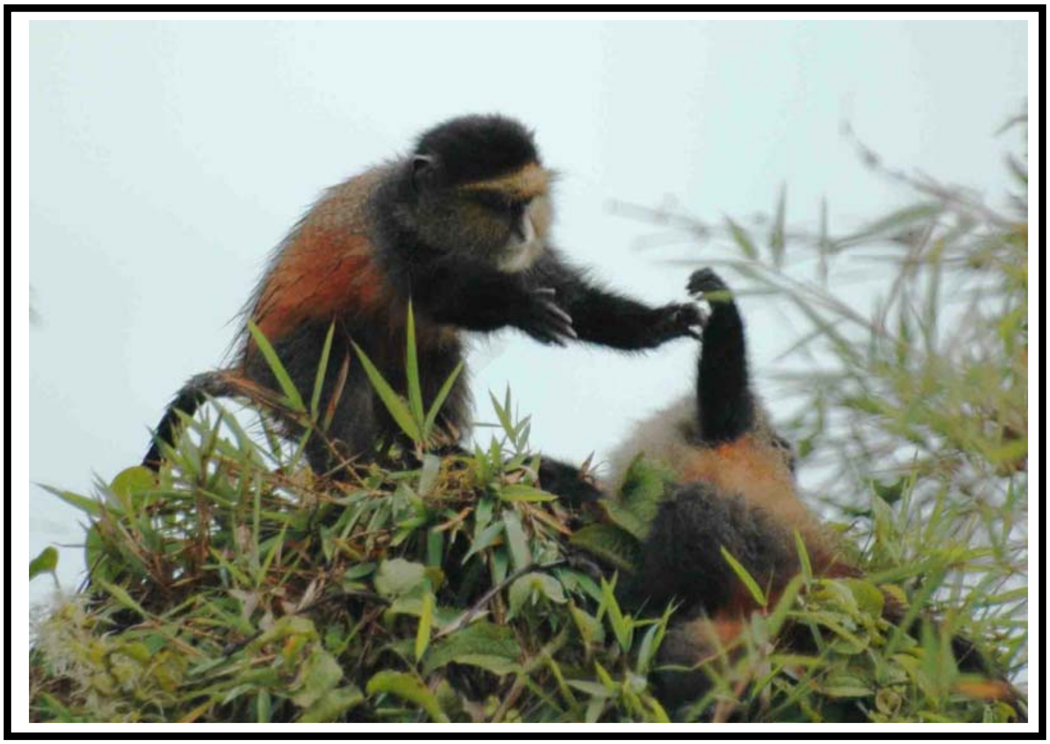
Impacts of climate Change and Industrial Development on the long-term changes in Wildlife Behavior in the Greater Virunga Landscape



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GVTC
GREATER VIRUNGA
TRANSBOUNDARY COLLABORATION

Executive Summary

This report summarises the in-depth study of existing knowledge of changes in animal behavior in the Greater Virunga Landscape (GVL) resulting from industrial development, climate changes and other factors as well as the assessment of changes in ecology resulting from habitat changes across the GVL. The objectives of this study were specifically to 1) assess the actual and potential changes in animal behavior resulting from Climate Change; 2) assess the actual and potential long-term changes in behavior resulting from oil/gas and geothermal exploration and production; 3) assess other factors (beside development and climate change impacts) that are or will affect animal behavior in the GVL; 4) map land cover changes over time in the GVL from 2000-2015/6; and 5) provide recommendations for mitigating adverse changes in animal behavior in the GVL.

From the study, the results show that climate change impacts area already being seen in the GVL, including movement upslope of birds on the mountains, increasing rainfall as predicted by climate models, and increasing temperatures. Phenology patterns in forests may is also being affected by increasing temperatures, particularly for those trees where minimum temperatures may trigger flowering. Models of predicted impacts of climate change on the endemic and threatened species (108) in the GVL indicate that significant range reductions will likely occur resulting from the need to move upslope to maintain similar niches. On average species ranges have declined by 55% because of loss of habitat to agriculture and infrastructure developments in the region around the GVL and an additional 70% of what remains will be lost to climate changes by 2070, if the projected emission scenarios follow the trajectory under RCP 8.5. The bird species that have lost more than 65% of their current range include the Blue headed sunbird, Grauers rush warbler, Montane masked apalis, Neumanns warbler, Purple-breasted Sunbird, Red-faced woodland warbler, Red throated Alethe, Rwenzori batis, Handsome francolin, Dusky crimson-wing, Kivu ground thrush,Yellow-eyed black_flycatcher, Chapin's flycatcher, Dwarf honey guide, Ruwenzori nightjar, Shelleys crimson-wing, Grauers Rush_Warbler, Chapin's Flycatcher, Shelleys Crimson-wing, Grey Crowned Crane and the plants are *Allanblackia kimbiliensis, Coccinia mildbraedii, Diplazium_humbertii Embelia libeniana, Grewia mildbraedii, Harungana montana, Impatiens mildbraedii, Melchiora schliebenii,Musanga leo-errerae, Oxyanthus troupinii, Rubus kirungensis, Rytigynia bridsoniae, Rytigynia kigeziensis, Thunbergia mildbraediana,Monanthotaxis orophila, Pavetta pierlotii,Tabernaemontana odoratissima, Beilschmiedia_ugandensis ,Carex runssoroensis, Casearia engleri, Entandrophragma angolense, Entandrophragma cylindricum, Entandrophragma excelsum, Helichrysum formosissimum, Lovoa swynnertonii, Lovoa trichilioides, Ocotea kenyensis, Prunus africana, Turraeanthus africanus.* Among the large mammal species, *Loxodonta africana, Hippopotamus amphibius, Cercopithecus lhoesti, Pan troglodytes, Cercopithecus hamlyni, Gorilla beringei* are currently being impacted by climate change. Fire frequency is also increasing, which may be a result of increasing fuel load with the wetter climate. These factors will likely lead to changes in vegetation composition as certain plants become more competitive with increasing moisture and fire frequency which will in turn affect animal distributions in the savannas of the GVL in particular. The areas in the GVL where the most species are likely to persist include Rwenzori national park, Mgahinga national park and Virunga volcanoes. These areas are important for the future conservation of endemic species in the GVL.

Mapping of the 2017 land cover land use showed that most of the protected areas are still covered by natural vegetation. The north western part of the landscape, however, under conversion to degraded forest, which is a mixture of small-scale agriculture and woodlands. Assessing land cover land use change showed that the grassland cover registered the highest net loss by 33% followed by wooded grassland at 29%. Natural land cover increase was highest in woodland and tree plantation land cover categories with 41% and 22% respectively. These changes were further emphasized when overall woody cover was assessed. Woody cover of QENP registered a 25% increase between 1954 and 2006. In terms of the entire landscape, there was a 14% increase in woody cover between 2006 and 2017, which is a slightly higher rate of loss over 11 years compared to the period of 52 years. Agriculture also gained 10% coverage within the same period. Overall, there has been a higher increase in woody cover inside protected areas due to reduced mammal densities and a higher decrease outside protected areas attributed to agricultural expansion, infrastructure development and human settlement. Savanna parks are becoming more woody, which may pose a threat to the survival of angulates that occur in GVL. The key drivers of land cover land use change need to be fully addressed by the regional governments under the transboundary collaboration framework already in place.

On the other hand, industrial developments have the potential to affect wildlife behaviour and examples are given of the impacts of oil exploration in Murchison Falls NP on elephant behaviour, impacts of the cobalt mines near Rwenzori Mountains NP on vegetation, impacts of the hydropower dam at Mpanga on Cycads and potential impacts of the proposed cable car to the top of Karisimbi volcanoe in the Volcanoes Park. Ideally, industrial developments would not take place in the GVL and all efforts should be made to avoid having a negative impact on the natural habitats and wildlife in the landscape by using directionally directed access from outside the landscape. Where avoidance is impossible and where there is no option to stop the development then the mitigation hierarchy should be followed and the key principles of this concept, that is, additionality, permanence, equivalences should be upheld. The company should go beyond simple compensation, but work toward achieving a net positive impact. This is because this is one of the most biodiverse places on Earth, has three World Heritage Sites and 10 Key Biodiversity Areas. We noted that poaching pressure on wildlife will also have an impact on where animals range and we showed that poaching pressure varies across the landscape using ranger patrol data from SMART in Uganda and DRC. Snaring is often found near the park boundaries, but killing of larger animals such as elephants, hippos and buffalo occur in the central areas of the parks because they have been extirpated near most park boundaries. Declines of species to small populations is of real concern and the case of the "Tree climbing lions of Uganda" is highlighted as they have fluctuated greatly between 10-33 individuals over the time they have been monitored. Given that wild animals will continue to move out of protected areas into the communities either as part of their normal movement and dispersal routine, running away from extractive industries activities taking place inside the parks or simply responding to availability of food outside protected areas, a comprehensive human-wildlife conflict plan needs to be developed and communities living adjacent to these protected areas need to be supported in order to be part of the conservation agenda. As such, a performance-based reward system needs to be developed in order to incentivize communities to participate in conservation.

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1.0 Introduction

The Wildlife Conservation Society (WCS) was contracted by the Greater Virunga Transboundary Core Secretariat to make an assessment of changes that are, or may take place in the future, affecting wildlife behavior of the species that inhabit the Greater Virunga Landscape (GVL). The GVL is one of the most biodiverse landscapes in the World with a known 1,462 terrestrial vertebrate species and 3,105 plant species of which 107 vertebrate and 145 plant species are endemic to the Albertine Rift ecoregion, and 74 vertebrates and 41 plants are globally threatened (Plumptre *et al.* 2016a). For most of these species we know very little about their ecological requirements or their behavior, but the long term research on large mammals and some birds in the Queen Elizabeth, Kibale, Virunga, Bwindi Impenetrable and Volcanoes National Parks in the GVL has provided data on their behavior.

In the 1960s, a research station, the Institute for Ecology was established in Queen Elizabeth National Park in western Uganda which was affiliated to Cambridge University. It operated until the late 1970s after which, civil war in Uganda stopped research until the late 1980s and it re-opened in the early 1990s but was closed in the late 1990s because of lack of funding. It focused its research on the ecology of the large mammals in the park as well as the impacts of fire and grazing/browsing on the vegetation. The Makerere University Biological Field Station (MUBFS) was established with initial funding from WCS to support the work of Tom Struhsaker from 1969-1988 in Kibale National Park and subsequently the establishment of the field station and its stronger ownership by Makerere University, and research continues up to the present. The research focus has been on the ecology of the primates in the forest and the impacts of selective logging on biodiversity. Similarly, a research station was established in Lulimbi in Virunga National Park in 1971 and during the 1970s there was a series of research studies of the ecology of large mammals. Prior to this, there had been biodiversity surveys of the park in the 1930s-50s and some large mammal surveys in the 1960s.

The Karisoke Research Station (KRC) was established by Dian Fossey in 1967 in Volcanoes National Park in Rwanda, following the work of WCS's George Shaller in 1959-60 in the Virunga Volcanoes studying the mountain gorilla (*Gorilla beringei beringei*). KRC has continued its research up to the present, focusing on the ecology of mountain gorillas, but more recently also studying the ecology of other species such as the golden monkey (*Cercopithecus mitis kandti*) and the vegetation of the park. Finally, the Institute of Tropical Forest Conservation was established in the Bwindi Impenetrable National Park in 1988 and has also been focusing its research on the mountain gorillas as well as vegetation and habitat studies linked to human use of the forest. Its activities continue to the present. As such, the GVL has been particularly well supported by research stations and a wealth of research exists for the landscape. WCS has also been undertaking research in the savanna areas of the landscape together with the Uganda Wildlife Authority since 2006, which build on the earlier work of the Uganda Institute of Ecology.

Much of this research has some relevance for this study, but it would be impossible to summarise all of the detail of the research at these sites. Olupot et al. (2010) and Olupot & Plumptre (2010) provide a good summary of the research made in savannas and forests in Uganda while Plumptre (2012) summarises much of the ecological research from the research stations in the Albertine Rift region (including Lulimbi and KRC which are not covered in the books by Olupot).

The vegetation of the GVL is varied and also is important in determining animal behavior (figure 1.1).

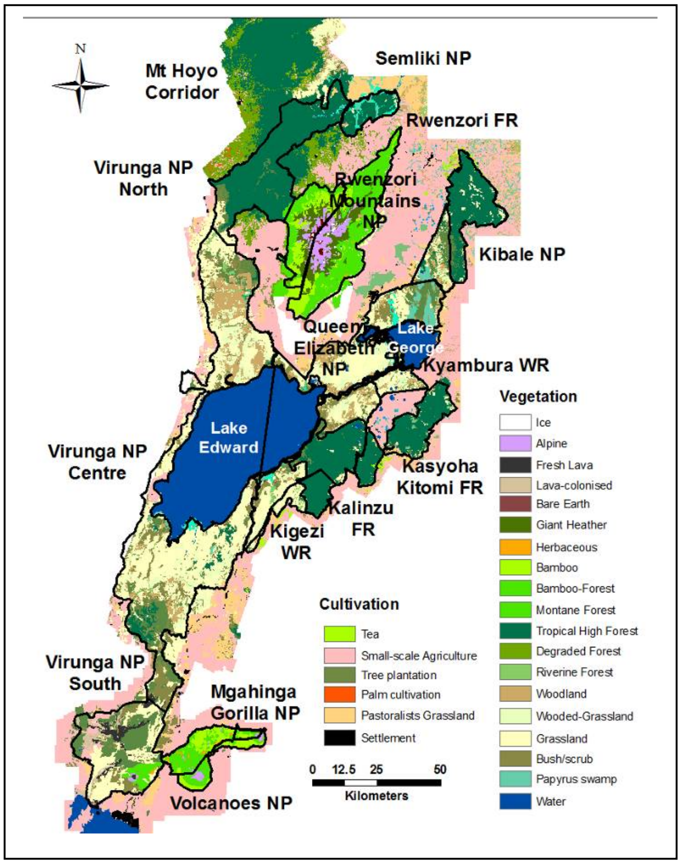


Figure 1.1. Vegetation map of the Greater Virunga Landscape (GVL) showing the wide diversity of habitats in the landscape

1.1 Objectives of the study

The goal of this study was to summarise the existing knowledge of changes in animal behavior in the GVL resulting from industrial development, climate changes and other factors and to assess changes in ecology resulting from habitat changes across the GVL. The objectives of this study were specifically to:

1. Assess the actual and potential changes in animal behavior resulting from Climate Change
2. Assess the actual and potential long-term changes in behavior resulting from oil/gas and geothermal exploration and production
3. Assess other factors (beside development and climate change impacts) that are or will affect animal behavior in the GVL
4. Map land cover changes over time in the GVL from 2000-2015/6

5. Provide recommendations for mitigating adverse changes in animal behavior in the GVL

We report on each of these objectives in the different sections of the report, with a chapter dedicated to each objective. Some of the information reported includes prior research relevant to this study in the GVL, including recent surveys of the QENP done by WCS as part of this study, and some comes from studies elsewhere in Uganda where there are no relevant studies from the GVL itself. For example, there have not been any studies of the impacts of oil exploration and development on animal behavior in the GVL, but there has been relevant research on these impacts on elephants in the Murchison Falls National Park (MFNP) and these findings are summarized here.

Where little information exists about a subject, such as industrial developments, we assess what likely impacts are, based on our experience with the industrial developments and from the literature to predict potential impacts on wildlife while recognizing that these are subjective and based on a best estimate of the impacts and recommend monitoring to measure actual changes as the industrial development unfold.

2.0 Impacts of climate change on animal behavior

2.1 Changes in climate in GVL

The climate of the GVL is very varied because of its great variation in altitude and habitats. Ranging from glaciers and afro-alpine vegetation around 5,100 metres above sea level (a.s.l.) to humid lowland rainforest at 600 metres a.s.l., there are extremes in temperature and rainfall within the same landscape which is what creates the diversity of niches for the many species that occur here.

Rainfall and temperature has been studied over a 100- year time period near Kibale National Park, both at MUBFS and in Fort Portal Town (Chapman *et al.* 2005a). Analysis of the data show that there has been an increase in both rainfall and maximum monthly temperature over time with as much as a 4°C rise in maximum temperatures over 33 years (Chapman *et al.* 2005b; Chapman *et al.* 2012). Much of this increase in temperature is attributed to deforestation and drainage of wetlands around the Kibale National Park rather than global climate change, but it shows that the impacts of climate change will be significantly exacerbated by land cover conversion to agriculture. Rainfall data at Beni (1974-2007), Kabale airstrip (1918-1996), and Ruhengeri airstrip (1928-1986) show significant increases over time (Figure 2.1). Data from Mewya Peninsula in QEPA and the Kiamara tea estate near Fort Portal both show near significant increases in rainfall and an increasing trend over time (Plumptre *et al.* 2012).

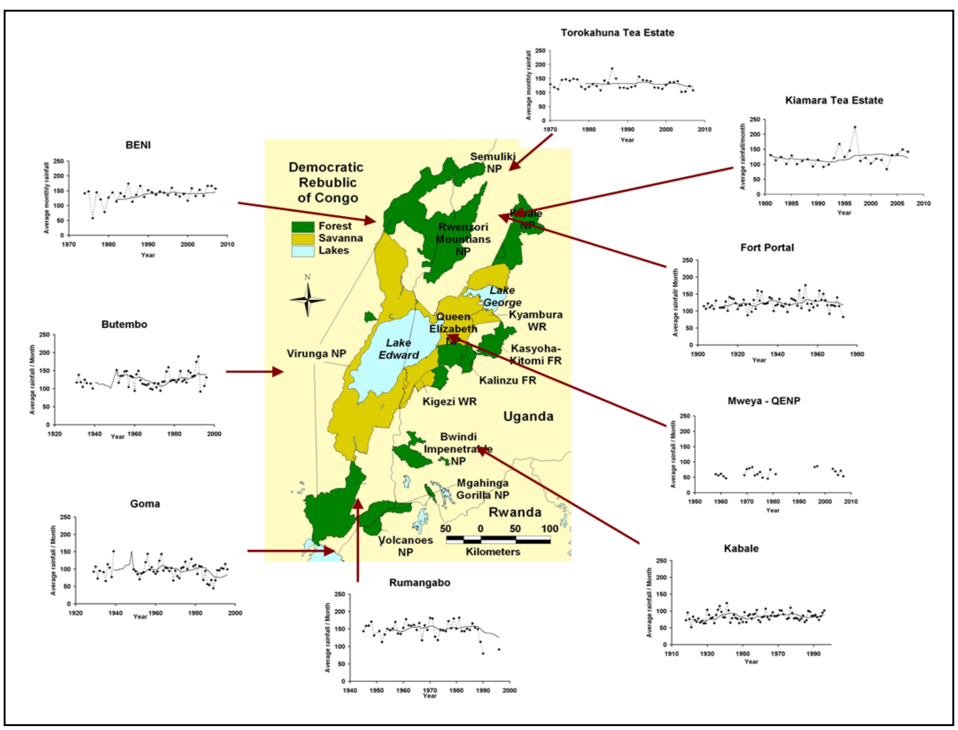


Figure 2.1. Annual rainfall data at sites around the Greater Virunga Landscape. Figure reproduced from Plumptre *et al.* 2012

Average monthly rainfall data were extrapolated from 43 weather stations around the GVL to estimate variation in the amount of rainfall across the GVL (figure 2.2). This analysis shows that the lowest rainfall occurs on Lake Edward and the savannas of the Rift Valley. Rainfall and temperature is a key determinant of the vegetation that occurs in the GVL.

