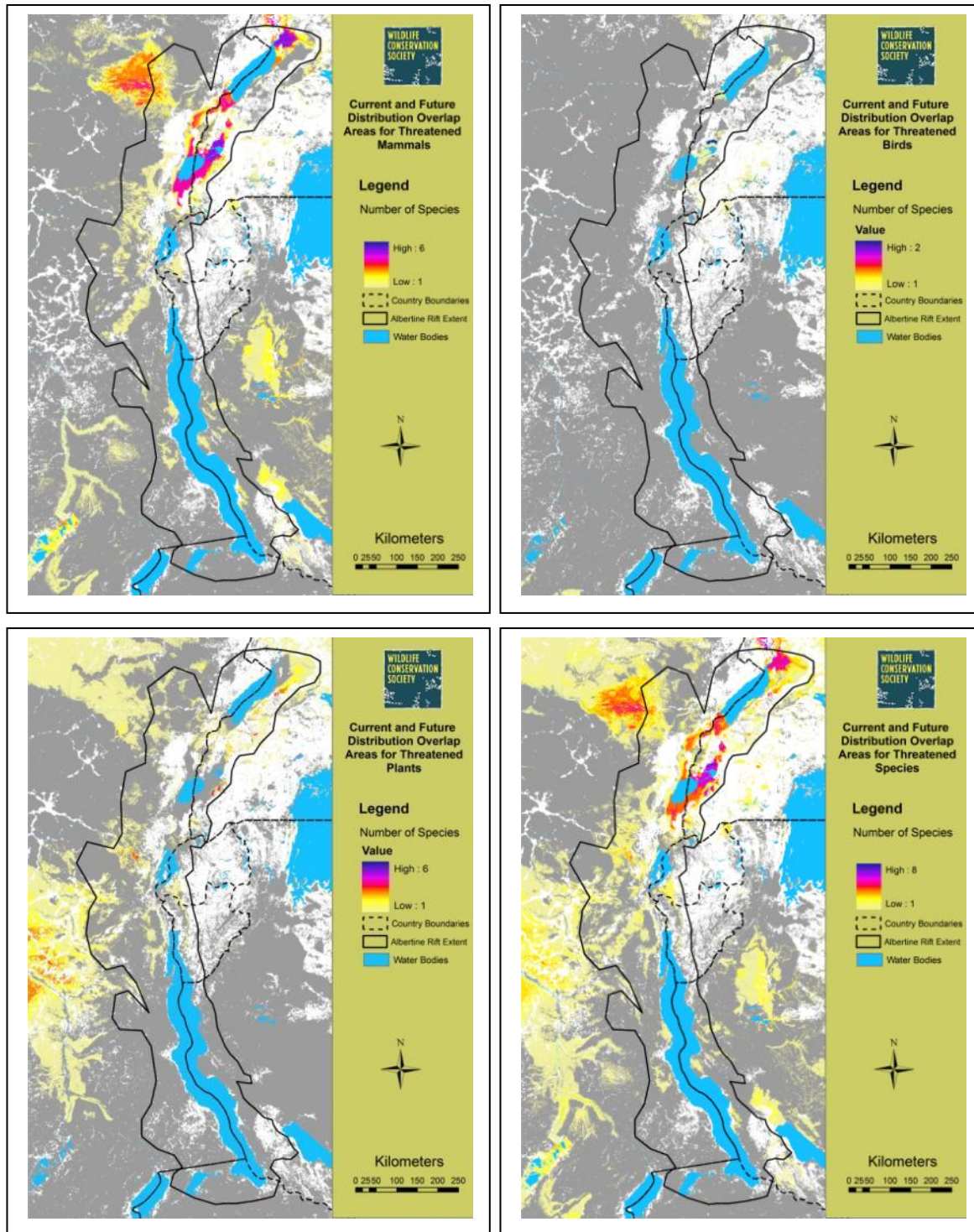


Figure 18. Species density in overlap areas for threatened large mammals (top left, n=11), threatened birds (top right, n=4), timber species of plant (bottom left, n= 10) and all threatened species (bottom right, n=25). Overlap areas based on model majority.

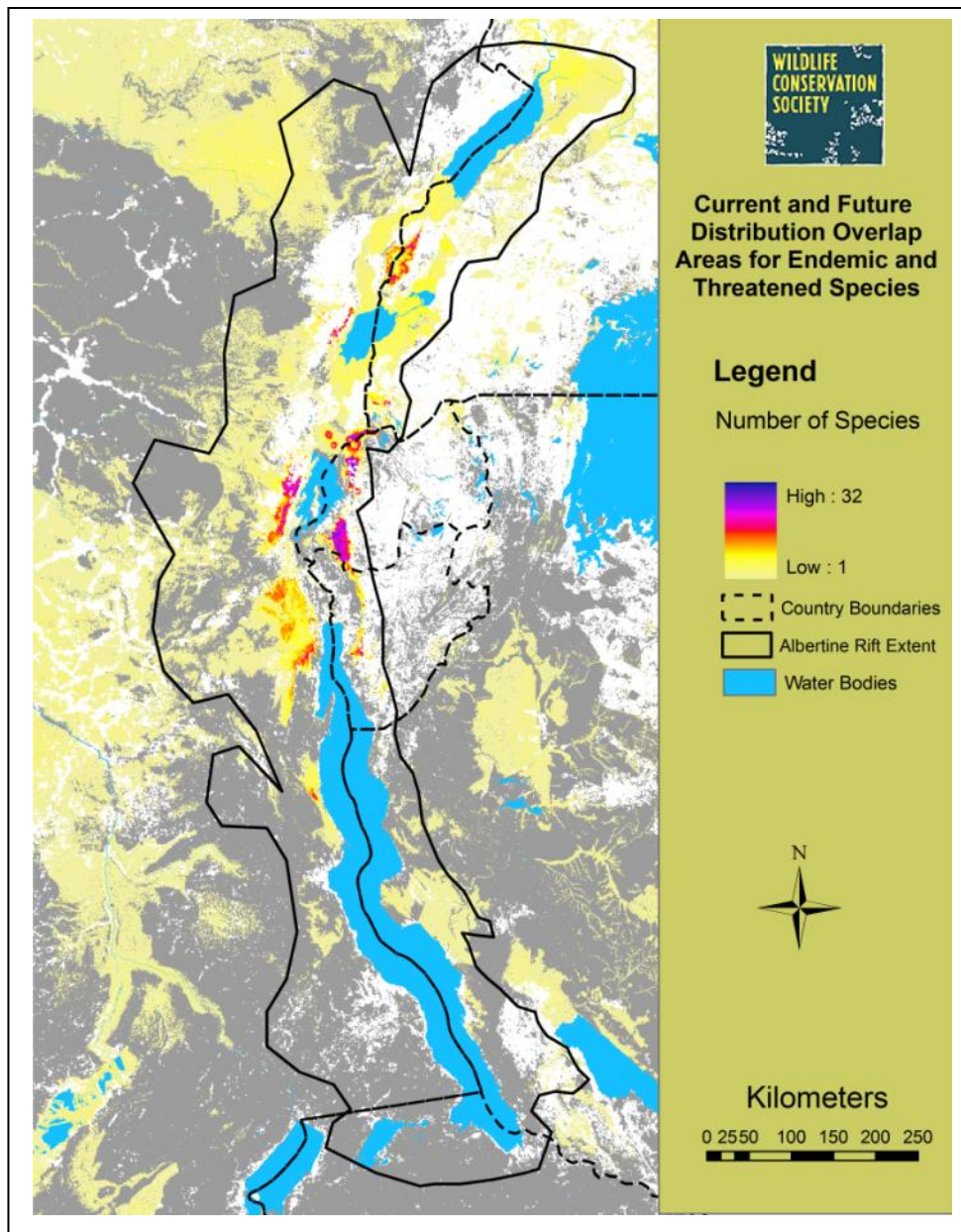


Figure 19. Species density in overlap areas for threatened and endemic plants, birds and large mammals per 1 km² cell in the Albertine Rift from all 93 modeled species. Overlap areas based on model majority.

Identification of corridors for vegetation types

A similar process was followed to assess overlap areas for potential corridors for the five modeled vegetation types. The thresholds for both current and future (three model agreement and also where only two models agree) predictions of the vegetation types were combined to identify current, future and overlap areas. Figure 20 identifies model consensus areas of overlap between present and future climate for each vegetation type. Figure 21 aggregates model consensus overlap areas into a single overlap layer displaying areas in the rift which are less likely to experience shifts in vegetation type. The same results are displayed in figures 22 and 23 respectively, for the model majority scenario.

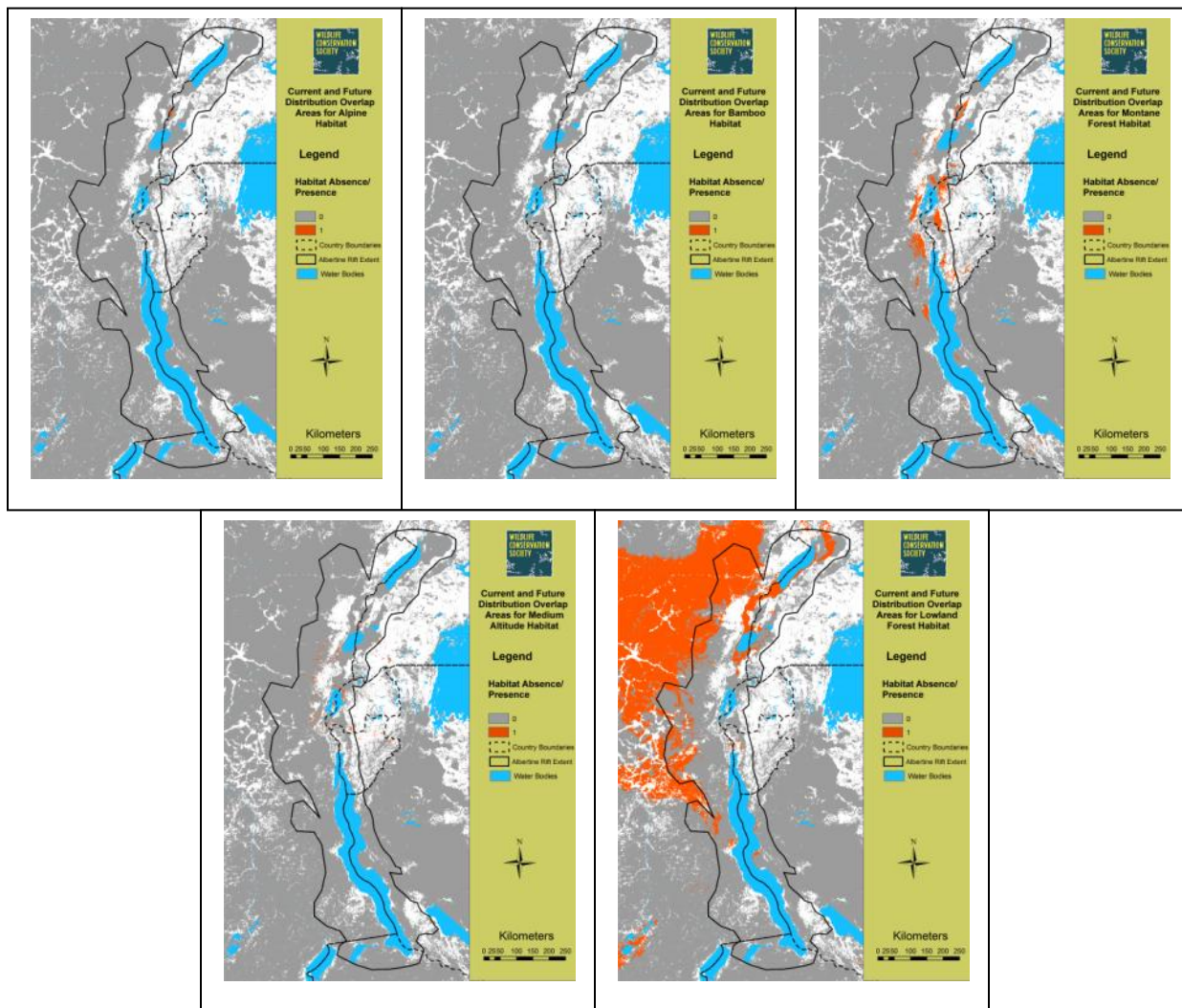


Figure 20. Overlap between current and future extent for the five vegetation types based on model consensus results. Alpine (top left), bamboo (top centre), montane forest (top right), medium altitude Tropical forest (bottom left), low altitude tropical forest (bottom right).