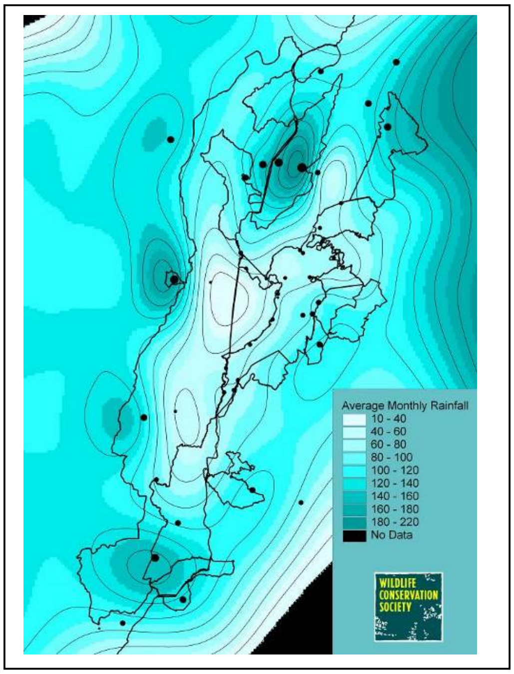


Figure 2.2. Average monthly rainfall across the GVL extrapolating from rainfall weather stations (black circles with circle size in relation to average monthly rainfall). Figure reproduced from Plumptre *et al.* 2012

Unfortunately, not many sites have recorded temperature over time and we do not know how temperature is changing apart from around MUBFS in the GVL. Data from the airport in Goma indicates there has been a 1^{o}C rise in temperature between 1971 and 2005 (unpubl. data), but records are not continuous. Due to insecurity in Uganda in the 1970s and 1980s, then in Rwanda and eastern DRC from 1991-1996 and 1996-2003 respectively have had an impact on the collection of meteorological data and equipment was stolen or destroyed at several sites also.

Recently, WCS in collaboration with the Appalachian State University with funding from MacArthur Foundation has been installing automatic weather stations at several sites within the Albertine Rift which will provide more accurate data. In Uganda, the stations are located at the following sites and data can be freely accessed.

UGANDA_SEMULIKI_NTANDI (https://www.hobolink.com/p/c05298f3448a4d0eacdebd7f2231a7c6)
UGANDA_NTOROKO_KANARA (https://www.hobolink.com/p/3bc125e009f3058deba50c3f1ffd6825)
Bwindi -Buhoma HQ (https://www.hobolink.com/p/e0ca016a025aaa0aef0009d927804d73)
Queen Elizabeth –Ishasha (https://www.hobolink.com/p/ef9e7f6fe58ba019f1b58b687aebeb39)
Queen Elizabeth -Katunguru HQ (https://www.hobolink.com/p/f01a534488c858023e2d212e484657e5)
Rwanda-NYUNGWE-Mt Bigugu (https://www.hobolink.com/p/475bf6d0e3cceeb5971e76c2dfd9cb8b)

Climate change modeling results for the region predict that the GVL will become wetter and warmer over time (Seimon & Picton Phillipps, 2012). Predictions for the landscape under the A2 scenario of climate change are summarized in table 2.1 from modelling of the potential changes. The A2 scenario at the time was the model that was tracking actual climate changes that were taking place. Net primary productivity (NPP) is modelled together with the productivity of three staple crops, beans, maize and a fodder grass *Brachiaria*. While NPP increases over time, productivity of beans and maize decline as temperatures become too warm for these crops to do so well. Unless people change what they grow this will lead to migrations of people with time.

Table 2.1. Predicted changes in climate, runoff and productivity for the GVL (table from Picton Phillipps and Seimon, 2009)

		1990	2030	2060	2090	
Mean Monthly Temperature	*Min*	16.6	17.5	18.6	20.2	°C
	Mean	**20.4**	**21.3**	**22.5**	**24.0**	
	Max	23.9	24.7	25.9	27.5	
Annual Precipitation	*Min*	740	747	791	904	mm
	Mean	**1145**	**1153**	**1207**	**1332**	
	Max	1653	1678	1739	1864	
Runoff	*Min*	43	28	50	127	mm
	Mean	**147**	**148**	**192**	**320**	
	Max	383	432	538	660	
Net Primary Production	*Min*	1131	1228	1335	1475	$gC\ m^{-2}$
	Mean	**1286**	**1383**	**1488**	**1560**	
	Max	1404	1524	1659	1712	
Heterotrophic Respiration	*Min*	928	1002	1088	1247	$gC\ m^{-2}$
	Mean	**1091**	**1201**	**1333**	**1451**	
	Max	1220	1326	1484	1597	
Bean Yield	*Min*	1	11	73	403	$kg\ ha^{-2}$
	Mean	**995**	**969**	**950**	**870**	
	Max	1497	1443	1387	1271	
Maize Yield	*Min*	46	213	667	571	$kg\ ha^{-2}$
	Mean	**1941**	**1935**	**1908**	**1787**	
	Max	3531	3539	3402	3111	
Brachiaria Yield	*Min*	2	4	6	15	$kg\ ha^{-2}$
	Mean	**1778**	**1931**	**2194**	**2487**	
	Max	3952	4059	4286	4957	

Climate models are constantly changing and the models used for these analyses are now outdated. However, there are no published updates on the predictions of these newer models yet for the Albertine Rift. We do not believe though that the general trends of increasing rainfall, temperature and Net primary productivity will change greatly. Seimon et al. (2017) used the National Center for Atmospheric Research's Community Earth System Model (CESM) to generate depictions of environmental futures under climate change for major African Great Lake watersheds based on the high greenhouse gas and land-use change Representative Concentration Pathway (RCP) 8.5 and examined how climatic extremes and vegetation may develop over coming decades across the region. The predictions shown in Figure 2.3 offer a single representation of possible environmental futures for the region in terms of rainfall and seasonal droughts in 2005 and 2045, but other predictions by CESM and other earth system models may show very different result. Most areas are expected to experience intense rainfall and the dry season shortens by up to one month in southern DR Congo, while it increases up to two months in duration in western Uganda, extending all the way to Tanzania. The hydrological Runoff, which is the amount of rainfall per year (mm) that flows into water bodies and is not taken up by vegetation, groundwater recharge or evaporation, in the highland regions of the Albertine Rift stand to increase their function as water towers against a heating and drying climate.

Intense Multiday Rainfall

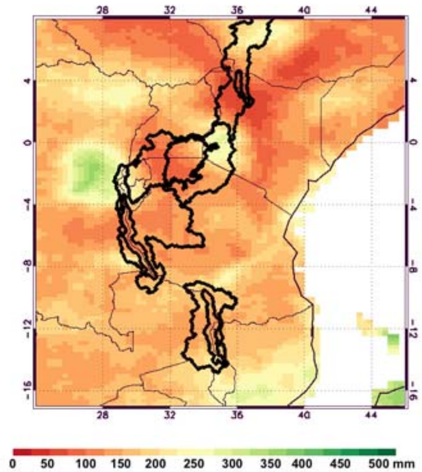
Maximum total rainfall (mm) expected over a 5-day period in a given year

Left: typical year around 2005

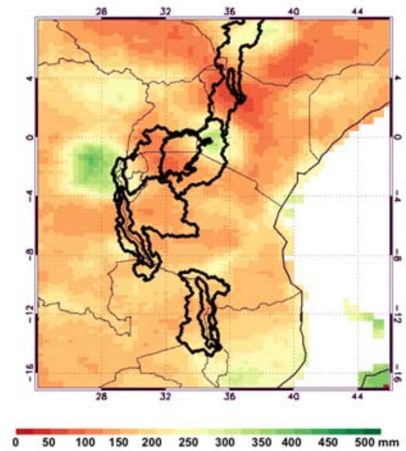
Right: typical year around 2045

NOTES: All values exhibit increases over time: there are no areas expected to experience less-intense rainfall. A major new hotspot of intense rainfall emerges in the Winam Gulf on Lake Victoria. The eastern DRC maximum is well represented, but an equally strong maximum over southwest Lake Victoria is not captured by the model well represented, but an equally strong maximum over southwest Lake Victoria is not captured by the model.

2005: 5-day rainfall maximum



2045: 5-day rainfall maximum



Seasonal drought

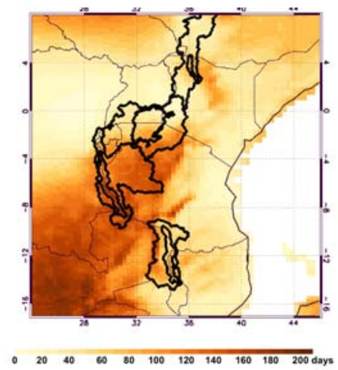
Number of consecutive dry days in the longest dry season:

Left: Dry season duration in a typical year around 2005

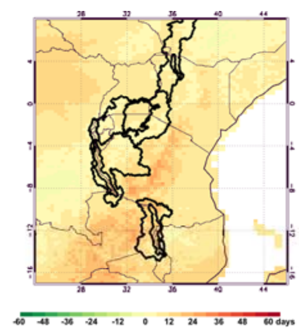
Right: change in number of days in 2045 compared to 2005

NOTES: Dry season shortens by up to one month in southern DR Congo, while it increases up to two months in duration in western Uganda extending to Tanzania

2005: Seasonal Drought



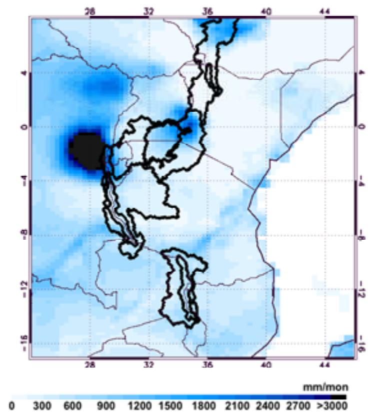
2045: Seasonal Drought Duration



Hydrological Runoff
The amount of rainfall per year **(mm)** that flows into water bodies and is not taken up by vegetation, groundwater recharge or evaporation.

Left: Runoff amount in typical year around 2005
Right: Change in runoff by 2045 compared to 2005

2005: Annual Runoff total (mm)



Difference in Runoff from 2005 and 2045

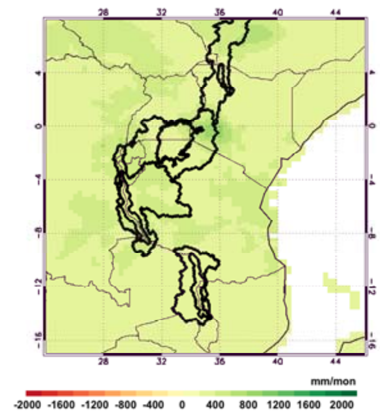
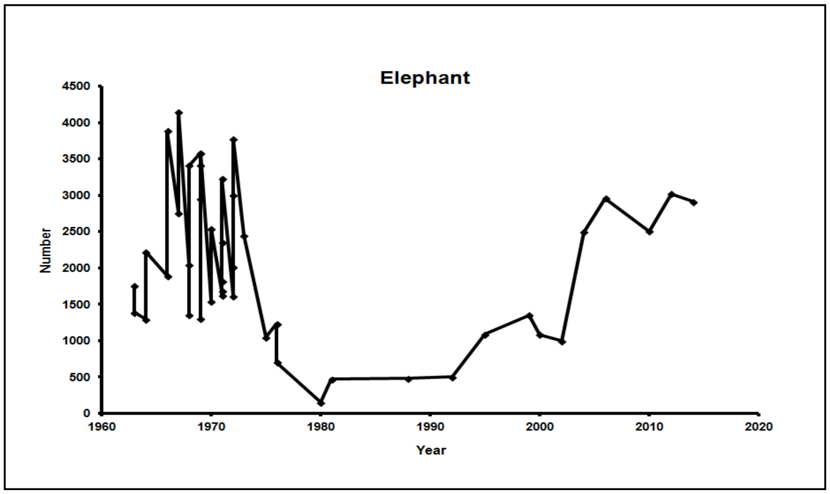


Figure 2.3 CESM model predictions of rainfall and seasonal drought in the African Great Lakes Region (Source: Seimon et al. 2017)

2.2 Impacts of climate change on vegetation productivity, phenology and fire

Vegetation productivity and changes over time

The data in Table 1 indicates that net primary productivity (NPP) will increase over time. This is partly a result of the increasing rainfall and temperatures. The balance of savanna and woody/forested natural habitat is in part determined by rainfall and temperature. Increases in these climate variables will tend to lead to a likelihood of loss of savanna grasslands and woodlands and a gradual replacement by forest. Data for the savannas of the GVL between 1954 and 2006 did show an increase in woody biomass but this has been exacerbated by the decline in large herbivores that occurred as a result of poaching in the 1970s-1980s in QEPA and then in 1990-2017 in Virunga Park. Elephants are known ecosystem engineers and at high density tend to convert woodland to grassland (Laws, Parker and Johnstone, 1975). Elephant numbers in the savannas of the GVL have declined and increased again in QEPA but continued to decline in Virunga Park (figure 2.4). This has had impacts on the vegetation (Plumptre *et al.* 2010).



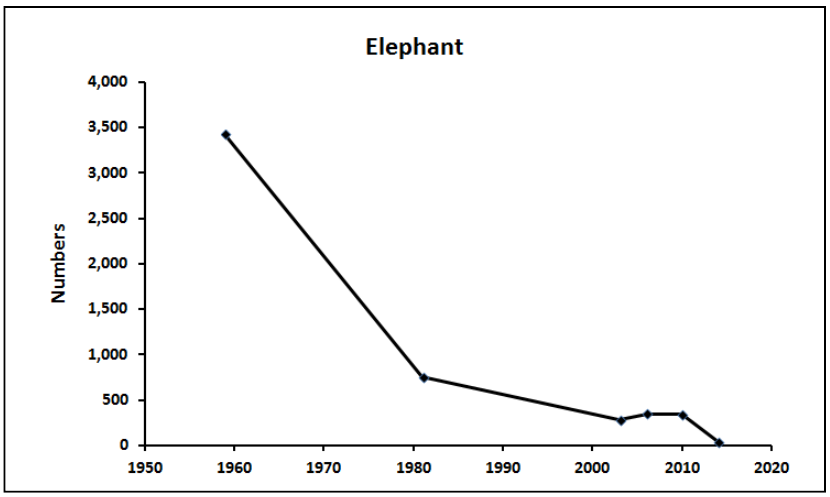


Figure 2.4. Plot of numbers of elephants for each year since 1963 in QEPA (top) and Virunga (bottom)

The dramatic decrease in numbers of elephants between 1970 and the mid to late 1980s, was accompanied by regeneration of *Acacia* trees, and expansion of the *Acacia* woodlands and thicket vegetation in general (Lock 1977a, 1977b; Lock 1985; 1988). In addition, not only the quantity of thicket vegetation but also the diversity of species was increased, with much greater numbers of *Euphorbia candelabrum* and *Securinega* (*Fluggia) virosa*, a favorite elephant food, and an increase in vegetation at the lake margins creating a fringe of *Vossia cuspidata* around the lakes (Lock 1985, 1988). The increase in thicket and lakeshore vegetation in the park between the 1960s and 1980s was a result of reduced intake as a result of a reduction in the numbers of elephant, as well as buffalo, and hippo, according to census estimates from 1969 and 1989 (Lock 1993). Analysis of mapped habitat changes between 1954 and 2006 showed a significant increase in woody vegetation across the savannas of QEPA although there has also been woody cover loss at some sites (figure 2.5). This analysis is updated to 2016 in Chapter 5.

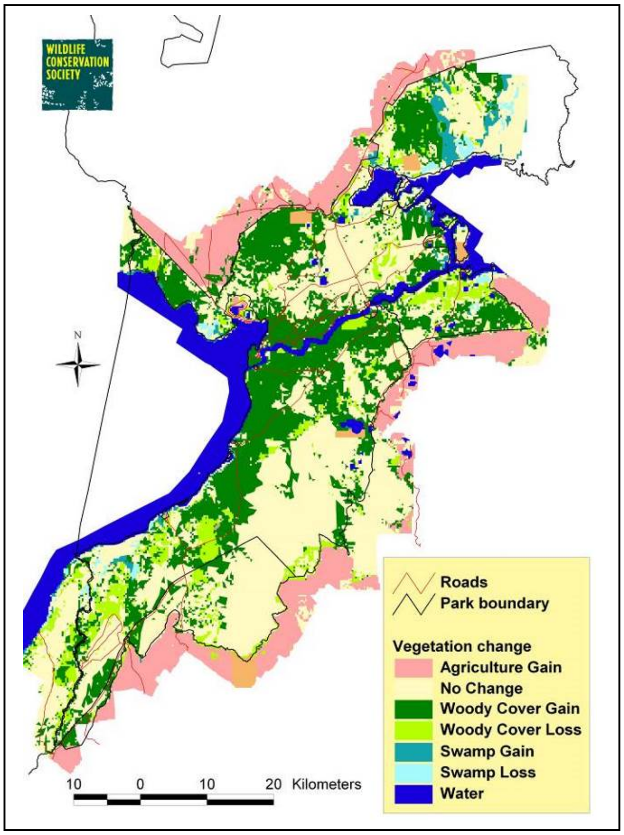


Figure 2.5. Changes in woody cover in QEPA between 1954 and 2006

Hippopotamus numbers have also had an impact on the vegetation in QEPA. In the 1960s Lake Edward contained 30,000 hippos, the largest population in the World but poaching in the 1970s to 1990s decimated the numbers to about 6-7,000 today. As hippos graze on land at night, and return to permanent water by day, the impact that they have on vegetation within a zone of about 3 km from water is noticeable, and particular grassland types occur in zones according to their distance from permanent water (Lock 1972). During the dry season, this zone can be increased somewhat, as the quality of vegetation within the zone becomes poorer (Laws, 1968; Laws *et al*. 1975). Hippos prefer to graze short grass and maintain it as such. Longer grass is left untouched for as long as there is enough short grass. This results in characteristic 'hippo lawns' often surrounded by longer un-grazed grass of the same species. Constant use may lead to a degree of overgrazing and trampling depending on soil and climatic conditions. Once this process gets beyond a certain point, rainwater runoff erodes a ridge or a terrace at the edge of a lawn which may become undercut. This happens because the roots of the heavily grazed grass are less numerous than those of less grazed lawn and bind the soil less tightly (Laurie 1974). In one study, where hippos were excluded from a grazing area for two years, the area that was originally a mosaic of short and tall grasses and bare patches of soil became relatively uniform (Lock 1972). Moderate hippo grazing in QENP maintains a mosaic of short and long grasses that are utilized by other grazing species (Lock 1972). However, high population densities of hippos can lead to complete loss of the vegetation, resulting in high rates of erosion and low permeability of the soil

(Thornton 1971). This deterioration of the habitat then decreases the carrying capacity of this grassland mosaic habitat for other species as well (Edroma 1981).