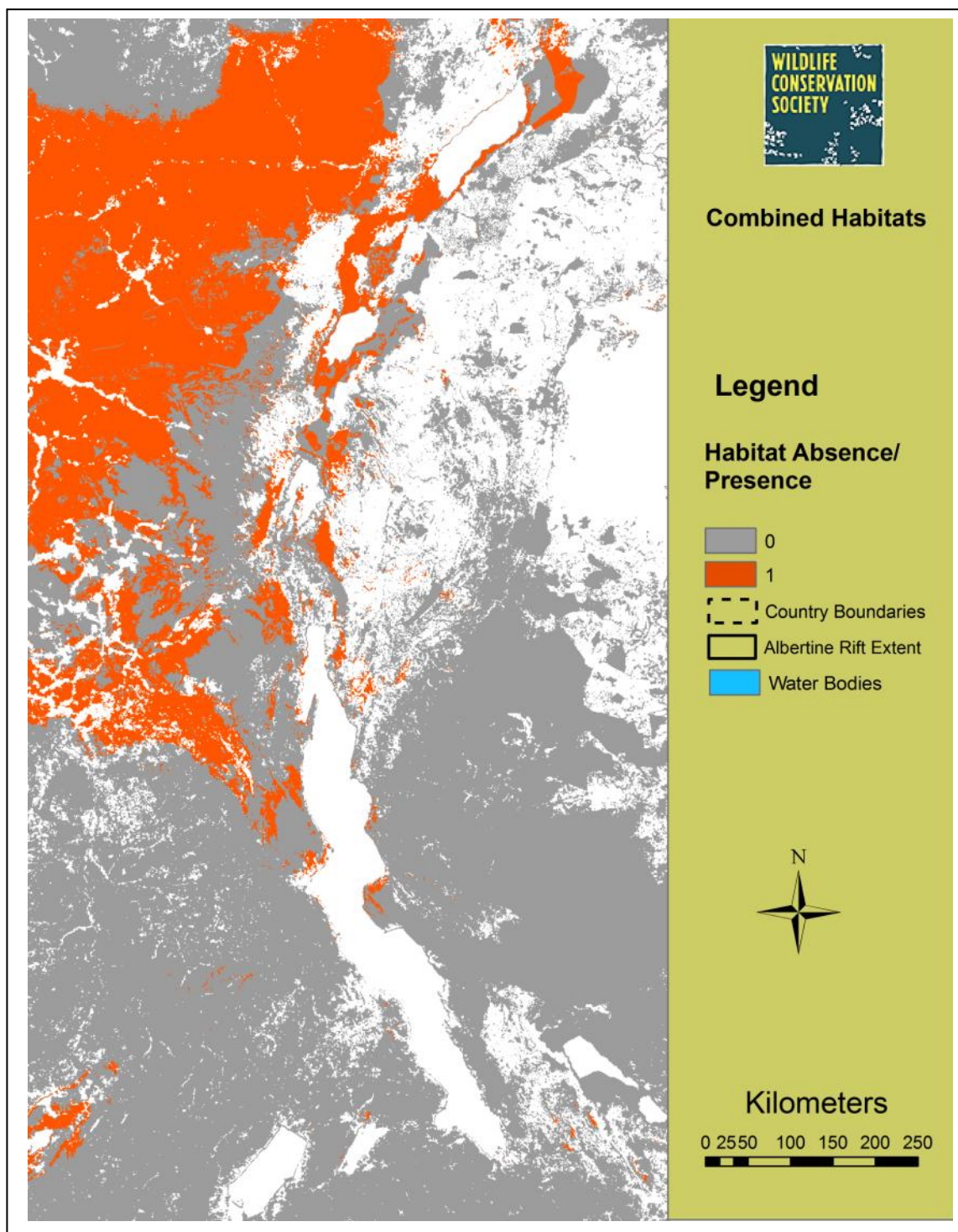


Figure 21. Combined overlap between current and future extent for all five vegetation types based on model consensus results.

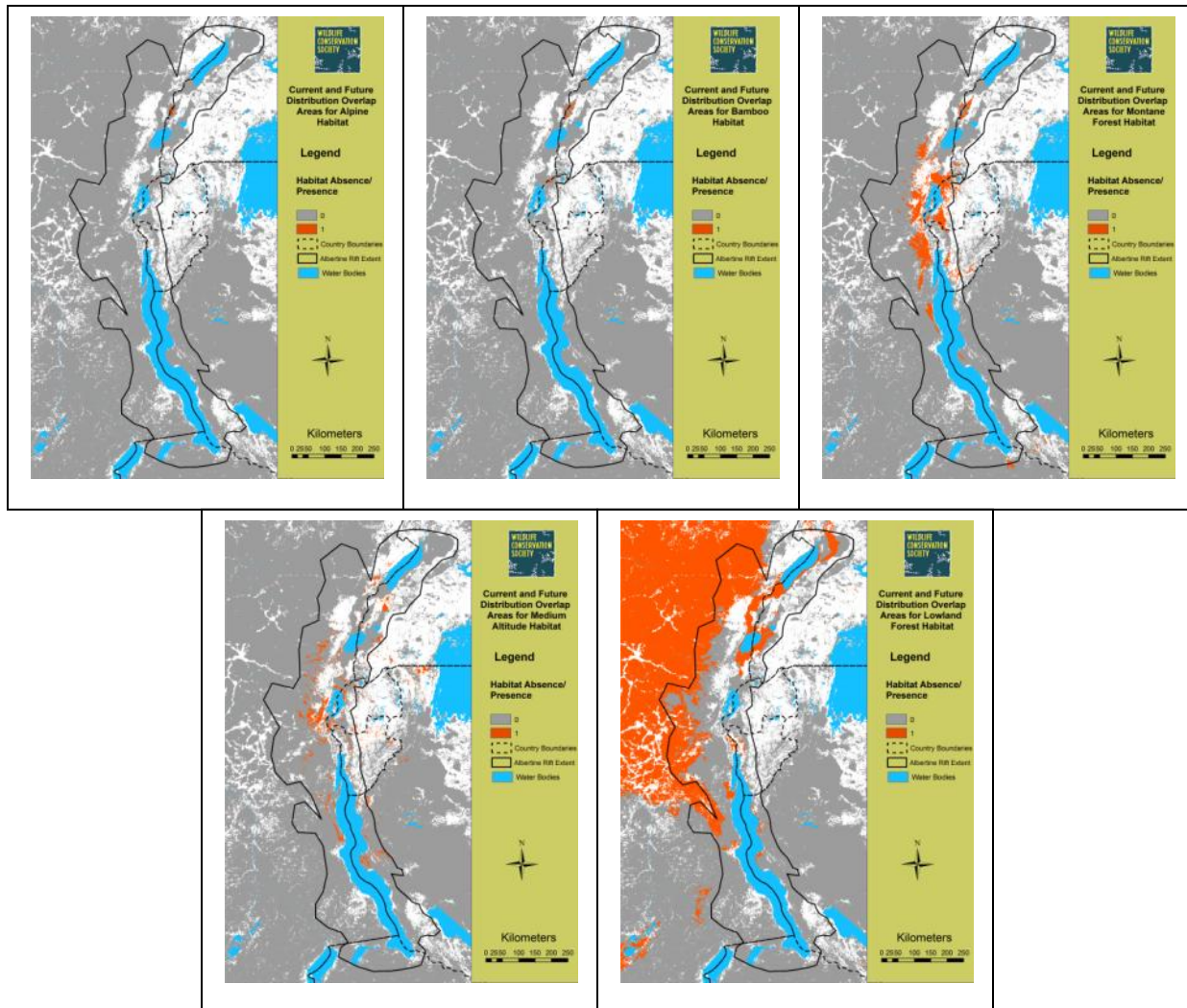


Figure 22. Overlap areas for the five vegetation types where future distribution is predicted by two of the three climate models. Alpine (top left), bamboo (top centre), montane forest (top right), medium altitude Tropical forest (bottom left), low altitude tropical forest (bottom right).

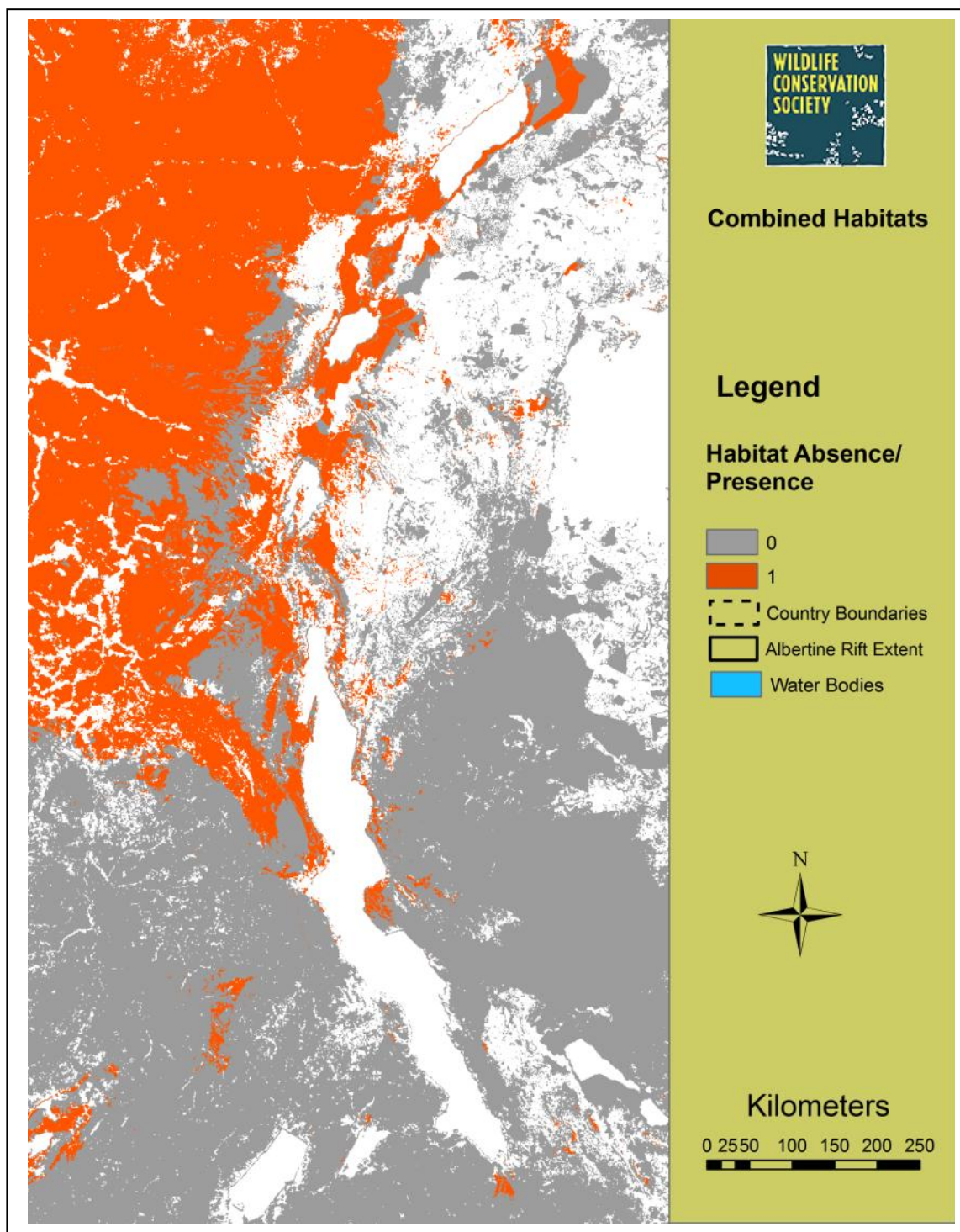


Figure 23. Overlap areas for all five vegetation types modeled combined under the majority model (2 of the three future predictions agree).