Comparison of vegetation plots measured in 1991 and 2009 showed that the impact of elephants and hippopotamuses on the vegetation of QEPA was significant at changing plant species composition over time (Plumptre *et al.* 2010) so it is difficult to separate the effects of climate and the changes in numbers of the large herbivores on the increasing woody cover in QEPA. Productivity of grasses and trees, and species composition of the vegetation are affected by the densities of these two large herbivores in the landscape as well as the grazing effects of the smaller ungulates which help maintain the grazing lawns established by hippos.

Fire

Fire has a major role in maintaining grasslands, particularly when there are no elephants. In the 1970s, up to 32.7% of QEPA burned in one season, and 55% of the park had burned at one time or another during a 3-year study (Eltringham 1976). Fire damages vegetation in the immediate term and the extent of subsequent effects of fire on vegetation depends on the available fuel. When the burn occurs at the beginning of the second dry season (June-August), it promotes growth and diversity of herbaceous species in *Hyparrhenia-Themeda* grassland (Edroma 1977, 1984). As the dry seasons in the park are too short to allow total drying of the soil and grasses, the duration and intensity of fires when allowed to burn is relatively low. Management of fire has promoted early burning at the end of the wet season so that the fires are less intense.

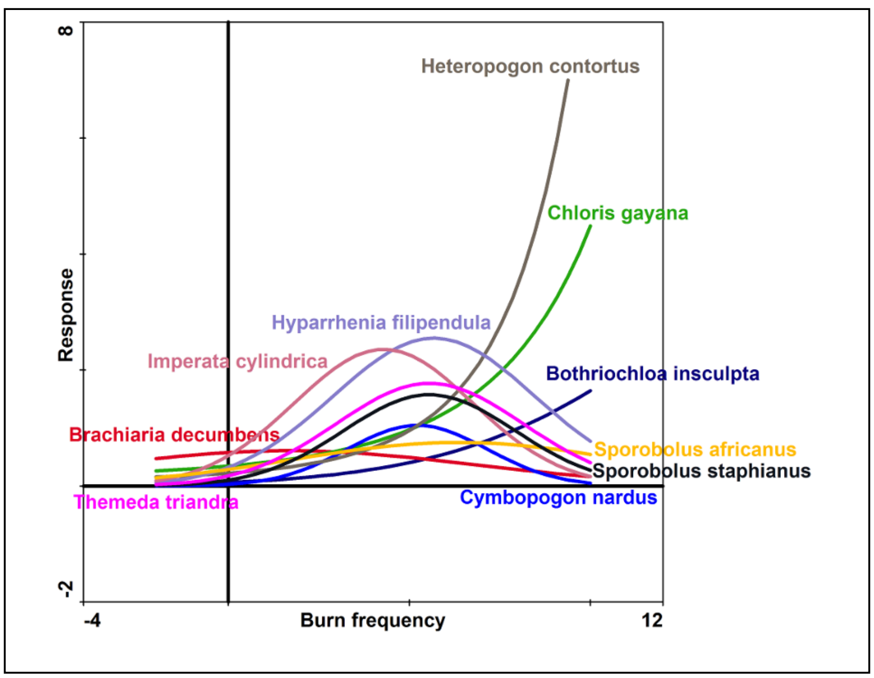


Figure 2.6. Relative abundance of grass species in QEPA in relation to burn frequency

A number of smaller herb species such as the grasses *Microchloa kunthii*, and other herbs such as *Hibiscus aethiopicus* and *Rhamphicarpa* sp., flower after burning when the taller grasses have been removed, suggesting that they are at least partly dependent on fire for their survival (M. Lock pers. comm.). Burning stimulates uniform sprouting and growth of grassland (Edroma 1984), which in turn attracts herbivores (and thus their predators) to areas that had been abandoned due to the maturity of the grasses. Fire has been shown to stimulate germination of the buried seeds of *Themeda triandra* (Lock and Milburn 1971). Under usual conditions, fire seems to have more of an effect in maintaining existing vegetation structure than causing changes in the habitat structure of the park.

Removal of grass by elephants and hippos reduces the frequency of fire at a site due to suppression of biomass accumulation and increasing rainfall increases leaf and stem production in grasses which increases the fuel load. Therefore, the trend towards increasing rainfall recorded at sites in and around the savannas of the GVL will likely lead to increases in the fuel load for fires during the dry season, particularly where poaching has reduced the large mammal numbers. Plumptre *et al.* (2010) assessed the impacts of burn frequency on vegetation in QEPA and found that plant species richness does not change greatly until very regular burning takes place at which point diversity declines. Species of herb that increased with increasing burn frequencies included *Digitaria diagonalis*, *Cymbopogon nardus*, *Chloris gayana; Sporobolus stapfianus*, *Bothriochloa insculpta*, *Vernonia smithiana*, *Microchloa kunthii*; *Hyparrhenia filipendula*, and *Heteropogon contortus*. Species such as *Brachiaria decumbens*, *Cynodon dactylon*, *Cyanotis foecunda*, *Cyperus articulatus*, *Justicia flava*, and *Oplismenus hirtellus* generally occurred where burn frequency was very low or never occurred between 2001 and 2009 (figure 2.6).

These species tended to be consistently found in these patterns whichever analysis was used to assess the impact of fire and some of them have been found to do well in areas of the park that regularly burn (Jaksic-Born, 2009). We updated the analysis of burn scars across the GVL savannas by digitizing the areas burnt from Landsat imagery obtained at the end of the Dec-Feb and June-Aug dry periods. Each dry season burn scar was mapped individually and then combined into one map of burn frequency (figure 2.7).

The maps comparing burn scar frequency between 2004-2009 did not include the satellite imagery mapping of the south of the Virunga Park conducted by the University of Maryland in 2009 and we did not update these maps), but results showed that there was more frequent burning of larger areas in the latter period although there were more dry season periods between 2004-2009 (10 dry seasons) compared with 2012-2017 (10 dry seasons). This is what would be predicted by increasing rainfall and biomass production. While control of fires in Virunga Park has been impossible in recent years due to the presence of armed rebels, the Uganda Wildlife Authority (UWA) has been trying to control fire frequency in QEPA, however, fire mapping results show that this has not been successful. This is mainly because poachers deliberately set fires to encourage animals to come close to their villages without risking entering the park illegally.

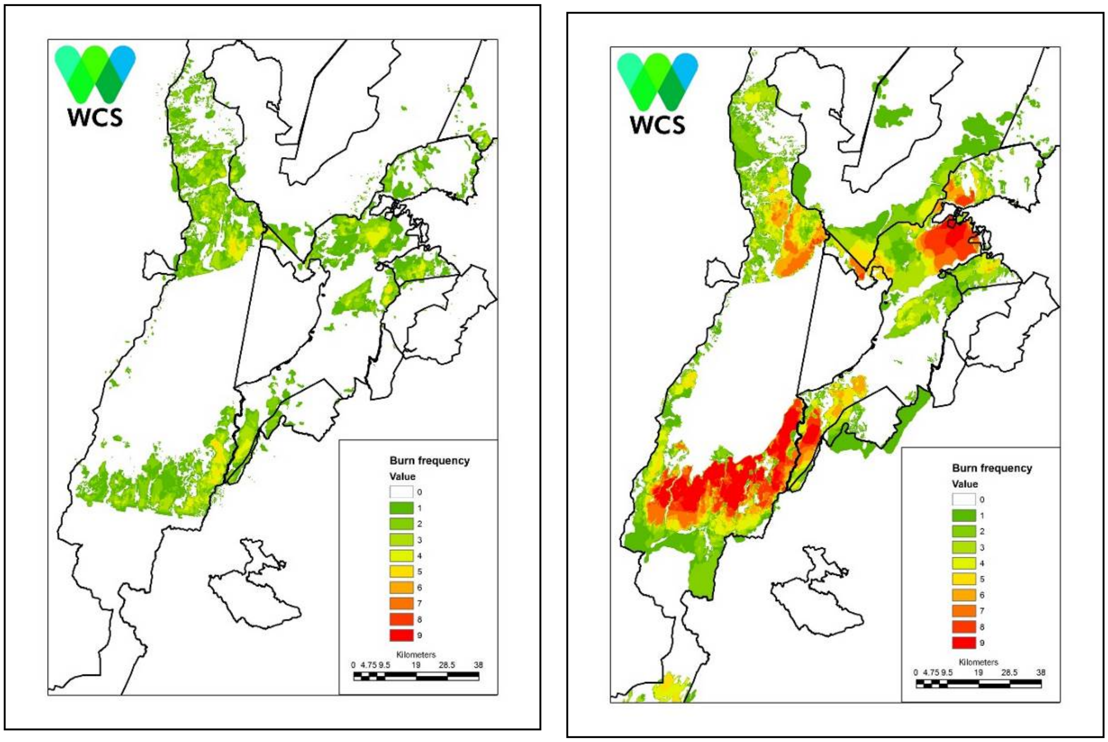


Figure 2.7. Map of burn frequency of fires on the savannas of the GVL between 2004-2009 (left) and 2012-2017 (right), each a five-year period with two dry seasons and equal possibilities of burning

Vegetation phenology

The phenology of leaf biomass production in savannas has been documented in relation to fire studies (see previous section). We here focus on the production of flowers and fruit in the forested parts of the GVL. Long term studies of flower and fruit production have been made at MUBFS. The studies show that during the 1970s there was a decrease in fruit production in the forest around the Kanyawara research station, but that between the early 1990s and mid 2000s there was an increase (Chapman *et al.* 2005; 2012) in the proportion of trees fruiting (figure 2.8). This study compared different trees during the two-time periods, but selected mature trees of the common species. During the 1990-2002 period, there was a trend of increasing maximum temperatures at MUBFS from 25 to 26°C, but a trend towards decreasing minimum temperatures (Chapman *et al.* 2005b). Chapman *et al.* (2005a) showed that several of the common species tended to exhibit a correlation between fruiting and minimum temperature a few months before fruit production (presumably when flowering may have occurred).

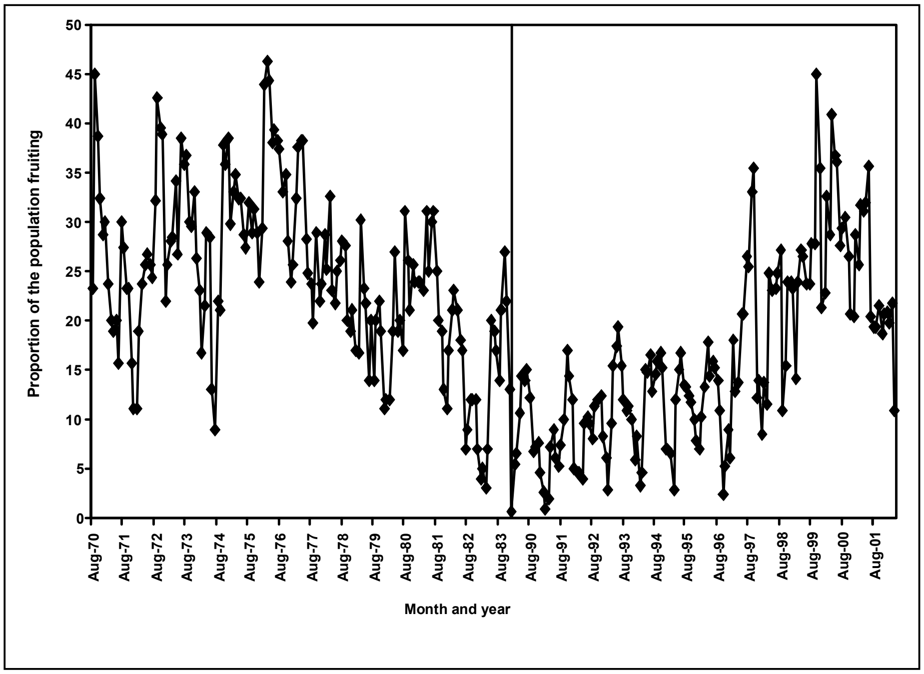


Figure 2.8. Changes in the proportion of trees monitored that bore fruit between 1970-1984 and between 1990-2002. Figure reproduced from Chapman *et al.* 2012

The only other site near this landscape with long-term phenology data is at Budongo Forest Reserve where 24 years of monitoring of tree phenology has occurred between 1993-2017 at the BudongoConservation Field Station (BCFS). The selection of trees for monitoring was based on trees in permanent plots and all trees with a Diameter at Breast Height (DBH) of 10 cm or larger were monitored. In Budongo, there has been a decline in fruiting (figure 2.8), particularly of trees producing fleshy fruits that are consumed by primates (Babweteera *et al.* in prep). Data on changes in rainfall and temperature from Budongo show that the wet seasons are becoming wetter while the dry seasons are drier indicating that there are more extreme variations in the climate, which is predicted by the climate models Seimon et al. (2012). Both maximum and minimum temperatures have increased at Budongo, which is a different to what is observed at Kibale and flowering is correlated with low maximum temperatures for fleshy fruiting trees and a small difference between maximum and minimum temperatures. It would appear therefore that temperature or something linked to it is important in triggering flowering. At Budongo, the feeding ecology of monkeys was studied in 1992-1994 and also in 2012-2014. With the decline in fruit production, there has been a halving of fruit in the diet of blue (*Cercopithecus mitis*) and redtail (*C. ascanius*) monkeys and an increase in leaf, bark and resin consumption (figure 2.10). It appears therefore that climate change is having an impact on flowering and in subsequent fruit production in the region of the GVL, but more research is needed to understand what factors trigger flowering in different species.

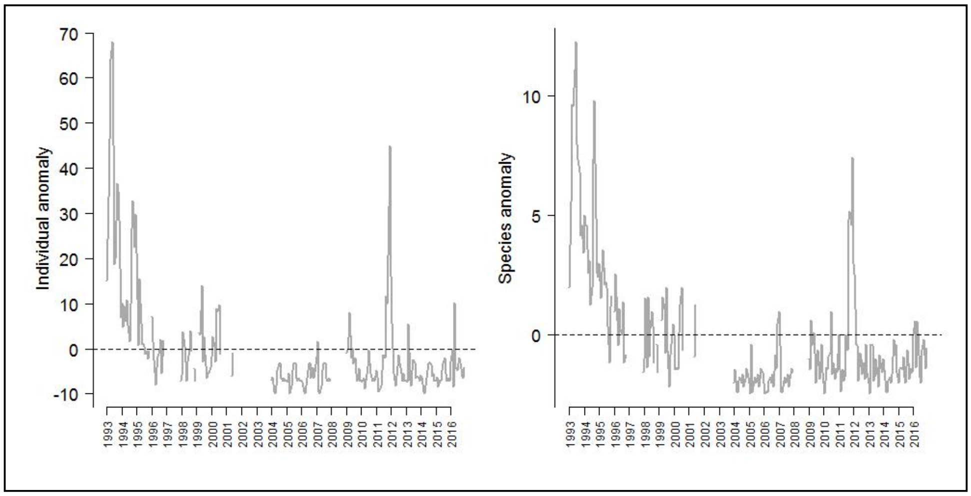


Figure 2.9. The relative number of individual trees fruiting (left) and species of tree fruiting (right) over time at BCFS

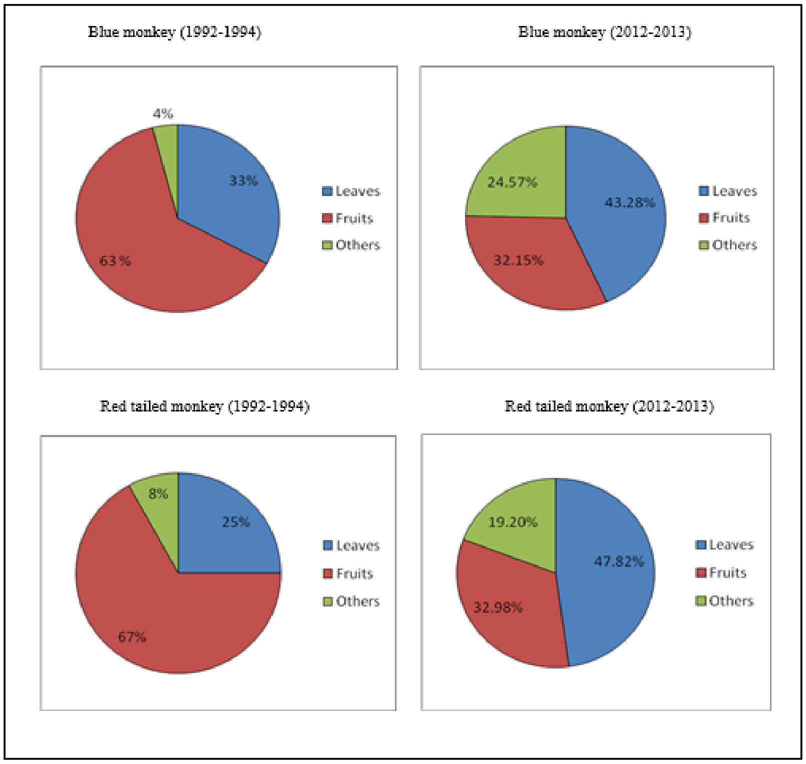


Figure 2.10. Diets of blue and redtail monkeys in 1992-1994 (left) and 2012-2013 (right). Figure from Nyombi 2015.

It is also possible that climate is affecting the pollination of flowers rather than the flowering per se (although in Budongo there has been some decline in flowering as well). A study of the availability of pollinators in Budongo showed that there are many pollinators available (F. Babweteera pers comm.), but it is possible that factors such as increased rainfall is preventing them from moving as much between trees as they used to in the past.

2.3 Predicting impacts of climate change on animal distributions

An estimated 20 to 30 % of higher plants and animal species that were assessed during the working group II of the Intergovernmental panel on Climate change, were found to be at a high risk of extinction if the global mean temperatures increases within the range of 2 to 3°C above preindustrial levels (Fischlin et al 2007). Five mass extinction events have occurred in past 540 million years and a potential sixth mass extinction trajectory is likely to be precipitated by habitat modification, invasive species/pathogens, over-exploitation and climate change (Barnosky, et al, 2011, IPCC, 2014). The interaction of climate change with other environmental stressors (habitat modification, invasive species/pathogens, pollution, over-exploitation) is likely to exacerbate the magnitude and rate of species extinction (Barnosky, et al, 2011, IPCC, 2014).