Corridor identification for abiotic gradients

Using the environmental gradients, we identified regional corridors that maximized environmental distance between the cells added and their neighbor cells, while constraining the analysis with an area based criteria. We considered three different area based constraints; 5%, 10% and 15% of the region.

To identify corridors we first excluded areas that were greater than 10% transformed, to prevent the placement of corridors in areas not suitable for biodiversity conservation. For areas that were partially transformed (<105) we counted only the non-transformed portion of the area towards the corridor objective. Corridor development then proceeded through an iterative process that started with the addition of the area with highest environmental gradient, and then proceeded to add additional areas until the area target was achieved.

The result is a nested set of areas that maximize environmental dissimilarity relative to adjacent areas at every target level. We refer to the corridor areas identified as nested because the areas identified to meet the 5% target are a subset of the areas identified to meet both the 10% and 15% targets, and the 10% target is a subset of the 15% target set.

Climate Resilient corridors – combining all three methods

The results of the individual approaches to corridor identification were integrated to identify corridor areas. Areas identified by all three approaches are areas where species and vegetation types are most likely to be resilient to climate change and which include a diverse array of locally available environmental conditions. These areas are likely to be important corridor areas for conservation between current and future distributions predicted in 2080.

For each summary corridor map identified using the distribution of species or vegetation types (figs 16/19, 21/23 and 24) we reclassified areas where there was any overlap to one (corridor) and left the rest of the area at zero. We did this separately for the consensus and majority models for future models. We selected the 10% area of the geophysical model (figure 24). This provided us with a binary surface for each analysis that classified the landscape as either corridor or non-corridor. We then combined the three outputs (species, vegetation types and geophysical) by adding the three together to generate figures for both the consensus model (figure 25) and majority model (figure 26). These show where there are overlaps in the corridor areas identified by the three methods and which areas are selected by one, two or all three approaches.

Areas selected by all three approaches include most areas within existing protected areas or protected landscapes such as the Greater Virunga Landscape (Virunga National Park in DR Congo, Queen Elizabeth, Rwenzori Mountains, Bwindi Impenetrable, Mgahinga, Semliki and Kibale National parks in Uganda and Volcanoes park in Rwanda), Congo-Nile Divide (Nyungwe and Kibira National parks), Murchison Falls National Park, Budongo Forest Reserve and Semliki Wildlife Reserve in the Murchison-Semliki Landscape, Kahuzi Biega and Itombwe in the Maiko-Itombwe landscape and Misotshi-kabogo in the Kabobo landscape and Mahale Mountains National park in the Greater Mahale Ecosystem.

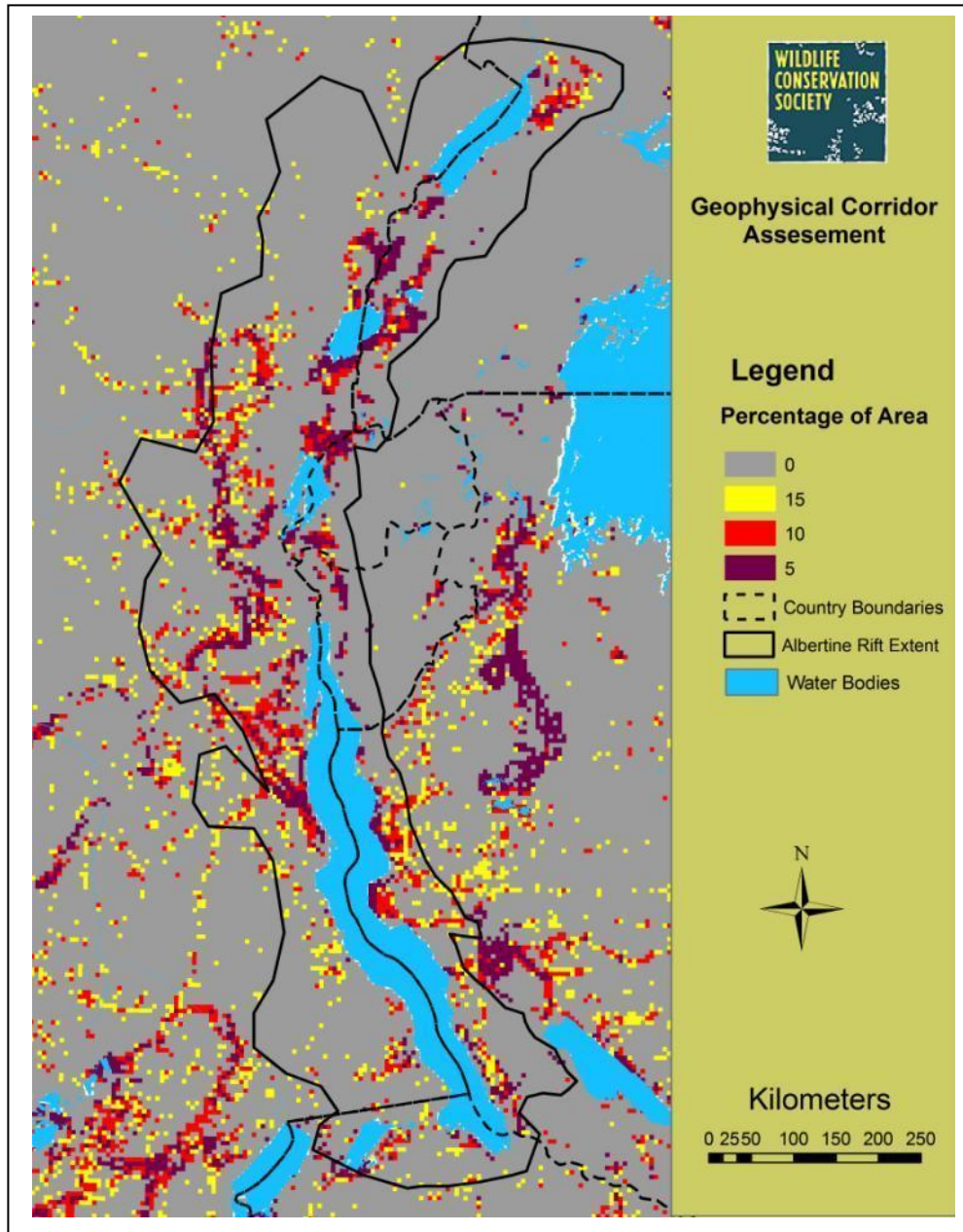


Figure 24. Conservation corridors that maximize the environmental dissimilarity of the areas included to adjacent areas. Corridors that achieve a 5% area target while maximizing dissimilarity are displayed in purple. Expanding the corridors to 10% of the region would include both the purple and red areas. Expanding corridors to 15% of the region would include purple, red and yellow areas.