Species will respond to climate change along three axes; spatial, temporal, and self (Bellard, et al 2012). The "spatial axis" involves a species tracking suitable climatic conditions in space, the "temporal axis" involves change in phenological events such as flowering, fruiting, reproduction and seasonal migrations and the "self axis" allows the species to track the suitable climatic conditions within their current range through physiological or behavior changes (Bellard, et al 2012). The ability of species to track suitable habitat under changing climate will be minimal for species that: a) inhabit flat terrain, b) have restricted ranges, c) occur in isolated habitats, and d) have low dispersal capacity (Sekercioglu, et al 2012; IPCC, 2014). Species range shifts, abundance and change in seasonal activities have been documented in recent decades especially in insects, birds and marine invertebrates as result of climate change (Jetz et al, 2007, Bellard, et al 2012, Sekercioglu, et al 2012, IPCC, 2014). The speed at which species will respond to climate change across landscapes through dispersal or migration will be slower than the rate at which climate will be moving across the landscape (IPCC, 2014).

A meta-analysis focusing on the impacts of climate change (825 papers; 1990 – 2015), using species traits evaluated how threatened species of birds and mammals are currently being affected by climate change (Pacifici, et al 2017). The estimated number of species of birds and mammals, whose populations have already been impacted by climate change at a global scale, was estimated to be about 700 (Pacifici, et al 2017). The following intrinsic species traits were considered; Body mass, dietary breadth, dispersal distance, generation length, litter size, litters per year, weaning age, activity pattern, habitat specificity, fossoriality, mean clutch size, forest dependence and the following extrinsic factors were considered Altitudinal interval, minimum altitude, precipitation seasonality, temperature seasonality, maximum temperature and mean temperature difference.

Species' intrinsic traits and environmental variables that were identified from the multinomial logistic regression as being indicators of species (mammals) vulnerability to climate change included;

a) Non fossorial species
b) High temperature differences in the past 60 years within their ranges
c) Low precipitation seasonality (mean precipitation between the driest and wettest seasons)
d) Species with a specialized diet

Intrinsic traits and environmental variables that infer negative responses in both breeding and non-breeding ranges of birds included:

a) High temperature differences in the past 60 years within their ranges
b) High altitude species
c) Low temperature seasonality within their ranges
d) High maximum temperature recorded within breeding ranges
e) Low dispersal distances
f) Longer generation length
g) Low precipitation seasonality
h) Restricted altitudinal ranges in non-breeding ranges

Rodents and insectivores showed positive responses to climate change and the three orders of Primates, Proboscidae and Marusipials were predicted to have a high likelihood of being impacted by climate change. Climate change was predicted to have positive impact on most of the threatened bird species except for the species that inhabit aquatic environments or are forest dependent. In this analysis, the mammal species that occur in the Greater Virunga Landscape that were identified as currently being impacted by climate change were *Loxodonta africana, Hippopotamus amphibius, Cercopithecus lhoesti, Pan troglodytes, Cercopithecus hamlyni, Gorilla beringei*. The species list was not comprehensive as the data that was available for the African region was less than 1 % of analysis.

An assessment of climate change vulnerability and adaption for the mountain gorilla (*Gorilla beringei beringei*) and its habitat in the GVL was also made using SDMs (McGahey, et al 2013, Thorne et al 2013). Expert opinion by primatologists who reviewed the predicted future suitable distributional areas in workshops, concluded that the models driven by climate variables and altitude do not fully represent the potential niche of the mountain gorilla (McGahey, et al 2013). The current realized niche of mountain gorillas is limited by anthropogenic activities and given that, eastern lowland inhabits low elevation areas, its highly plausible that the mountain gorillas would be able to inhabit lowlands (McGahey, et al 2013).

The range of occurrence records and temperature variables that were used in estimating the current and future distribution areas of mountain gorilla have been limited by land use change which has eliminated *potential* mountain gorilla range from lower elevations. Net primary productivity was considered as an important limiting factor in the distribution of mountain gorilla within its current range and future model outputs driven by net primary productivity were considered to better represent future distributional areas (McGahey, et al 2013, Thorne et al 2013). A large portion of the current range of mountain gorilla will likely remain suitable under future climate conditions and expanding the current protected areas boundaries would significantly contribute to the long term survival of the mountain Gorillas (Thorne et al 2013).

A climate change vulnerability assessment for species (2358) of mammals, birds, reptiles, amphibians, fish, plants that are known to occur in the Albertine rift was also made based on species trait data by

IUCN and Traffic (Carr et al. 2013). The climate change vulnerability assessment was based on the following three components;

a) Sensitivity (ability to persist in situ)
b) Adaptive capacity (the ability to mitigate impacts by dispersing or undergoing micro-evolutionary change)
c) Exposure (the degree to which the species will be subjected to climatic changes)

A species' ecological, life history, genetic and physiological traits were considered for the sensitivity and adaptive capacity components and the variability in temperature and precipitation across a species range were used to measure the exposure component. Considering all the three components of climate change vulnerability assessment, a total of 31 amphibians, 199 birds, 31 fish, 107 mammals, 79 plants, 70 reptiles were identified as the most likely to be impacted by climate change in the Albertine rift.

Species that are found in the Greater Virunga Landscape that are vulnerable to climate change and are also harvested for food, pet trade, medicine, timber are shown in the Table 2.2. Species that Globally threatened and are vulnerable to climate change are shown in Table 2.3.

Table 2.2. Species vulnerable to climate change and exploited by humans in the GVL

Birds	Mammals	Plants
Balaeniceps rex	*Cephalophus silvicultor*	*Entandrophragma angolense*
Balearica regulorum	*Cercopithecus lhoesti*	*Entandrophragma cylindricum*
Cryptospiza shelleyi	*Cercopithecus mitis*	*Entandrophragma utile*
Glaucidium albertinum	*Damaliscus lunatus*	
Pseudocalyptomena graueri	*Galago senegalensis*	
Buccanodon duchaillui	*Gorilla beringei*	
Bycanistes subcylindricus,	*Hippopotamus amphibius*	
Dendrocygna viduata	*Kobus ellipsiprymnus*	
Nigrita canicapillus	*Kobus kob*	
Pogoniulus scolopaceus,	*Papio anubis*	
Sarothrura pulchra,	*Phacochoerus africanus*	
Spermophaga poliogenys,	*Cephalophus nigrifrons*	
Spermophaga ruficapilla	*Cephalophus weynsi*	
	Cercopithecus ascanius	
	Cercopithecus denti	
	Cricetomys emini	
	Genetta genetta	
	Lepus microtis	
	Neotragus batesi	

Table 2.3. Globally threatened and vulnerable to climate change

Birds	Mammals	Plants
Apalis argentea	*Cercopithecus lhoesti*	*Afzelia bipindensis*
Balaeniceps rex	*Crocidura lanosa*	*Entandrophragma angolense*
Balearica regulorum	*Crocidura stenocephala*	*Entandrophragma cylindricum*
Cryptospiza shelleyi	*Gorilla beringei,*	*Entandrophragma utile*
Prionops alberti	*Hippopotamus amphibius*	*Khaya grandifoliola*
Pseudocalyptomena graueri	*Rhinolophus ruwenzorii*	*Ocotea kenyensis*
Torgos tracheliotos	*Ruwenzorisorex suncoides*	*Guarea cedrata*
Trigonoceps occipitalis	*Sylvisorex lunaris*	
Hirundo atrocaerulea	*Thamnomys kempi*	
	Myosorex blarina	
	Lophuromys rahm	
	Dasymys montanus	
	Delanymys brooksi	
	Hybomys lunaris	
	Lophuromys medicaudatus	
	Lophuromys rahmi	
	Myosorex blarina	
	Crocidura kivuana	

There are two methods that can be used to assess how climate change may affect the distribution of species. The first is to develop niche models with climate variables as predictors and then predict under future climate models to the future. The second is to revisit sites that have been surveyed previously and assess how species ranges have changed. This second method often looks at changes in the altitude range of a species as it is predicted species will move upslope as temperatures warm to remain in the same niche. In order to predict impacts of climate change on particular species in the GVL, we assessed how their niches may change using species distribution modeling.

2.3.1. Predictive modeling of species ranges (Species Distribution Modeling)

Species Distribution Models (SDMs) have been widely used in projecting the potential impacts of climate change on species and ecosystems. For example, predicting the spread of invasive species, conservation planning and prioritization, guiding of field surveys to find new populations /unknown species, assessing impacts of land cover change, guiding translocation and reintroduction of threatened species, assessing disease risk, testing ecological theory, testing evolutionary and biogeographical processes (Pearson, 2008). We used SDMs to estimate the current and future suitable distribution areas of endemic and threatened species (large mammals, birds, plants) in the Greater Virunga Landscape (Ayebare et al 2013). Species distribution models estimate the actual and potential suitable distribution areas of a species through a combination of a species occurrence records with environmental layers across space and time (Elith, et al 2011; Elith & Leathwick, (2009); Pearson, 2008). Estimating the actual and potential distribution areas across space and time involves visualizing species' occurrence records in both environmental and geographical space. The models are calibrated in environmental space through the identification of the climatic conditions that a suitable for a particular species and then projected into geographical space. Species were modelled at the scale of the Albertine Rift to ensure a good estimate of their overall environmental niche was considered and then the extrapolation of the models within the GVL used in the results below.

Species occurrence records and environmental variables.

A total of 118,305 species occurrence records across three taxa (110 species) of large mammals, birds and plants were used in establishing the species-environmental relationship across the Albertine rift. The records were obtained from the Wildlife Conservation Society database, Tanzania mammal Atlas and the Global Information facility. The Albertine rift scale was considered as the modeling extent for the Greater Virunga Landscape, in order to capture a higher percentage of the distribution range of the occupied "niche" for the species of interest. Environmental variables (19 bioclimatic variables) were obtained from the Worldclim database (http:\\www.worldclim.org). The bioclimatic variables represent more biologically meaningful variables that are derived from monthly temperature and rainfall values. The current variables are interpolations of observed data representative of 1960 -1990.

Table 2.4. Predictor variables used for modeling the distribution of endemic and threatened species

Covariate	Description of Variable	Reference
Bio2	Mean daily temperature range	(Hijmans et al. 2005)
Bio5	Maximum temperature of warmest month	(Hijmans et al. 2005)
Bio6	Minimum temperature of coldest month	(Hijmans et al. 2005)
Bio7	Temperature annual range	(Hijmans et al. 2005)
Bio12	Annual precipitation	(Hijmans et al. 2005)
Bio16	Precipitation of wettest quarter	(Hijmans et al. 2005)
Bio19	Precipitation of Coldest Quarter	(Hijmans et al. 2005)

Multicollinearity was assessed using the ENMTOOLS and a pairwise pearson correlation between predictor variables was obtained (Warren et al. 2010; a toolbox for comparative studies of environmental niche model; http://purl.oclc.org/enmtools). Only variables with less than (+/-0.75) correlation were retained for use in the final model (Table 2.4).

General Circulation Models (GCMs)

Numerical models (General Circulation Models) representing physical processes in the atmosphere, ocean, cryosphere and land surface are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (IPCC 2000, 2007, 2013). While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis. A new set of scenarios referred to as Representative Concentration Pathways (RCP) were established for use in the new IPCC climate model simulations conducted under the framework of the Coupled Model Intercomparison Project (CMIP5) of the world Climate Research Program (Taylor et al., 2012). The IPCC's Assessment Report Five (AR5) present four different sets of RCPs based on radiactive forcing scenarios namely RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (van Vuuren et al. 2011). It should be noted that the baseline period for the IPCC AR5 is 1986-2005.

In this study, RCP8.5, a very high end climatic change scenario was used in the assessment of climate change impacts on wildlife behavior. By justification, there are differences among the RCPs defined by the radioactive forcing and the associated temperature change. Under RCP2.6, a more conservative pathway, the peak in radiative forcing is at approximately three watts per meter squared (~3 W/m2), (~490 ppm CO_2 equivalent) before 2100 and then declines to 2.6 W/m2 by 2100 (Clark et al. 2007; Wise et al. 2009; van Vuuren et al. 2011). In the case of RCP6.0, concentrations stabilize without overshoot pathway to 6 W/m2 (~850 ppm CO_2 equiv.) at stabilization after 2100 (Hijioka et al. 2008) while RCP8.5 is considered to be the rising radiative forcing pathway leading to 8.5 W/m2 (~1370 ppm CO_2 equiv.) by 2100 (Riahi et al. 2011; van Vuuren et al. 2011). According to IPCC (2013), global surface temperature change for the end of the 21st century is likely to exceed 1.5^0C relative to 1850 to 1900 for all RCP scenarios except RCP6.0. As such, the RCP8.5 is the most ideal scenario as it captures the worst case situation and any species that can adapt to these conditions will obviously coupe well under the lower climate change scenarios.

Ecological modeling

The Maximum Entropy approach (hereafter 'Maxent', Maxent version 3.3.3e) is a machine learning species distribution modeling algorithm that uses presence only occurrence records (Elith, et al 2011, Phillips & Dudík, 2008, Phillips *et al.* 2006, Phillips et al 2004). We selected the Maxent algorithm for species distribution modeling, because it has been shown to perform better compared to the other species distribution modeling approaches and it had been previously used in the assessment of the impacts of climate change on the distribution of endemic and threatened species in the Albertine rift (Elith *et al.* 2006, Ayebare et al 2013). Default Maxent model parameters (Auto features, convergence threshold of 0.00001, maximum number of background points =10,000, regularization multiplier=1) were used for all species. The output from Maxent is a raster file that represents an index of habitat suitability and has values that range from 0 to 1. We used the maximum training sensitivity plus specificity to convert the habitat suitability index values into a binary output map of 0 and 1. Cross validation model validation technique (10 folds) was used to evaluate the model performance on independent data and receiver operating characteristic curve (AUC; Hanley and McNeil, 1982), was used to assess the accuracy of model results. An AUC score above 0.7 is considered good model performance (Fielding and Bell 1997). After model validation, all the species occurrence records were used to run the models.

Current distribution areas for endemic and threatened species

The current distribution of suitable habitat for endemic and threatened species was estimated and then projected across the Albertine rift /Greater Virunga Landscape. The mapped suitable habitat represents:

a) The level of "equilibrium" of a species with its environment
b) The actual and potential suitable habitat
c) The environmental space occupied by the observed species' occurrence records

The montane forests contain more threatened species of birds and plants compared to the savannah areas in the GVL (Figure 2.11). However, the savannah areas have more threatened and landscape mammal species relative to montane forest areas (Figure 2.12). These maps already exclude where natural habitat has been converted to agriculture and settlement so do not show the original extent of species ranges. We assessed the extent of habitat loss also from the predicted niche range before it was clipped by the agriculture/settlement layer to estimate loss.

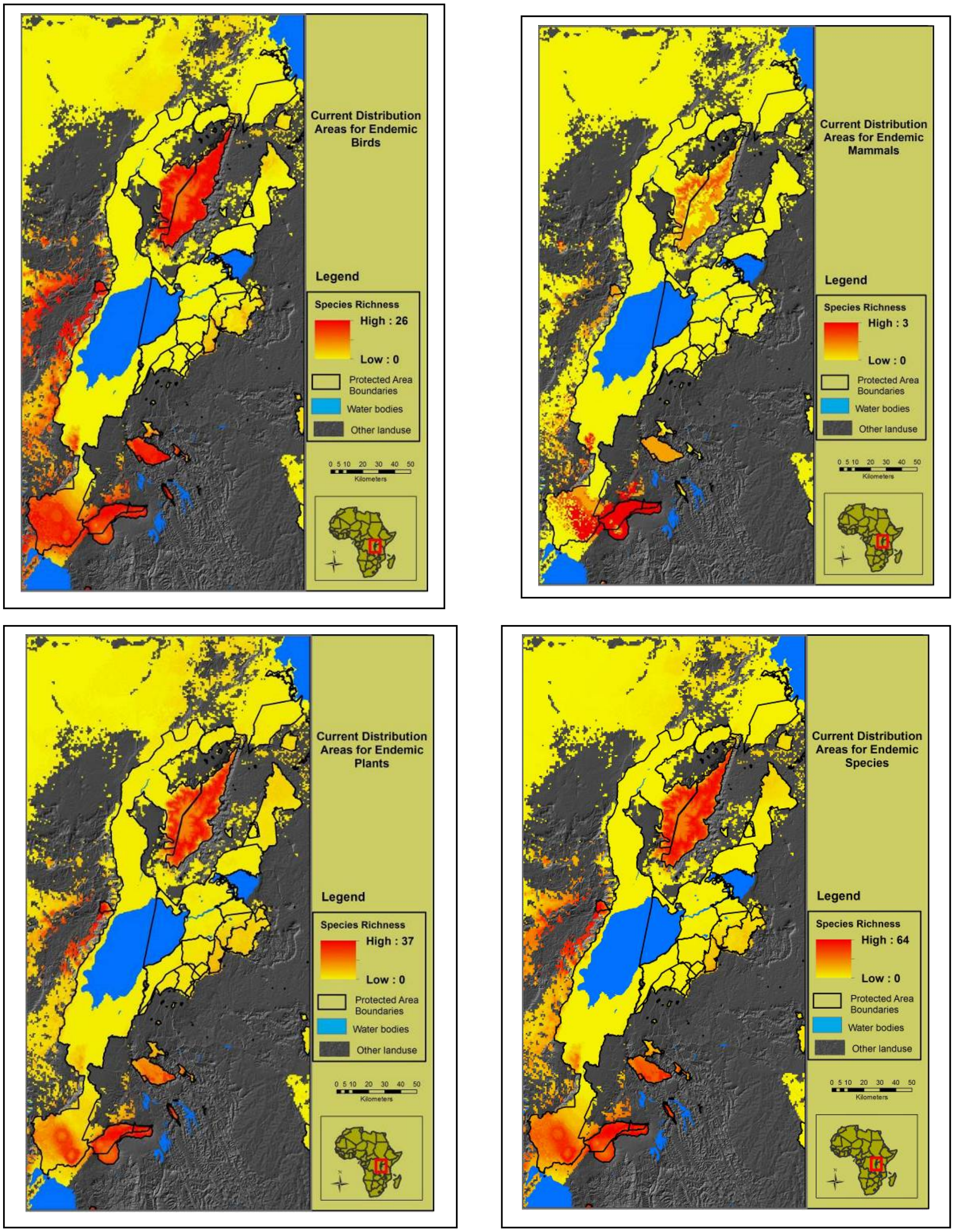


Figure 2.11. Current species richness for endemic birds (top left, n=30), endemic large mammals (top right, n=3), endemic plants (bottom left, n=47) and all endemic species (bottom right, n=80)

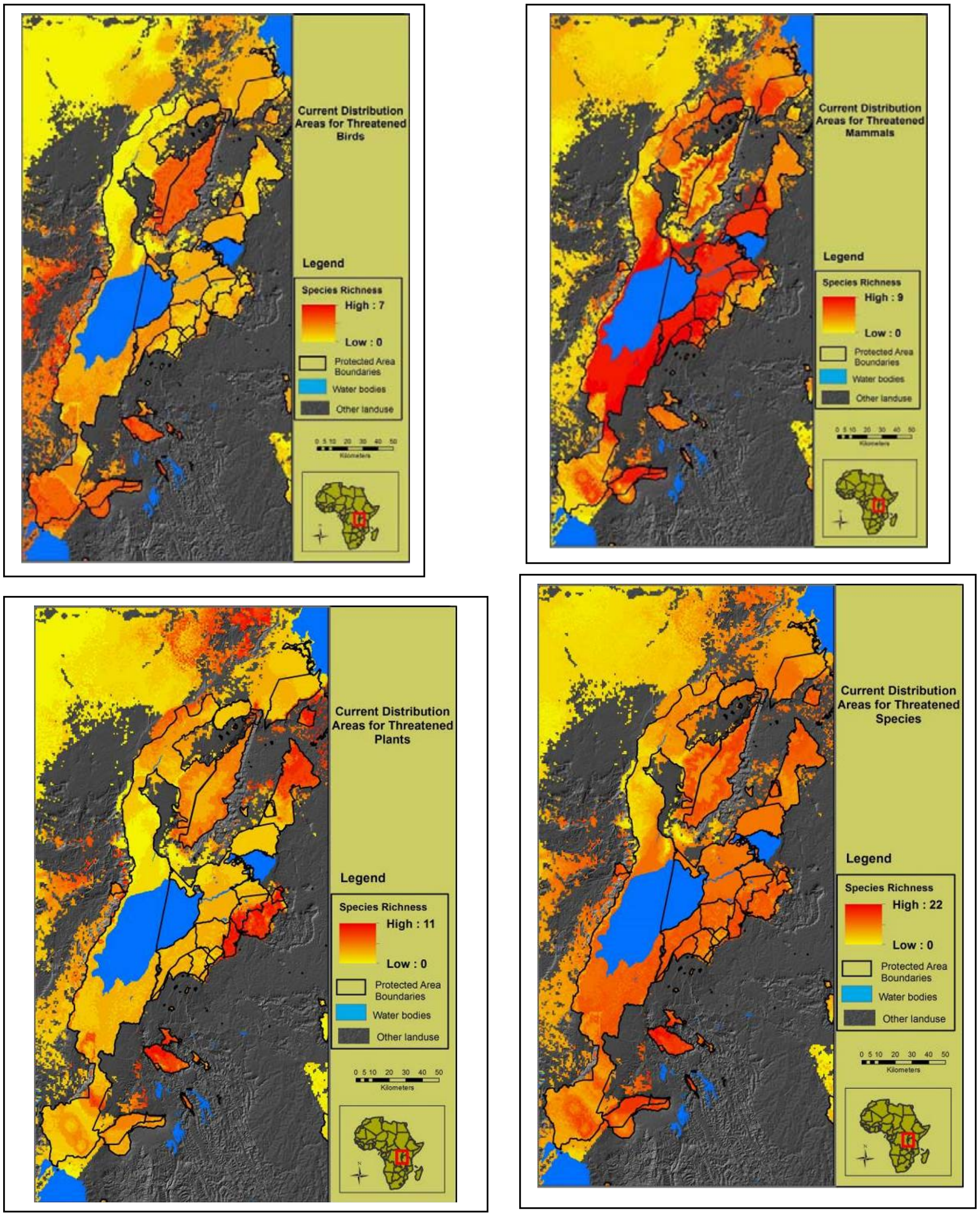


Figure 2.12. Current species richness for threatened birds (top left, n=11), landscape and threatened large mammals (top right, n=11), threatened plants (bottom left n=17) and all threatened species (bottom right n=39)

The predicted current species' ranges were clipped by the agriculture/infrastructure layer to quantify the extent of the suitable habitat that has already been converted to other forms of land use in the rectangle around the GVL in figures 2.12 and 2.13 (Table 2.5).

Table 2.5. Predicted current range size, percentage loss due to conversion to agriculture and infrastructure that has already occurred

		Range size (km^2)			Range Loss (%) to habitat conversion		
Status	Taxa (species)	Min	Mean	Max	Min	Mean	Max
Endemic (80 species)							
	Birds (30)	687	5158.3	10185	18.1	58.3	73.3
	Large mammals (3)	1476	2075	2855	47.4	53.1	58.4
	Plants (47)	200	3221	21008	0.2	55.8	83.1
Threatened and Landscape species(39)							
	Birds(11)	687	5918	14476	14.1	47.9	73.3
	Large mammals (11)	1476	10314	23132	23.2	44.3	58.8
	Plants (17)	329	6148	22539	24.1	55.3	72.3

The three assessed endemic taxa (birds, mammals, plants) have an average current range of 3,484 km^2, with the plants being the most widely distributed in the landscape (Table 2.5). On average the endemic species in the GVL have already lost about 55.7% of their current range to agriculture and infrastructure development in the region around the GVL (Table 2.5), although much of this loss occurred last century.

Species that have lost more than 65% of their current range to agriculture and other forms of landuse include: Birds: Blue headed sunbird, Grauers rush warbler ,Montane masked apalis ,Neumanns warbler, Purple-breasted Sunbird, Red-faced woodland warbler, Red throated Alethe, Rwenzori batis, Handsome francolin, Dusky crimson-wing ,Kivu ground thrush,Yellow-eyed black_flycatcher,Chapin's flycatcher, Dwarf honey guide, Ruwenzori nightjar, Shelleys crimson-wing.Plants: *Allanblackia kimbiliensis, Coccinia mildbraedii ,Diplazium_humbertii Embelia libeniana,Grewia mildbraedii, Harungana montana,Impatiens mildbraedii, Melchiora schliebenii,Musanga leo-errerae, Oxyanthus troupinii, Rubus kirungensis, Rytigynia bridsoniae, Rytigynia kigeziensis, Thunbergia mildbraediana,Monanthotaxis orophila, Pavetta pierlotii,Tabernaemontana odoratissima.* Threatened and landscape species (birds, mammals, plants) have an average current range of 3,484 km^2 with mammals having the largest average ranges (10,314 km^2). The current range of threatened species has already been reduced by 49% by agriculture and infrastructure development (Table 2.5).

The montane forests contain more threatened species of birds and plants compared to the savannah areas in the GVL (figure 2.12). However, the savannah areas have more threatened and landscape mammal species relative to montane forest areas (figure 2.12). Threatened bird and plant species that have already lost more than 60% of their current range to agriculture and infrastructure development include Grauers Rush_Warbler ,Chapin's Flycatcher, Shelleys Crimson-wing, Grey Crowned Crane bird species, plant species such as *Beilschmiedia_ugandensis ,Carex runssoroensis, Casearia engleri, Entandrophragma angolense, Entandrophragma cylindricum, Entandrophragma excelsum, Helichrysum formosissimum, Lovoa swynnertonii, Lovoa trichilioides, Ocotea kenyensis, Prunus africana, Turraeanthus africanus.* Landscape and threatened large mammals whose current ranges have been reduced by more than 50% due to agricultural production and infrastructure development include Chimpanzee, elephants, giant forest hog and African buffalo.

Future distribution areas for endemic and threatened species

The future distribution of suitable habitat for endemic and threatened species in the GVL was estimated using three Global Circulation models for the year 2070 under the Coupled Model Intercomparison Project Phase5 (CMIP5). The three General circulation models were:

a) ACCESS1.0: (Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology

b) HadGEM2-CC (Hadley Centre for Climate Prediction and Research)

c) CCSM4 (US National Center for Atmospheric Research)

The same General Circulation Models that we used to estimate the impacts of climate change on the distribution of endemic and threatened species in the Albertine rift under the Coupled Model Intercomparison Project Phase3(CMIP3) were considered for CMIP5 where available (Ayebare et al 2013, Plumptre et al 2016a). The GCMs are simulated using different climatic components depending on the modeling center. Under the frame work of the Coupled Model Intercomparison Project Phase5, various modeling centers submit their GCMs. To account for the variability from the three General Circulation models' predicted suitable areas, we used the “model majority” method to combine the threshold distribution for endemic and threatened species in the GVL (Ayebare et al 2013). Across the whole Albertine Rift, we estimated that an additional 70% of the remaining current suitable niche/habitat of the endemic and threatened species is likely to be lost to climate change by the year 2070, if the projected emission scenarios follow the trajectory under RCP 8.5 (Table 2.6). This loss is on top of the losses that have occurred to agriculture and settlement in the region around the remaining protected areas in the GVL region.

The results for the predicted future suitable areas indicate that Rwenzori national park, Mgahinga national park and Virunga volcanoes are important for the future conservation of endemic species in the GVL (Figure 2.13). For threatened species the savannah areas are important for the future conservation of large mammals (Landscape) and montane forests are important for the conservation threatened birds and plants (Figure 2.14).

Table 2.6. Percentage loss of range due to climate change (CC) and percentage overlap of the predicted future ranges with current range

		Range size in 2070 (km^2)			Range Loss (%) to CC			Overlap of future range with current range (%)
Status	Taxa(Species)	Min	Mean	Max	Min	Mean	Max	Average percentage overlap
Endemic (68 species)								
	Birds (27)	2	1446	4156	50.2	74.6	99.8	25.4
	Large mammals (3)	594	704	815	44.7	61.9	79.2	14.2
	Plants (38)	3	1164	14757	9.3	70.4	99.9	27.7
Landscape and threatened species (38)								
	Birds (11)	182	2864	11803	50.2	68.5	96.7	33.7
	Large mammals (11)	0	22561	5003	44.7	83	100	32.7
	Plants (17)	3	2725	11685	48	83.2	99.9	27.3

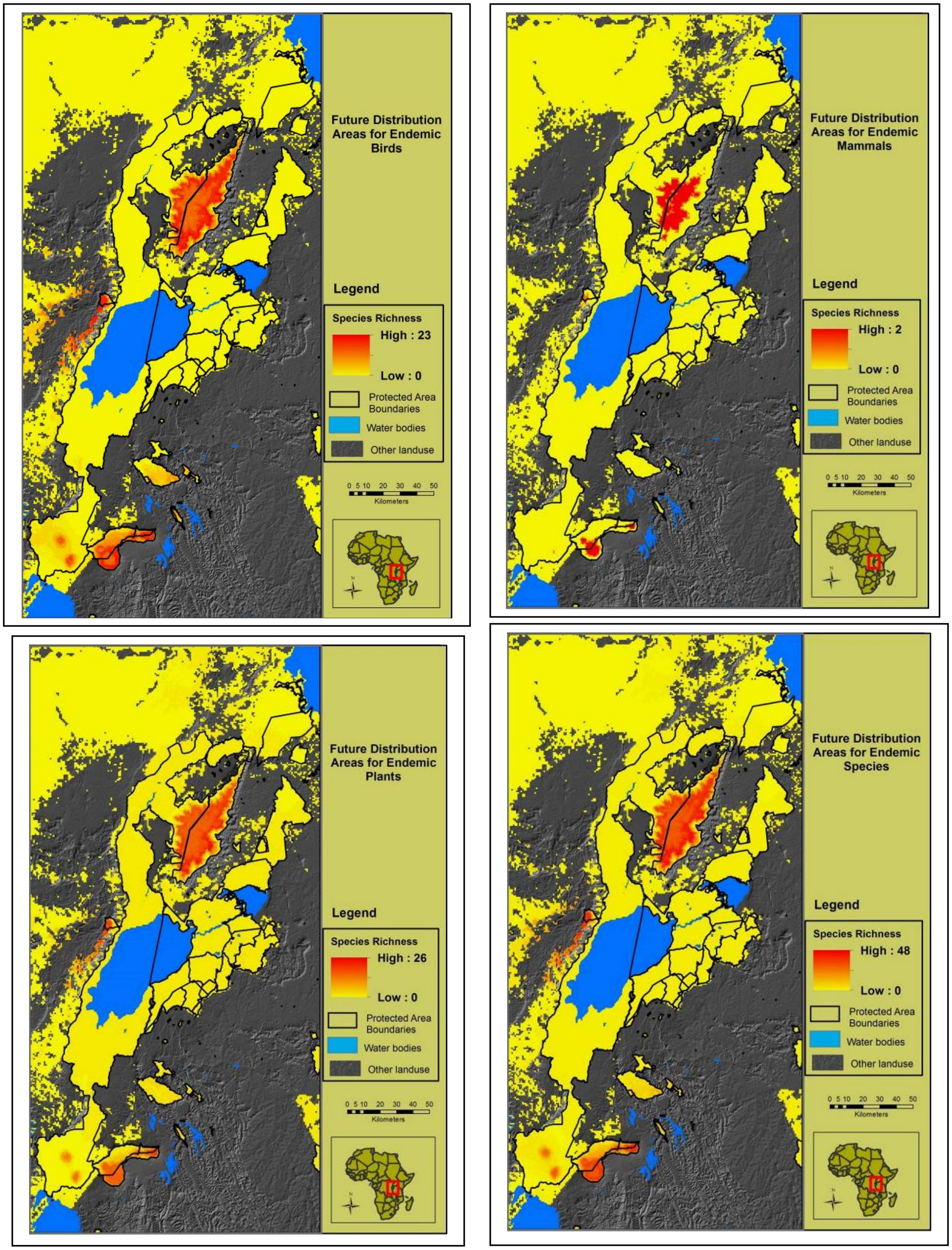


Figure 2.13. Predicted species richness for endemic birds (top left, n=27), endemic large mammals (top right, n= 3), endemic plants (bottom left, n=38) and all endemic species (bottom right, n=68) in 2070

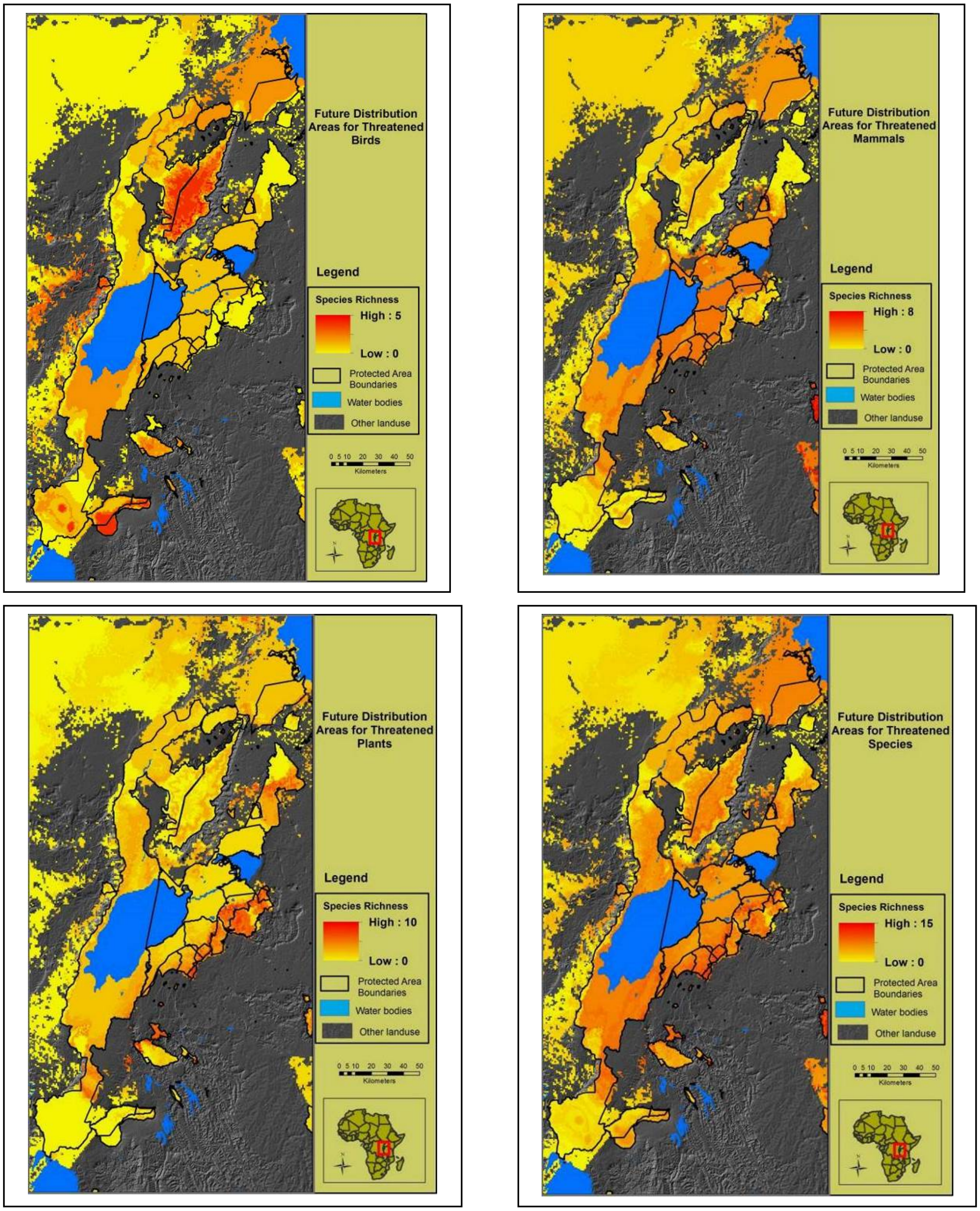


Figure 2.14. Predicted future species richness for threatened birds (top left, n=11), landscape and threatened large mammals (top right, n=11), threatened plants (bottom left, n=17) and all endemic species (bottom right, n=38) in 2070.

Results for the overlap of the current and predicted future distribution areas show that Rwenzori National park is likely to provide the largest refugia for endemic and threatened species in the GVL with more species with overlapping suitable habitat than any other site in the GVL (Figure 2.15).