Other areas of significance (selected by two of the three approaches) include the Okapi Wildlife Reserve and its surroundings and parts of the Maiko National Park-Tayna Community Reserve region and the links between this area and Kahuzi Biega National Park. There is also a corridor region between Itombwe and the Misotshi-Kabogo massifs in eastern DR Congo, and a corridor region in western Tanzania that links two blocks of Wildlife Division managed hunting concessions between Ugalla Game Reserve and the Moyowosi /Kigozi Game Reserves. These would appear to be the more critical areas for “no-regret” conservation in the Albertine Rift region. It is encouraging that many of the areas identified by all three approaches are already afforded protection within the existing protected areas of the region. It also makes conservation efforts to target the remaining corridor areas outside the protected areas more feasible and realistic.

Areas where the current and future distribution of a species or vegetation type overlap can be thought of as “no-regrets” conservation corridor areas. Protection or allocation of resources within these areas expands the extent of protected habitat or quality of habitat today, while also targeting areas that are most likely to be suitable for in the future (Glick *et al.*, 2011). As such they are likely to be good areas to invest in for conservation of biodiversity both now and in the future. All areas identified using the environmental gradient approach would also qualify as “no-regrets” because they are not predicated on any climatic change. The areas identified using the environmental dissimilarity approach represent areas where a diverse set of environmental conditions exist in close proximity to each other today. These are areas where the distance a species has to travel to find dissimilar conditions is likely to be minimized.

While the areas identified by all three approaches may represent high priority areas for the establishment of corridors that does not mean that the areas would be the most efficient corridor network for the region. These areas and maps tell us only part of the story- what is the benefit of establishing a corridor in a location? A more complete story would also include an understanding of the cost of establishing a corridor in an area. Evaluation of the economic cost (opportunity and management) of establishing corridors within each area was beyond the scope of this project but should be considered in future analysis of corridors for the region. To identify corridors that most efficiently achieve our ecological objectives a more refined analysis is required that examines the reasons each area was identified as a potential corridor, and an understanding of what management action will be required to maintain the ecological value of that area. By estimating the likely cost of management and then developing a more complete understanding of what activities will be excluded from the corridor areas, we will be better able to estimate the cost of establishing a corridor in any location in the Rift. This will allow us to explore the costs and benefits of establishing corridors within the region, and allow us to minimize the overall cost of corridors while ensuring that ecological objectives are achieved.

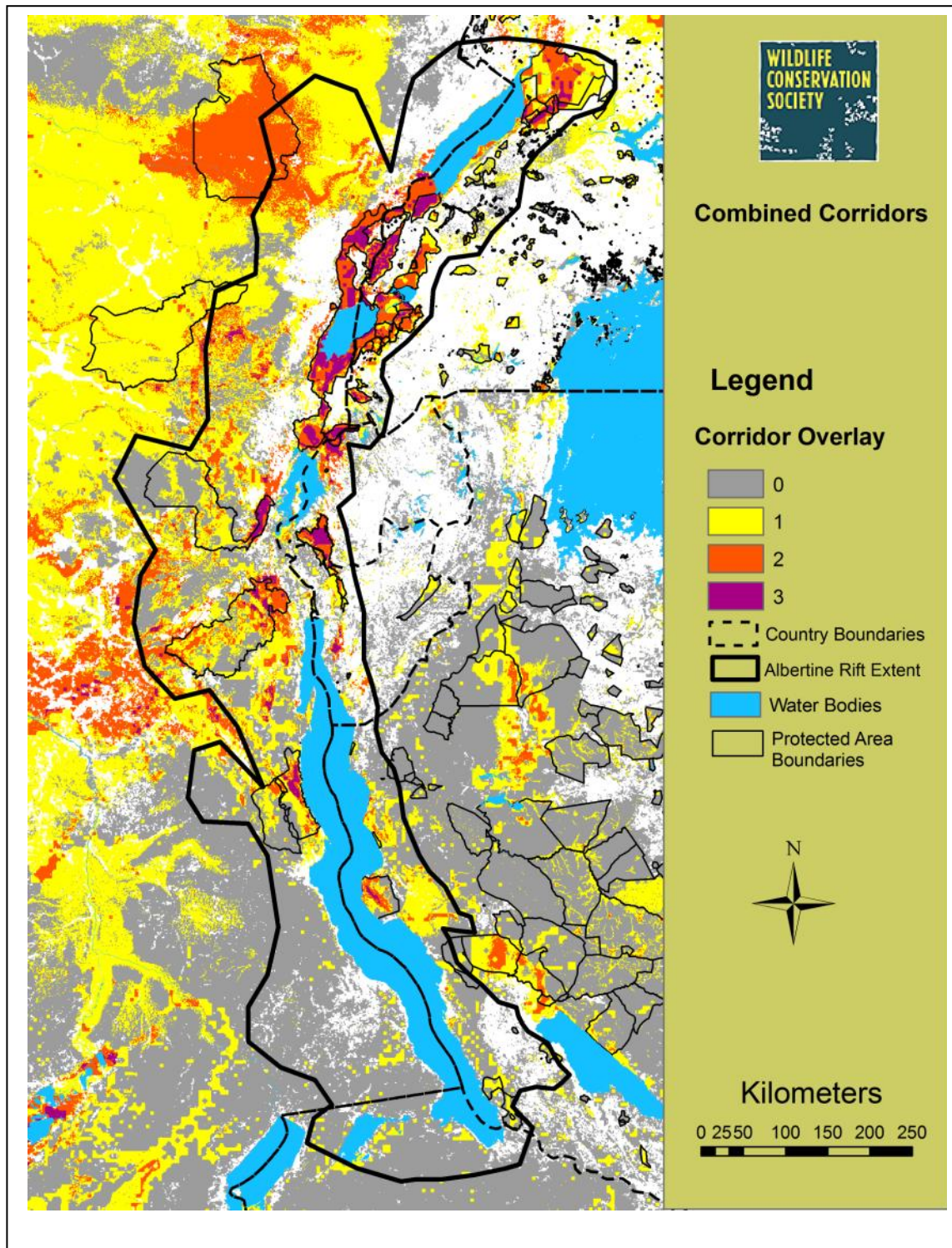


Figure 25. Coincidence of predicted corridor/overlap areas for species, vegetation types and geophysical attributes under the consensus model where all three future predictions of species and vegetation types agree. The numbers in the corridor overlay legend refer to the number of approaches that identify an area as a potential corridor. Three indicates that it was identified in all three approaches (geophysical, species and vegetation type), two means that it was identified in two of three approaches, and one means it was identified in only one approach.

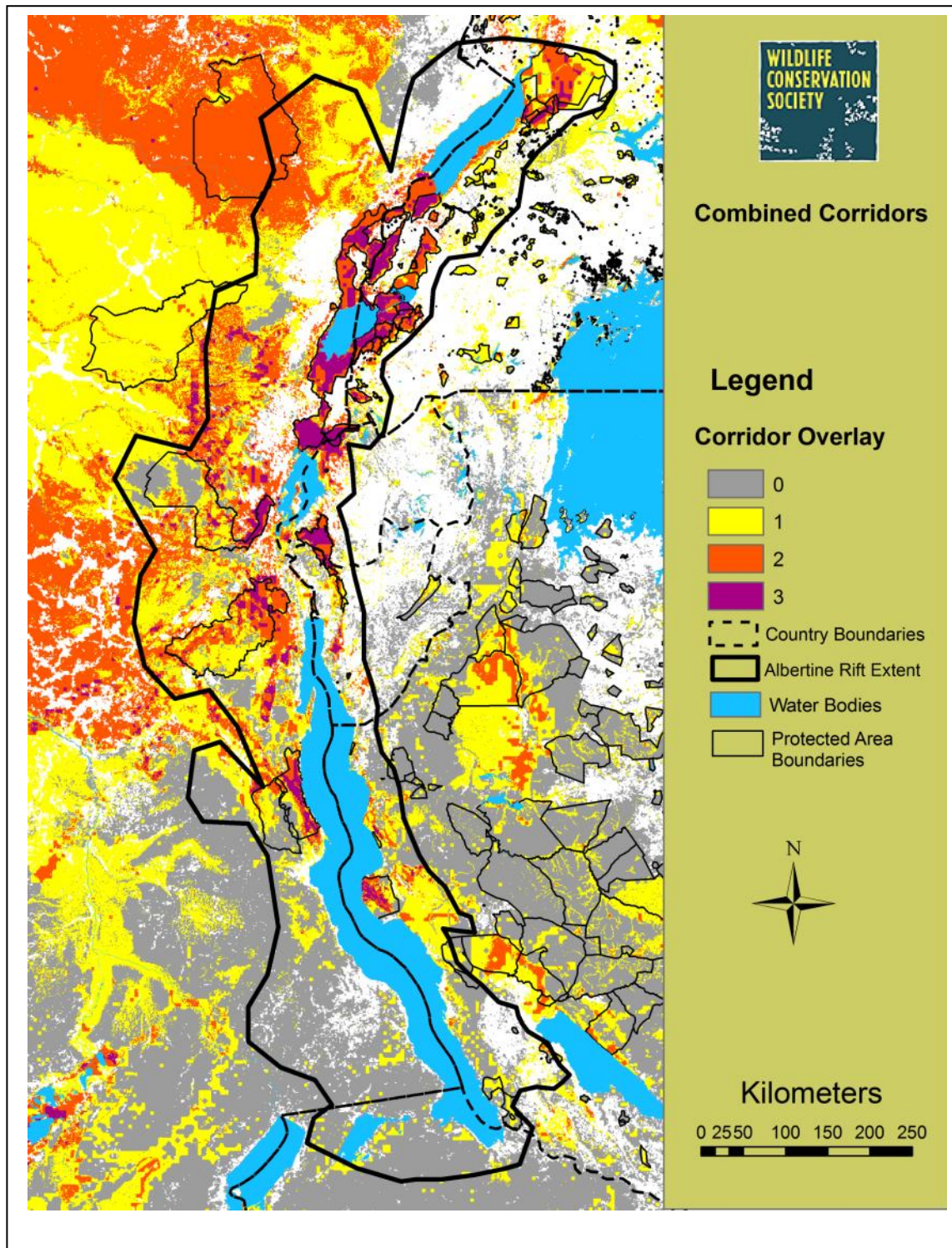


Figure 26. Coincidence of predicted corridor/overlap areas for species, vegetation types and geophysical attributes under the majority model where two of the three future predictions of species and vegetation types agree. The numbers in the corridor overlay legend refer to the number of approaches that identify an area as a potential corridor. Three indicates that it was identified in all three approaches (geophysical, species and vegetation type), two means that it was identified in two of three approaches, and one means it was identified in only one approach.

Future work

We regard this analysis as preliminary at the moment. There are several additional analyses that we envision conducting in the coming year to ensure that the final result incorporates greater diversity of taxa as well as aspects of target setting and conservation planning. These activities include:

1. Modeling current and future distribution of additional threatened plant species
2. Modeling current and future distribution of endemic and threatened amphibian species
3. Modeling current and future distribution of endemic and threatened small mammal species
4. Modeling current and future distribution of endemic and threatened reptile species
5. Modeling the opportunity and management cost of setting aside corridor areas
6. Using Marxan to identify minimum cost areas that would conserve viable populations of each species of conservation concern in the region.
7. Identify where corridors outside existing protected areas need to be conserved in order to ensure these minimum cost areas are fully conserved.

The extension of the current analysis along the lines identified above will provide additional insight into where corridors will be most effective in conserving biodiversity in the Albertine Rift when we consider the long-term impacts of climate change.