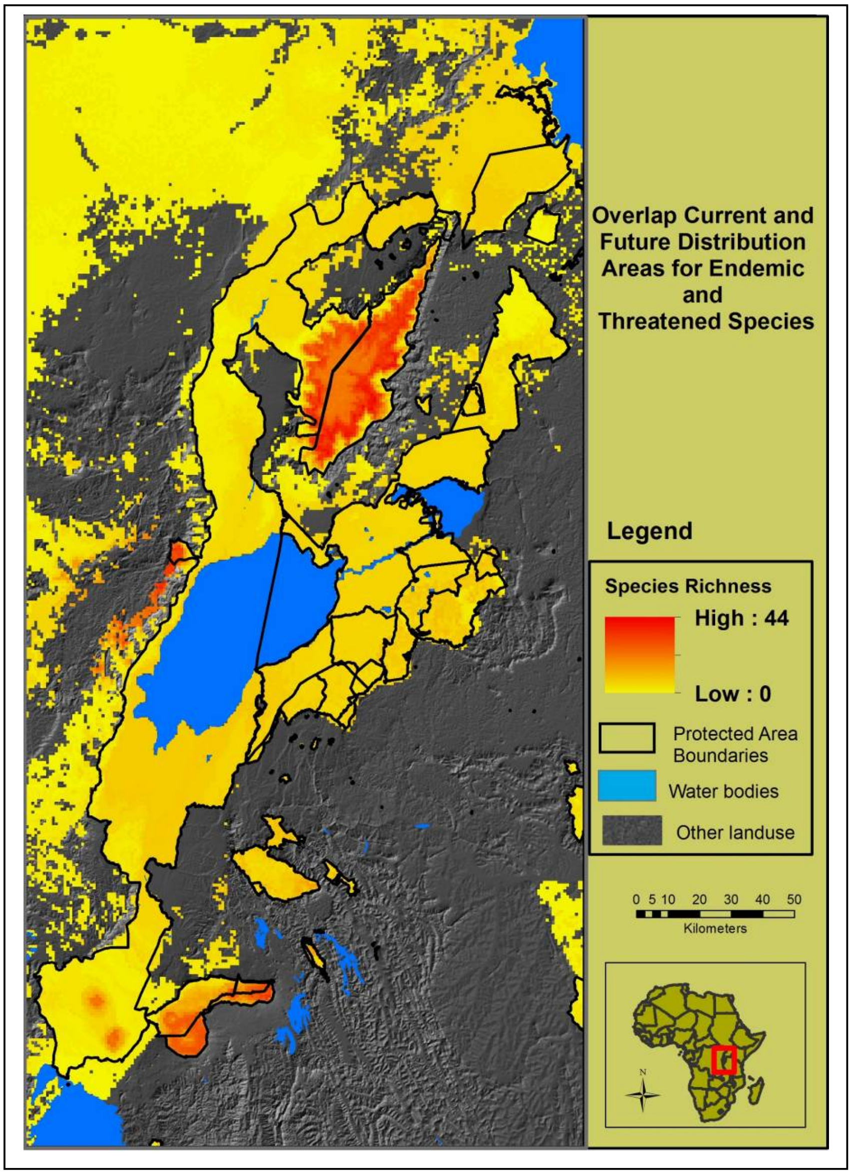


Figure 2.15. Number of species with overlapping suitable habitat currently and in 2070 for endemic, landscape and threatened species in the GVL

2.3.2. Changes in species ranges

Not much work has looked at changes in species ranges to assess possible changes resulting from climate change in the GVL. The only work we know of is a study made by WCS with University of York which revisited point count sites for birds in the Rwenzori Mountains National Park (RMNP) and Mgahinga Gorilla National Park (MGNP) (Byrne, 2016). Five-minute point counts were made in RMNP in 2002 and again in 2015 and in 2004 and 2015 in MGNP. A total of 256 points were revisited across both sites at different altitudes on the mountains. At both sites there was evidence of range shifts upslope, averaged across all species (figure 2.16). In RMNP, the upper range of species was significantly shifted upslope over this time period while in MGNP there was a trend for increasing upper range shifts, but these were not significant when tested.

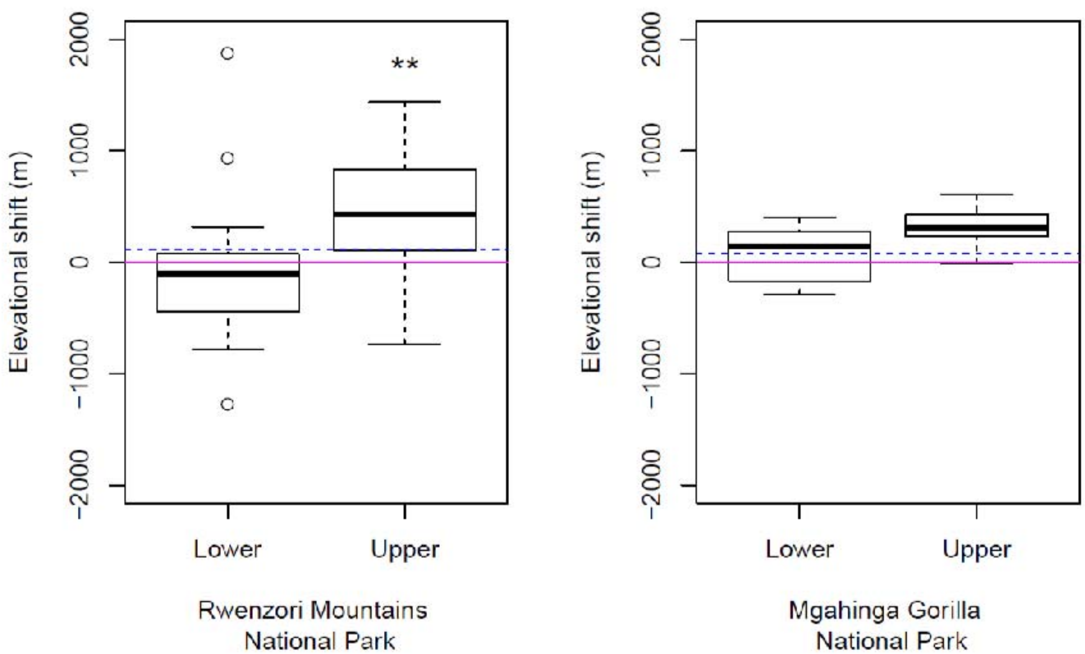


Figure 2.16. Elevational range shifts experienced at species' upper and lower distribution limits between survey periods. Box plots show medians, quartiles, and whiskers at 1.5 the IQR. The solid magenta line marks where no range shift has occurred, whereas the blue dashed line shows the range shift expected if species were to track the estimated temperature change in elevation. "**" indicates that the distribution limit has significantly shifted between sampling periods where $p < 0.005$, in a Wilcoxon signed rank test

The study also separated birds by their dependence on forest (taken from Birdlife International 2016) and analysed the movement in upper and lower boundaries of the range of the species (figure 2.16). This showed that forest dependent species are finding it more difficult to respond to climate changes compared with species with low dependency on forest and the low dependency species are the only ones that are keeping track of estimated climate changes (estimated from satellite data – see Byrne 2016).

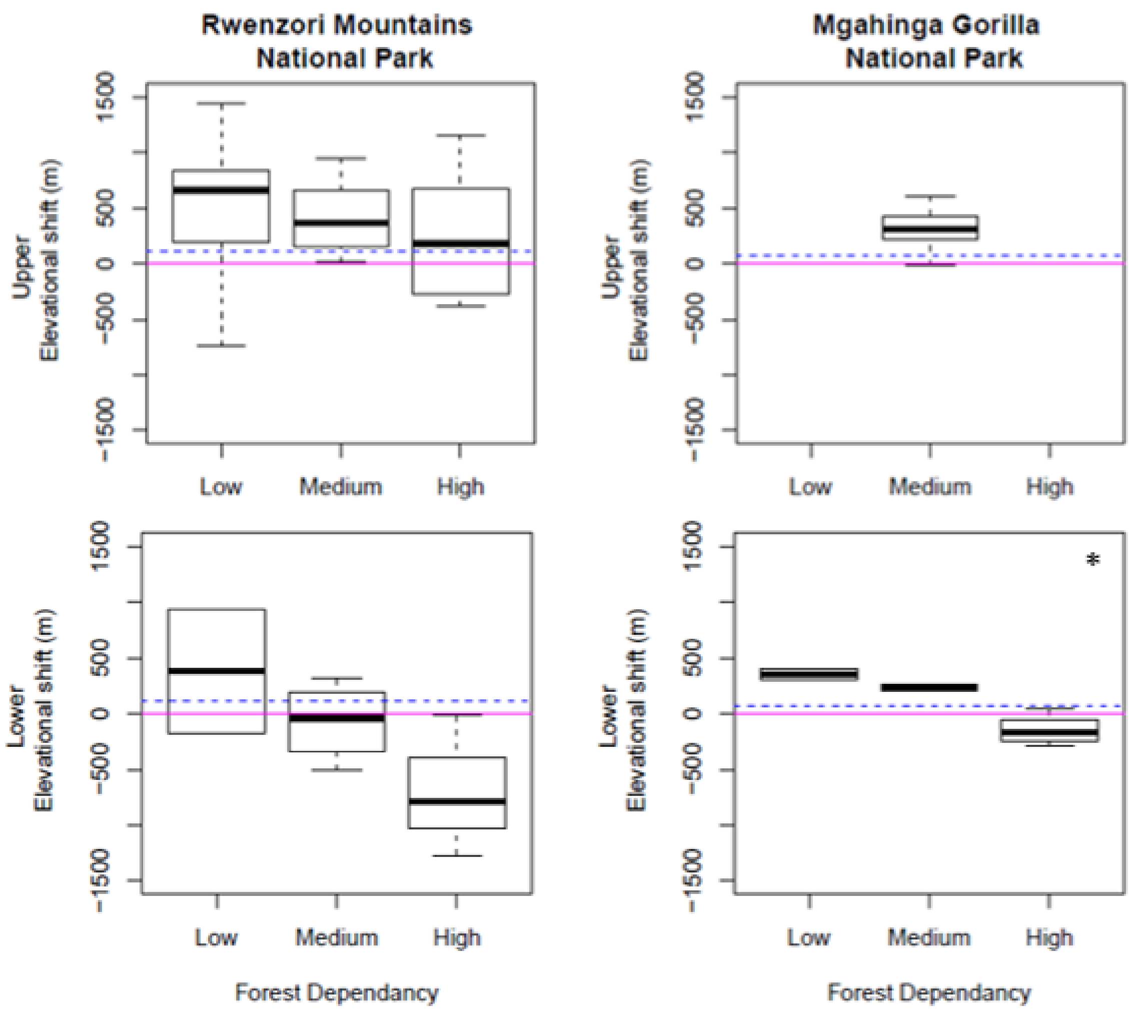


Figure 2.17. Elevational range shifts experienced at species' upper and lower distribution limits between survey periods, separated by the degree of forest dependency. Box plots show medians, quartiles, and whiskers at 1.5 the IQR. The solid magenta line marks where no range shift has occurred, whereas the blue dashed line shows the range shift expected if species were to track the estimated temperature change in elevation

While most of the tests were not significant (see asterisks in figures 2.16 and 2.17) the trend is there and given that there was only 12 or 14 years separating the two time periods and an estimated warming of only 0.46°C in MGNP and 0.65 °C in RMNP, it is unlikely that significant range shifts will be detected yet. Repeating these point counts in another 10 -15 years would be valuable.

3.0 Potential impacts of infrastructure developments on animal behavior

Several infrastructure developments related to oil and gas exploration and production, and also geothermal and hydropower developments have been planned or proposed for the GVL. A number of hydropower plants such as Mpanga Falls hydropower dam, Mbuku River hydropower plant, Kansangali Mini hydropower plant in Kasese district near RMNP have been constructed to date in Uganda. In addition, several mini-scale hydropower projects have been identified for development inside and outside RMNP. For example, a 5.25MW hydro-power project on the Sindila River in the Bundibugyo District, Bunyamera Parish, near Nyahuka is already under construction by Lereko Metier Sustainable Capital (a private equity fund based in Johannesburg), Fieldstone Africa Investment Resources (an energy development company based in Johannesburg), KMR Infrastructure (a US-based energy development company), and WK Power (a construction company based in Johannesburg). Near Bwindi Impenetrable National Park, Kanungu Power Station is a 6.6 megawatts (8,900 hp) run-of-the-river hydroelectric power station on the Ishasha River in Uganda and two hydropower dams have been constructed outside Virunga Park (Mutwanga and Matebe) to provide power to Beni and Rutshuru respectively. Oil and gas exploration occurred in QEPA with one site drilled and no oil discovered and seismic exploration occurred in Virunga Park across Lake Edward and some of the savanna habitat around the lake. No studies have looked at the impact of these activities on animal behavior that we are aware of. Some studies were made as part of SOCO's seismic surveys, but these are not publically available and we are not sure what they studied as part of their impact measurement.

3.1 Oil and gas developments

The one oil drilling site, drilled by Dominion Oil, had an impact on the habitat where it occurred but was restored after drilling had been completed (figure 3.1). The access road to the site was just off the public road to Rwenshama fishing village and of short distance so that the overall impacts, while significant for about a month, have not been long term.

Figure 3.1. Rwenshama test drill site in the Ishasha sector of QEPA

The only other oil exploration has been the seismic operations in Virunga Park which were led by SOCO and it is unclear what environmental studies were made as part of this operation. More extensive studies, however, have been made in the Murchison Falls National Park (MFNP) with the exploration work by Heritage Oil and subsequently Total E&P Uganda. Detailed studies have been made on the ranging behavior of elephants in the Buligi area of MFNP by WCS with now 9 years of radiocollar data, some of the same individuals over several years. Elephants were monitored during periods of seismic exploration and also test drilling at well pads. The test drilling process was divided into four activities: 1. pad preparation, 2. Drilling, 3. Flaring of oil/gas and 4. Restoration of the pad. Elephants responded to both seismic exploration and to drilling and flaring by moving away from the activity up to a distance of 5 km from the site. However, not all elephants responded similarly with one individual seeming to show no fear of drill sites and possibly approaching the site out of curiosity. Most though moved away from the sites (figure 3.2).

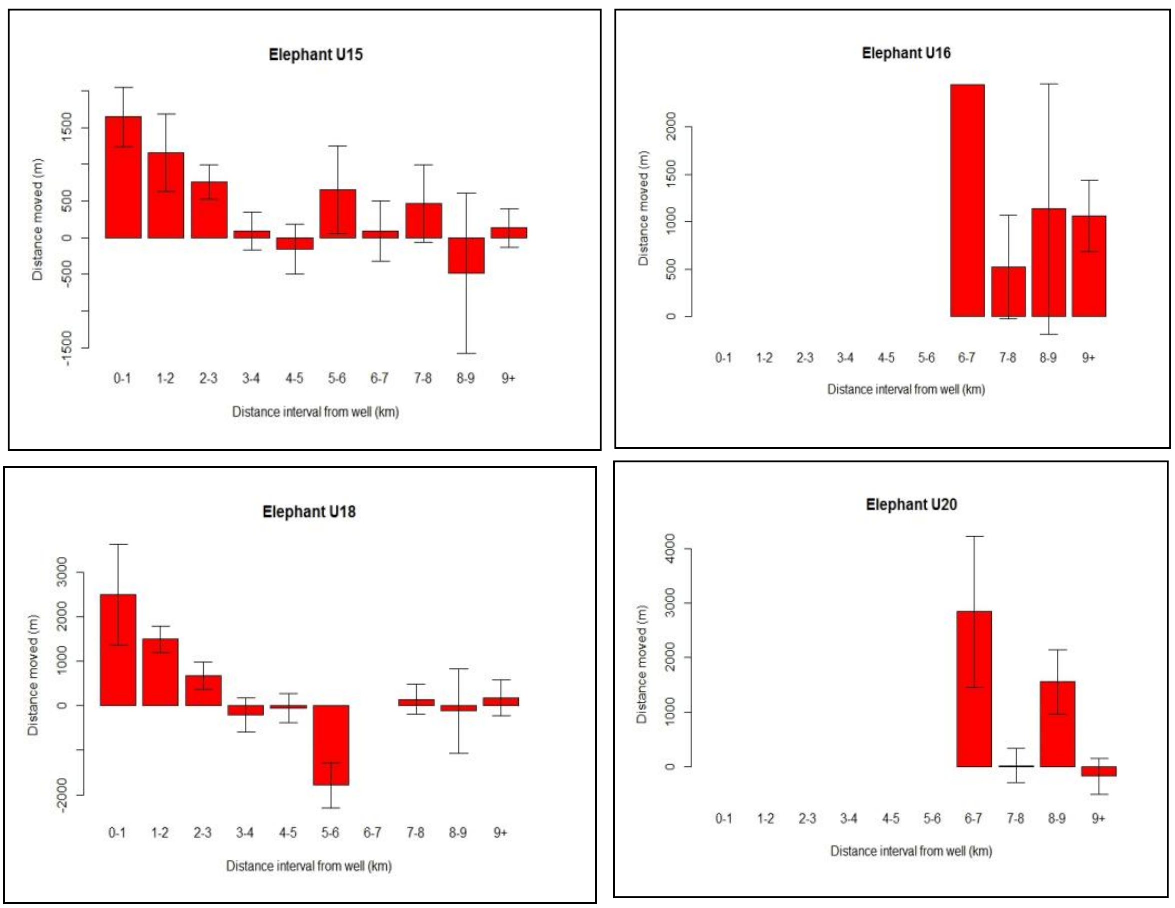


Figure 3.2. The average distance moved (with standard error bars) for each elephant when its initial location was within a particular 1 km distance interval from a well pad while it was being drilled. Positive values indicate movement away from the well pad and negative values towards the well pad.

Tests of the distance elephants were from well pads during drilling and at other times were significantly different with elephants consistently located further away from the pads during the drilling process (Table 3.1).

Table 3.1 T-tests of the differences in mean distance to a well pad during drilling and when no drilling was taking place.

Elephant ID	Distance to well pad with drilling (m)	Distance to well pad without drilling (m)	T-test value	Probability
U15	6,618	5,728	2.274	0.0240
U16	11,448	9,047	3.973	<0.0001
U18	6,553	4,712	3.943	0.0001
U19	12,315	11,748	1.895	0.0653
U20	10,276	7,706	6.506	<0.0001

There have been some short studies of giraffe in MFNP and surveys of biodiversity but we do not know of any other studies that specifically assessed the impacts of the test drilling and seismic operations on the movement and behavior of species in MFNP. This is unfortunate as there are no data to help plan the development operations in the park. Should further oil exploration proceed in QEPA then it would be wise to incorporate studies on the impact of the exploration activities on a wider suite of species. The policy in Virunga Park is to prohibit any development because it is a World Heritage Site and this policy has the support of the wider conservation community and UNESCO. Any oil development in Uganda would also have to make sure that it did not impact the World Heritage Site of Virunga Park or RMNP.

3.2 Geothermal and hydropower developments

In Uganda, the Ministry undertook a nationwide survey of all known geothermal sites and fourteen companies were licensed to conduct preliminary assessment of the geothermal potential at selected sites (Bahati, 2003). Detailed surveys were undertaken at Kibiro (Hoima), Panyimur (Nebbi), Buranga (Bundibugyo) and Katwe-Kikorongo (Kasese) (Figure 3.3). Only Buranga and Katwe sites are relevant to this study. At these two sites, pre-drilling surveys are aimed at locating drilling targets were conducted with the hope to move to the full scale exploration drilling soon. Since then, the geothermal exploration which was proposed for the craters region of QEPA has not started yet. One site visit was made in 2015 but there has been no follow up so it is unclear whether this will go ahead. Geothermal power production is also feasible at the hot springs in Semliki National Park in the north of the GVL, but again there has not been any concrete move toward exploration drilling.

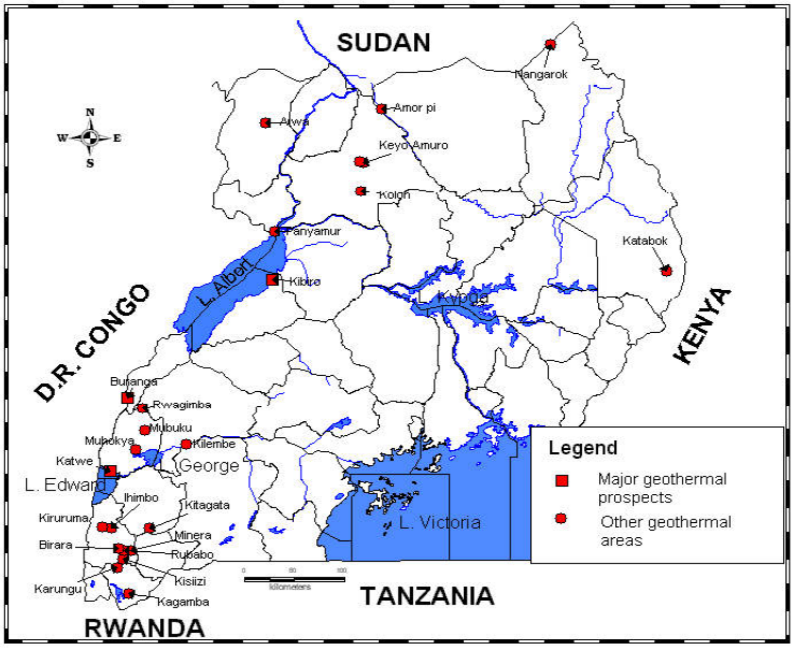


Figure 3.3. Geothermal energy sites in Uganda (Source: Bahati, 2003)

Most of the hydropower production sites occur outside the national parks of the GVL and as most of the rivers continue outside the parks, or the water used to generate power is fed back into the parks along the same river course, it is unlikely that there is a major impact of these hydropower sites on animal behavior. While there are fish of conservation concern within the rivers, these are mostly within the national parks and won't be affected by the hydropower developments – they are not known to migrate along the rivers.

The Mpanga Falls is the only site within a national park, at the edge of QEPA. This site is globally important for the endemic cycad, *Encepholaertos whightlockii*, which is only known from this location. Of particular concern was the fact that the hydropower route was diverting the river around the Mpanga Falls and would reduce the mist and spray provided by the falls which is where the cycad tends to be found (figure 3.4). While there is no research on the impacts of the hydropower development at Mpanga on wildlife, changes in the moisture available in the atmosphere may lead to a decline in woody vegetation here and red colobus (*Pilocolobus rufromitratus*) are known to inhabit the forest along this river. The area outside the park, where these cycads were known to occur have been converted to grazing land and ecotourism infrastructure development, hence, reducing the suitable area and population of cycads in the area. Mpanga riverine forest, itself has been cut down by illegal charcoal producers. It is therefore likely that both the cycads and the corridor connecting Kibale National Park to QENP will be lost, if UWA does not strengthen law enforcement in the area.

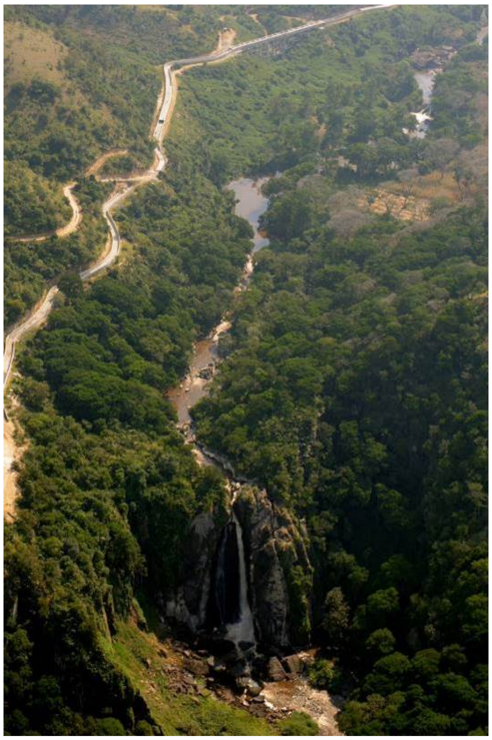


Figure 3.4. Photo of hydropower channel bypassing Mpanga Falls (left) and endemic cycad *Encepholaertos wightlockei* (right)

One of the issues linked to Hydropower and geothermal power is the transmission lines for electricity which will be established alongside the development. The recent large transmission lines that were built across QEPA are an eyesore and take away from the experience of wilderness of the park. Power lines are known to have impacts on bird mortality, particularly large birds when they touch two wires with their wings. Vultures are already globally threatened and declining in the GVL (R. Ssemanda unpublished data) so these power lines are of particular concern for these species as well as crowned cranes and marabou storks.

A review of what tourists most want to see in QEPA and MFNP identified that as well as some of the key species (lion, leopard, elephant, giraffe and hippo) the feeling of being in a pristine wilderness in Africa was as important as the animals (Plumptre & Roberts, 2006; WCS 2012). Loss of the wilderness experience and large pylons spoiling tourist's photographs will deter people from coming to the parks and lead to a drop in revenue for the parks authorities. We would urge that all power lines are buried underground in the protected areas, which is likely to be of similar cost as building large metal pylons.

3.3 Other industries in GVL

Mining sites

The re-opening of the copper mine in RMNP which was contracted to a Chinese company, Tibet Hima Industry Company Ltd, has the potential to increase heavy metal pollution in the river Nyamwanba that runs through Kilembe and Kasese town and provides most of the water for people living here. Tailings dumped on the banks of this river when the copper mine was active in the 1960s have slowly been leaching into the water and tests of heavy metal levels in plants growing along the river show there is three times the amount of copper in plants than elsewhere in the GVL (O. Oriyega pers. comm.). A particular danger is that these metals are being washed into Lake George and will be taken up in the fish and concentrated in the fish, thereby making them a health risk for people. Fishermen tend not to fish where the river enters Lake George already because they believe the fish there are sickly.

Tailings from the Cobalt mine outside Kasese have also impacted QEPA providing heavy metal pollution which has killed all vegetation in the park downstream of the site (figure 3.5). Efforts have been made to reduce this pollution by providing a dam that traps the heavy metals in a slurry pond, which are then supposed to be dredged out and put in land fill regularly. Plants known to uptake heavy metals such as *Phragmites* reeds have been planted below this dam to capture any heavy metals. They are supposed to be harvested regularly and then buried in landfill but this is not happening.

Figure 3.5. Cobalt slurry pond to left of Kasese Road with bare earth in QEPA to the right resulting from heavy metal pollution.

The figures 3.6 show areas where heavy metal pollution killed plants and left those patches as bare ground. These areas continued to increase in size between 1954 and 1990 when mining was still happening. According to the land cover land use maps of 2006 and 2017, the area is recovering. Both the maps in figure 3.6 and Table 3.2 were generated from google earth images.

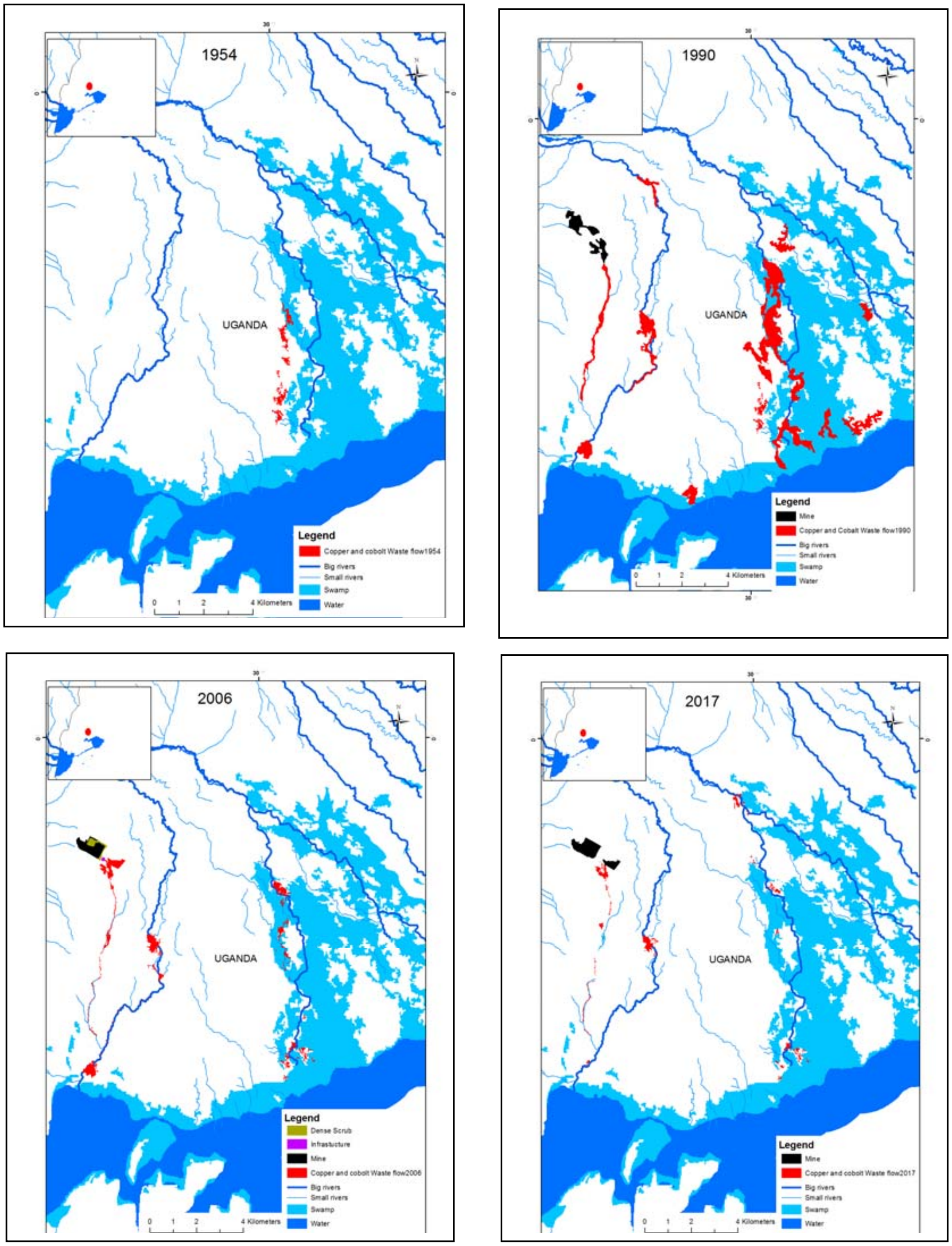


Figure 3.6 Changes in area affected by the cobalt and copper mines between 1954 and 2017. The bare areas are referred to as 'copper and cobalt waste flow

The affected areas covered 61 ha in 1954. By 1990, they had increased to 858 ha (Table 3.2). Since the mining ended, there has been some recover and the 2006 and 2017 mapping showed a decrease of bare land, signifying a recovery of the vegetation.

Table 3.2 The area in hectares of the sites that have been affected by the cobalt and copper mining between 1954 and 2017. The wetland had developed within an originally effluent flow area

Land cover	1954	1990	2006	2017
Bare Area	61	858	200	96
Dense Scrub			18	10
Infrastructure			12	10
Mine		97	54	83
Wetland				5

Hima Cement is also mining a 1 km^2 area of the Dura sector of QEPA, removing lime for the cement factory in Hima town. While some baseline surveys of wildlife were made at the start of the operations and UWA has continued this monitoring intermittently the data have not been written up and published. Plans to open the road that runs across the swamp at the northern end of QEPA where it meets Kibale National Park has the risk of spreading lime dust to the swamp and changing the alkalinity of the water over time. While it has been proposed that any trucks using the road are covered with tarpaulins it is unlikely to stop all dust from the trucks. This could impact the birds and aquatic species that use this swamp, a region that has been poorly surveyed to date. We do not know what impact the heavy metal pollution is having on animals or people in QEPA as they are not being tested for heavy metal accumulation. Animals avoid areas where there is no vegetation below the cobalt slurry pond as there is nothing for them to eat.

Cable car in Volcanoes National Park

The proposed development of a meteorological observatory together with a telecommunications site near the summit of Karisimbi Volcano in Volcanoes National park in Rwanda and the proposed cable car link to this site for tourism and staff of the observatory/telecommunications site is a concern. Mountain gorillas now range around the southern part of Karisimbi and potentially can climb up the cable car pylons where they could be electrocuted or maimed by the cars. For a long time, gorillas were not ranging in this area but now are (figure 3.7).

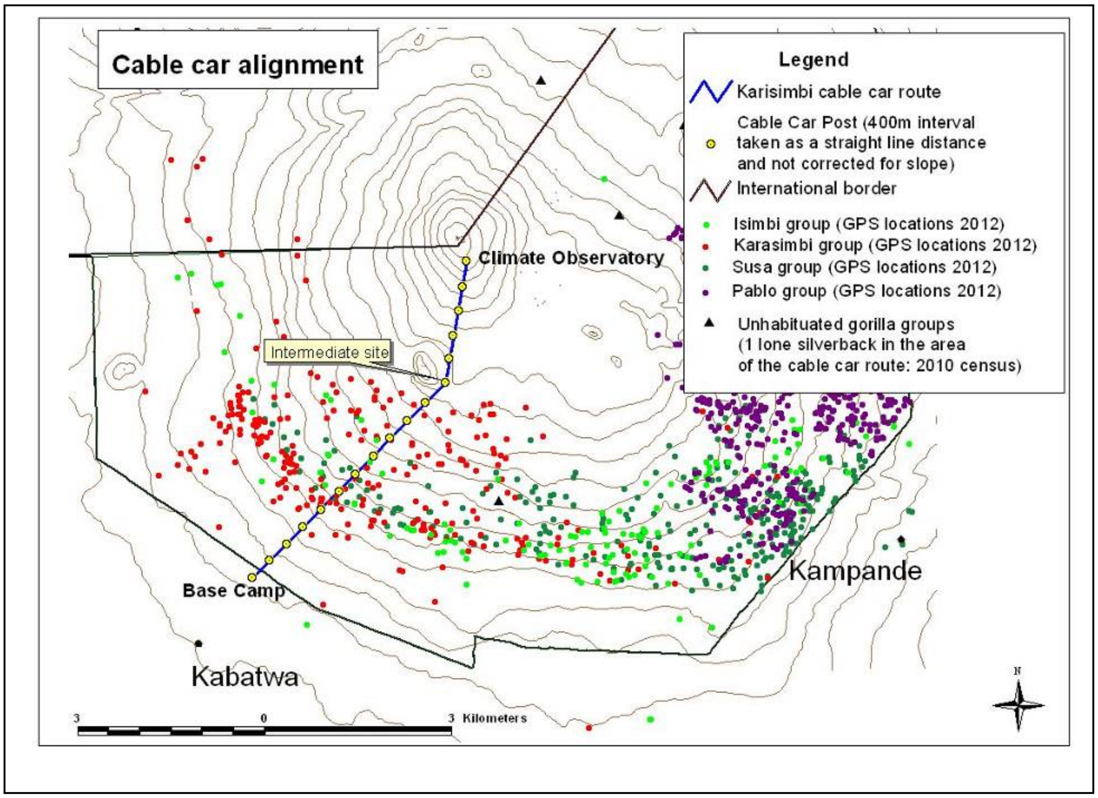


Figure 3.7. Map of proposed cable car route and locations of gorilla groups tracked in the same area of Volcanoes National Park. Source IGCP

Again the cable car will have a similar impact on the wilderness aspect of the park and will deter some tourists from visiting that part of the park. Other species that may be impacted are the golden monkey, *Cercopithecus mitis kandti* (cover of this report) which is a subspecies of blue monkey and possibly a separate species confined to the Virunga Vocanoes and Gishwati National Park. The vegetation of the park at high altitude along the route of the cable car is also likely to be very sensitive to disturbance and will take a long time to recover. It is unknown what other impacts may result from this habitat loss.

4.0 Other factors potentially that could impact animal behavior

Two other factors that are likely to most affect animal behavior is the hunting of large mammals by people both through active hunting as well as snaring. This may result in small populations of species which no longer play their functional role in the ecosystem and as a result will lead to behavior change.

4.1. Human threats to wildlife from hunting

As mentioned in chapter 2, the GVL has seen major fluctuations in its large mammal species, particularly in the savannas as a result of hunting/poaching for bushmeat. WCS has compiled aerial survey data from QEPA and Virunga from as many records we have been able to find by reviewing the published literature and working through old records in the library at QENP (table 4.1). In the 1960s and early 1970s total counts of elephant and buffalo were made and the switch to systematic reconnaissance flights (SRFs) was made in the mid-1970s.

The numbers are provided in tables 4.1 for QEPA and 4.2 for Virunga Park from all of the aerial surveys to date in the landscape. Many fewer surveys were made in Virunga over the years. At one time the national parks in then Zaire refused to allow planes to overfly the parks because it would disturb their pristine nature. As a result, there are only a handful of surveys (Table 4.2). Poaching mainly has targeted the larger species with elephant and buffalo numbers dropping precipitously in Virunga. However, recently even the smaller species such as the Uganda Kob which had remained stable until 2006 have started to decline.

A recent survey around Queen Elizabeth and Murchison Falls Parks in Uganda has shown that an estimated 40-50% of households around the parks had been involved in poaching ungulates from the park in the previous year. Most do this only once or twice but some hunters are regularly involved in poaching and tend to be richer members of the community also (Travers et al. 2017). Hunting sign has been mapped for both QEPA, Virunga and Kibale National parks using data that were collected in MIST and then Spatial Monitoring and Reporting Tool (SMART). These show that most snaring sign is located near the edges of these protected areas or along access routes through the protected areas, but that hunting of larger mammals (elephants, buffalo and hippo) occur more deeply within the protected areas (figure 4.1). No study has yet looked at how animals are distributed in relation to these threats but a student at University of York has just started to do this for the aerial survey data for QEPA and MFNP. It is likely though that animals avoid areas where hunting pressure is high and alter their behavior to avoid being in places at night where hunters are more likely to find them. According to the study conducted by Nampindo (2014), poaching and sustained civil wars were the biggest threat to elephant conservation in the region. Improvement in law enforcement, monitoring, and increasing household incomes for communities living adjacent to protected areas would help to reduce the impact of poaching on elephants. More so, if wars and poaching are not controlled, the region may witness an elephant population dominated by juvenile and subadult elephants.

Table 4.1. Counts from aerial surveys in QEPA since the early 1960s. Numbers for all surveys that WCS have been able to compile information from published and unpublished records are given.