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Appendix 1

List of species modeled for the threatened and endemic species analyses.

Common Name	Latin Name	Threatened	Endemic
Mammals			
L'Hoest's Monkey	<i>Cercopithecus lhoesti</i>		Near Endemic
Owl-faced Monkey	<i>Cercopithecus hamlyni</i>		Near Endemic
Red Colobus	<i>Procolobus tephrosceles</i>	VU	
Uganda Mangabey	<i>Lophocebus ugandae</i>	Threatened if accepted as species	
Golden monkey	<i>Cercopithecus kandti</i>	Threatened if accepted as species	Endemic
Mountain gorilla	<i>Gorilla beringei beringei</i>	EN	Endemic subspecies
Grauer's gorilla	<i>Gorilla beringei graueri</i>	EN	Near Endemic Subspecies
Chimpanzee	<i>Pan troglodytes</i>	EN	
Elephant	<i>Loxodonta africana</i>	VU	
Rothschild Giraffe	<i>Giraffa camelopardalis</i>	EN	
Okapi	<i>Okapia johnstoni</i>	NT	
Hippopotamus	<i>Hippopotamus amphibious</i>	VU	
Virunga buffalo	<i>Syncerus matthewsi</i>	Threatened if accepted as species	Endemic
Lion	<i>Panthera leo</i>	VU	
Leopard	<i>Panthera pardus</i>	NT	
African Wild Dog	<i>Lycaon pictus</i>	EN	
Birds			
White-backed Vulture	<i>Gyps africanus</i>	VU	
Shoebill	<i>Balaeniceps rex</i>	VU	

Common Name	Latin Name	Threatened	Endemic
Grey-crowned Crane	<i>Balearica regulorum</i>	VU	
Nahan's Francolin	<i>Fringolius nahani</i>	EN	
Ruwenzori tauraco	<i>Ruwenzornis johnstoni</i>		Endemic
Dwarf honey guide	<i>Indicator pumilio</i>		Endemic
Handsome Francolin	<i>Fringolius nobilis</i>		Endemic
Red-collared Mountain Babbler	<i>Kupeornis rufocinctus</i>		Endemic
Kivu Ground Thrush	<i>Zoothera tanganjicae</i>		Endemic
Archer's Ground Robin	<i>Cossypha archeri</i>		Endemic
Red-throated Alethe	<i>Alethe poliophrys</i>		Endemic
African Green Broadbill	<i>Pseudocalyptomena graueri</i>		Endemic
Stripe-breasted tit	<i>Parus fasciiventer</i>		Endemic
Collared Apalis	<i>Apalis ruwenzorii</i>		Endemic
Montane Masked Apalis	<i>Apalis personata</i>		Endemic
Kabobo Apalis	<i>Apalis kaboboensis</i>		Endemic
Kungwe Apalis	<i>Apalis argentea</i>		Endemic
Rwenzori Batis	<i>Batis diops</i>		Endemic
Grauer's Warbler	<i>Graueria vittata</i>		Endemic
Grauer's Rush Warbler	<i>Bradypterus graueri</i>		Endemic
Neumann's Warbler	<i>Hemitesia neumanni</i>		Endemic
Red-faced Woodland Warbler	<i>Phylloscopus laetus</i>		Endemic
Yellow-eyed Black Flycatcher	<i>Melaenornis ardesiacus</i>		Endemic
Blue-headed Sunbird	<i>Cyanomitra alinae</i>		Endemic
Purple-breasted	<i>Nectarinia purpureiventris</i>		Endemic

Common Name	Latin Name	Threatened	Endemic
Sunbird			
Regal Sunbird	<i>Cinnyris regius</i>		Endemic
Ruwenzori Double-collared Sunbird	<i>Cinnyris stuhlmanni</i>		Endemic
Strange Weaver	<i>Ploceus alienus</i>		Endemic
Dusky crimson wing	<i>Cryptospiza jacksoni</i>		Endemic
Shelly's Crimson wing	<i>Cryptospiza shelleyi</i>		Endemic
Plants			
Timber species	Albizia coriaria		
Timber species	Entandrophragma angolense	VU	
Timber species	Entandrophragma cylindricum	VU	
Timber species	Entandrophragma excelsum		
Timber species	Entandrophragma utile	VU	
Timber species	Fagaropsis angolensis		
Timber species	Khaya anthotheca	VU	
Timber species	Lovoa swynnertonii	EN	
Timber species	Milicia excelsa		
Timber species	Olea welwitschii		
	Allanblackia kimbiliensis		Endemic
	Balsamocitrus dawei		Endemic
	Beilschmiedia michelsonii		Endemic
	Chassalia subochreatea		Endemic
	Coccinia mildbraedii		Endemic
	Crassocephalum ducis-aprutii		Endemic

Common Name	Latin Name	Threatened	Endemic
	Diplazium humbertii		Endemic
	Embelia libeniana		Endemic
	Erica johnstoniana		Endemic
	Grewia_mildbraedii		Endemic
	Harungana_montana		Endemic
	Helichrysum_stuhlmannii		Endemic
	Impatiens_erecticornis		Endemic
	Impatiens_mildbraedii		Endemic
	Impatiens_purpureo-violacea		Endemic
	Impatiens_gesneroidea		Endemic
	Isoglossa laxiflora		Endemic
	Isoglossa_vulcanicola		Endemic
	Lobelia_mildbraedii		Endemic
	Lobelia_stuhlmannii		Endemic
	Melchiora_schliebenii		Endemic
	Musanga_leo-errerae		Endemic
	Ocotea_michelsonii		Endemic
	Oxyanthus troupinii		Endemic
	Peddiea_rapaneoides		Endemic
	Peucedanum_runssoricum		Endemic
	Pristimera_polyantha		Endemic
	Psychotria_palustris		Endemic
	Pycnostachys_goetzenii		Endemic
	Rubus_kirungensis		Endemic
	Rubus_runssorensis		Endemic

Common Name	Latin Name	Threatened	Endemic
	Rytigynia_bridsoniae		Endemic
	Rytigynia_kigeziensis		Endemic
	Senecio_johnstonii		Endemic
	Tabernaemontana_odoratissima		Endemic
	Thunbergia_mildbraediana		Endemic