Year	Elephant	Buffalo	Topi	Uganda Kob	Waterbuck	Warthog
1963	1,758					
1963	1,389					
1964	1,295					
1964	2,222					
1966	1,891	16,036				
1966	3,884					
1967	2,757					
1967	4,139					
1968	2,039	17,478				
1968	1,353					
1968	3,410					
1969	3,581	18,040		19,117		
1969	2,948					
1969	1,299					
1969	3,410					
1969	3,581					
1970	1,543	17,953				
1970	2,540					
1971	1,678	13,449	1,477	10,654	3,559	2,175
1971	1,814	12,922				
1971	2,355	14,610				
1971	1,624	14,060				
1971	3,230	17,180				
1972	1,616	14,358	4,600	11,500	3,000	1,500
1972	3,002	13,836				
1972	2,009	14,645				
1972	3,769					
1973	2,447	18,000	5,000	10,000	3,500	4,000
1975	1,047					
1976	1,232					
1976	704			12,500		4,000
1977			2,575		3,500	
1980	150	4,206	1,500	20,000	2,100	1,100
1981	471					
1988	480	5,000	400	18,000	1,500	1,600
1992	500					
1995	1,088	16,549	493	31,899	1,860	1,175
1999	1,353	7,250	325	20,588	2,227	1,931
2000	1,086	10,674	94	32,245	4,666	2,423
2001			100			
2002	998	6,807	157			

2004	2,497	6,777	440	17,440	3,382	1,880
2006	2,959	14,858	1,521	20,971	3,548	1,388
2010	2,502	8,128	262	8,483	2,483	1,466
2012	3,018	12,825	1,097	19,855	2,767	1,465
2014	2,913	15,771	2,005	12,987	2,981	1,456
2016	2,970	10,721	305	15,469	3,928	374

Table 4.2. Counts from aerial surveys in Virunga since the late 1950s. Numbers for all surveys that WCS have been able to compile information from published and unpublished records are given.

Year	Elephant	Buffalo	Topi	Uganda Kob	Waterbuck	Warthog
1959	3,425	28,307	5,939	11,218	2,223	
1981	751	9,715	3,460	10,300	780	
2003	286	2,292	855	12,121	211	
2006	348	3,822	1,353	12,982	374	
2010	347	2,154	1,040	6,954	169	296
2014	35	586	630	4,584	236	227

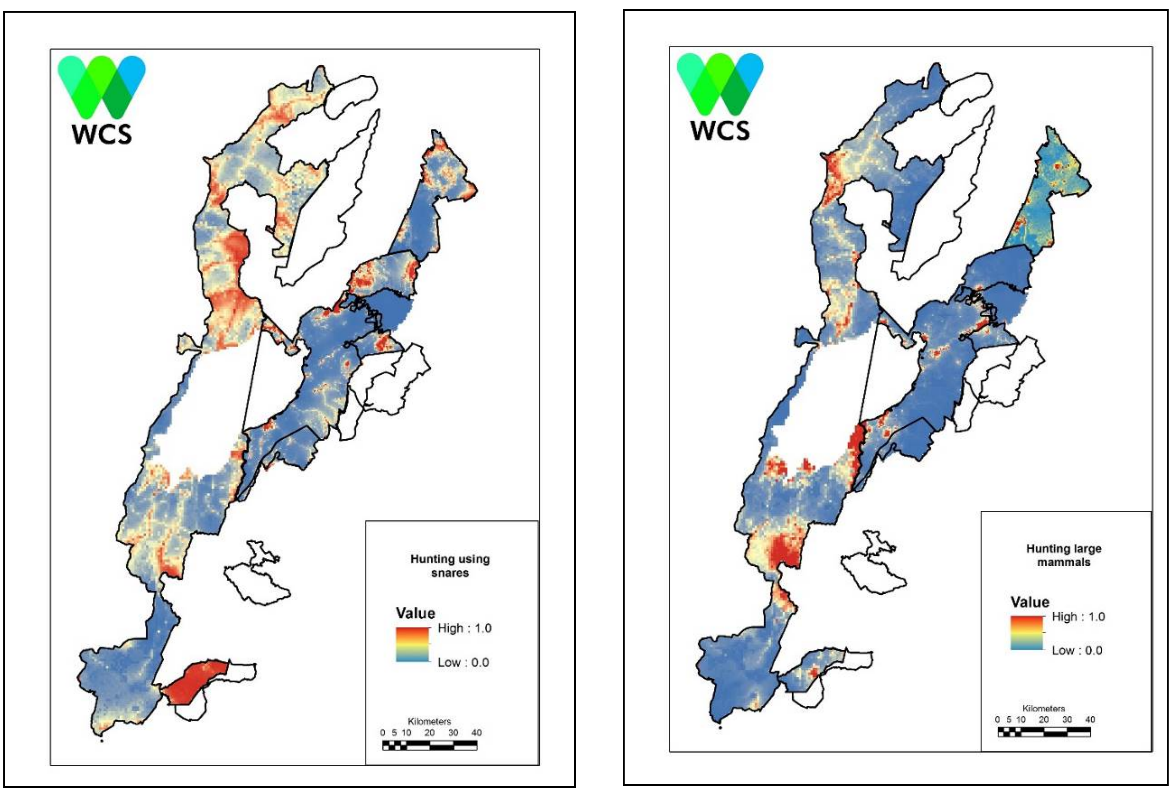


Figure 4.1. Locations of hotspots of snaring and small antelope carcasses (left) and hunting of larger elephant, hippo and buffalo (right) in Virunga Park

4.2 Low population size of species

The impacts of small population sizes in the GVL has not been studied to our knowledge. However, it is known that small populations of a species suffer from inbreeding depression and are also more prone to going extinct locally because of fluctuations in their numbers. Species which are known to have small populations in the GVL include:

1. Large carnivores that come into conflict with man and are killed in retaliation: lions, spotted hyaenas and leopards
2. Species that have been hunted to low numbers: e.g. topi in Ishasha sector of QEPA and almost extinct in Virunga.
3. Species confined to restricted habitats: e.g. Grauer's rush warbler (montane swamps)
4. Species that need large home ranges and naturally occur at low densities (e.g. Chimpanzees, pangolins and large carnivores again).

Monitoring of lion numbers in Ishasha show that the famous tree-climbing lions of Uganda are at perilously low numbers and that these do fluctuate widely (figure 4.2). In-migration from north of Maramagambo Forest as well as from Virunga Park has helped to boost the numbers of the Ishasha lions as well as the genetic diversity but numbers of lions in these adjacent sites are few also. There is an urgent need to stop retaliatory killings of lions by cattle herders and to assess options for compensation if lions are to survive in the GVL. Maintaining the corridors linking these sites is also vital.

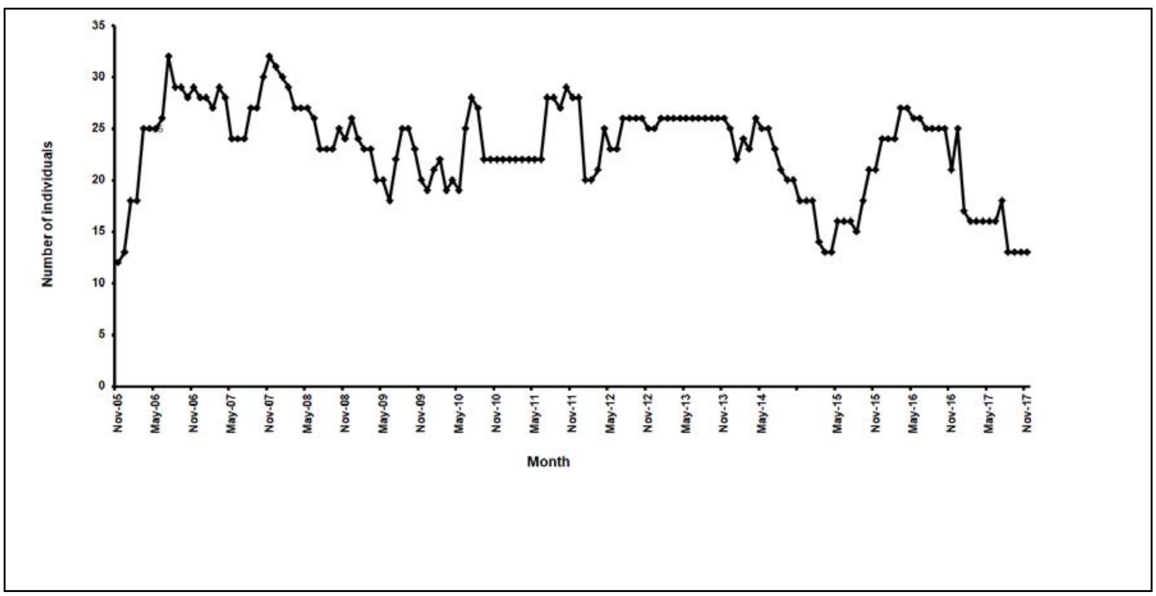


Figure 4.2. Lion numbers in Ishasha sector of QEPA (the tree-climbing lions of Uganda) between 2005 and 2017.

5.0 Mapping land cover change

An up-to-date land cover/use map of the landscape was prepared using 2017 Landsat 8 satellite images. The generated map is shown in Figure 5.1. Although most of the area within protected area boundaries still has natural forest, the area outside is mainly small-scale agriculture. Where the forest cover occurs outside protected areas, it is being converted to agricultural land and thus the presence of the degraded forest class, which is a mixture of small-scale agriculture and remnants of tropical high forest e.g. in the north western part of the landscape. This partly indicates the high human pressure around protected areas in the GVL.

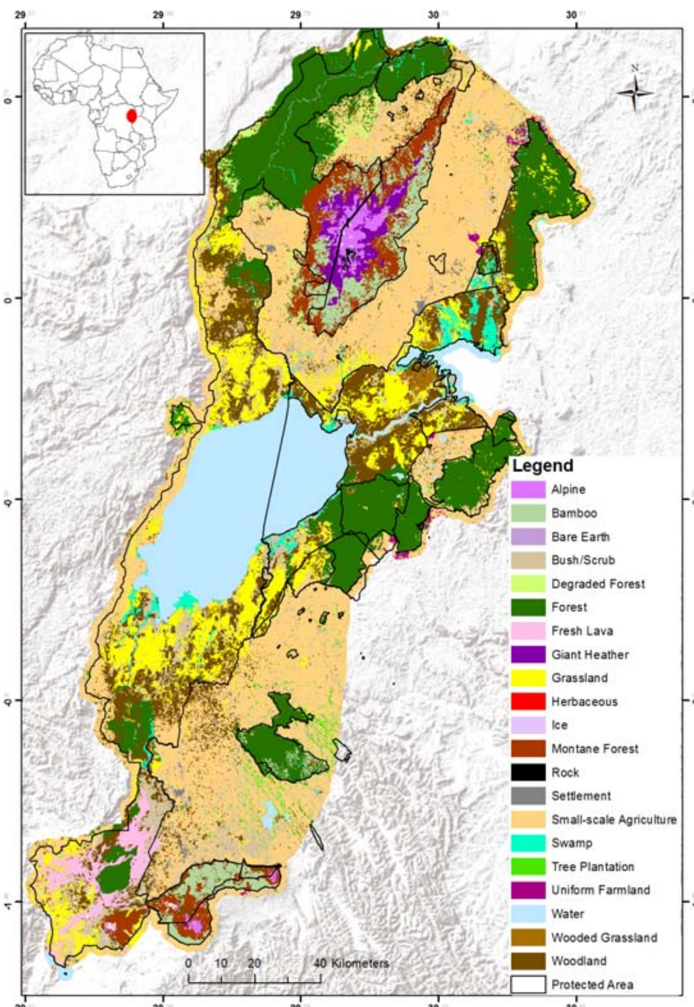


Figure 5.1 Land cover/use of the Greater Virunga landscape based on Landsat satellite images of 2017

5.1 Land cover/use changes in GVL from 1954 to 2016

Land cover land use change was analyzed between 2006 and 2017. Land cover land use has changed greatly over the years. Although a class may lose covering a specific place, it often acquires coverage in another area. Figure 5.2 provides an overview of the changes that have taken place over the last ten (10) years. The accompanying land cover loss and land cover/use gain maps are shown in Figure 5.3. Loss represents the coverage that a specific class has lost to all other classes and gain represents all spatial coverage acquired by a specific class irrespective of which class it came from.

Comparing the loss and gain of each class, grassland had the highest net loss (-33%) followed by wooded grassland (-29%). Montane forest and Low stature forest followed closely with -25% and -24% respectively. Two cover types, Ice and colonised lava did not gain any coverage anywhere but only lost cover. There was, however, high volcanic activity, which resulted in a high net gain (61%) for the fresh lava class. Other classes that had a high net gain were woodland, tree plantations and bamboo with 41%, 22% and 20% respectively.

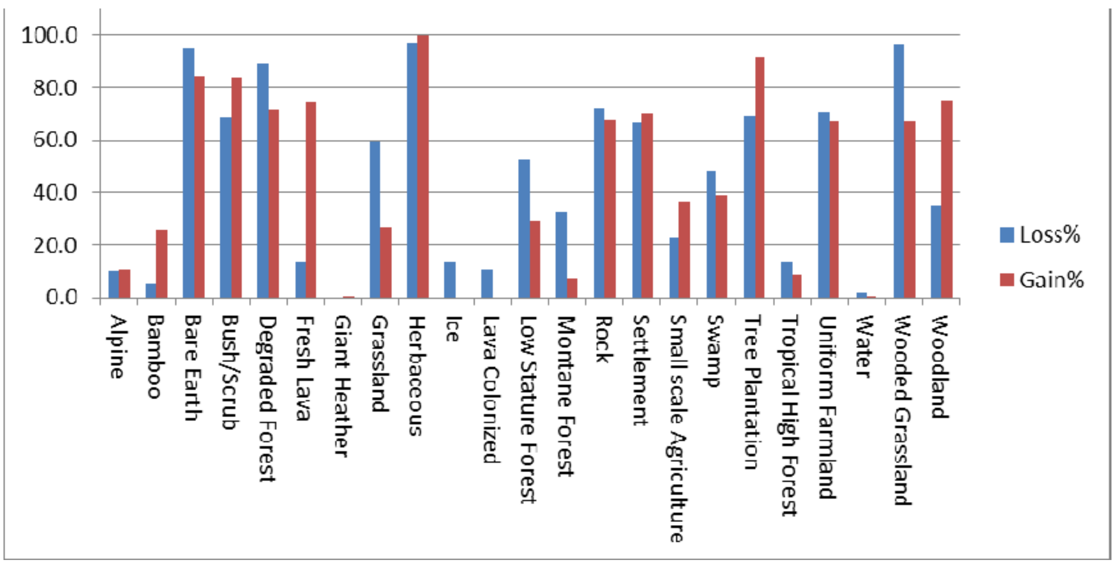


Figure 5.2: Land cover/use gain and loss between 2006 and 2017. The difference between the percentage gain and loss for a specific class provides that class' net (overall) change

Exploring the maps (Figure 5.3) shows that whereas grassland loss and woodland gain have occurred over the whole landscape, wooded grassland loss has mainly occurred in queen Elizabeth National Park (QENP), around the adjacent lakes and Dura sector, south of Kibale National Park (KNP) where the area adjacent to the park has been settled in by livestock keepers and Mpanga riverine forest has been deforested by charcoal making. Tree plantation gain has occurred mainly in the Uganda part of GVL around kashoha kitomi and Kalinzu forests (forests adjacent to QENP), and the northern part of KNP. Small-scale agriculture registered an increase. It was mainly outside protected areas in Uganda but generally inside protected areas in DRC.

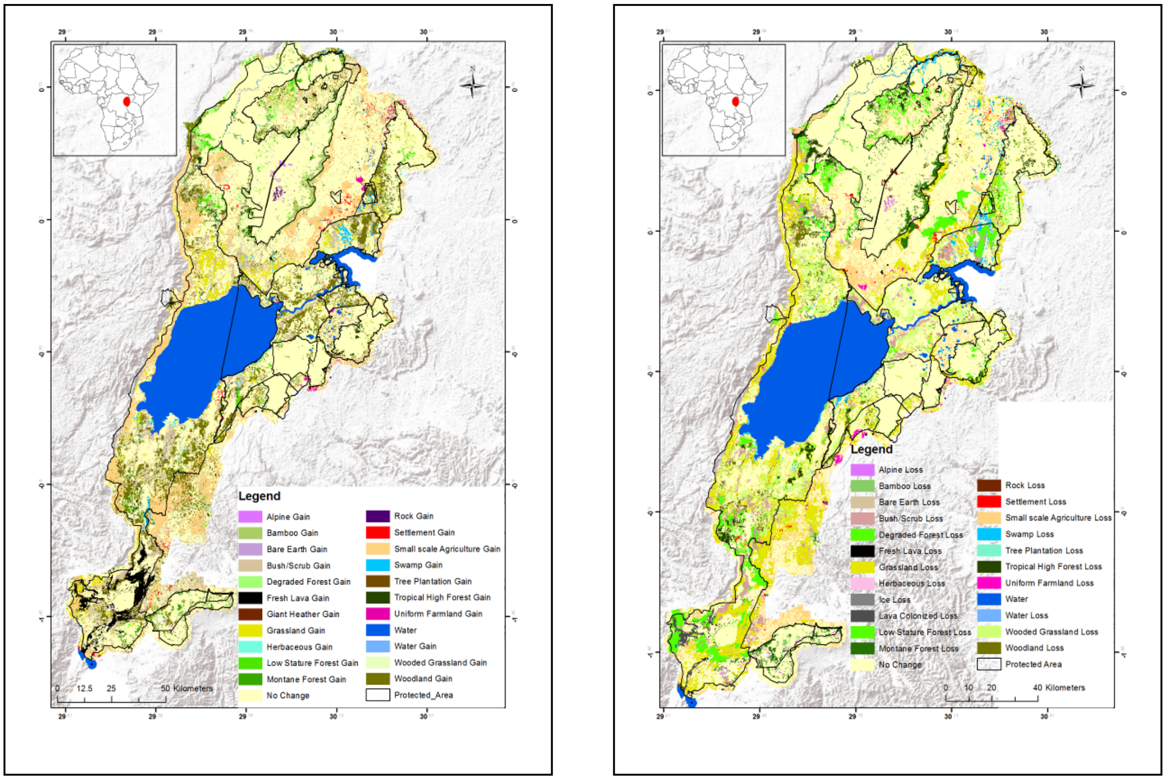


Figure 5.3 Land cover land use gain map (left) and loss (right) between 2006 and 2017

5.2 Changing habitat as a result of decline and recovery of large mammals in QENP

Increasing or decreasing woody cover

Overall woody cover changes were assessed over the landscape. For the areas where data was available for earlier years (1954-2006), the results are presented in section 2.2 (Figure 2.5). Whereas between 1954 and 2006, 36% of the land mass in the area remained stable, woody cover increased by 25% of the mapped area and showed a decrease of 6%. The increase was mainly at the heart of QENP, between the two lakes and the decrease was in the southern part of the protected area. Agriculture also increased by 20%. Assessing changes between 2006 and 2017, the land cover land use map shows that there has been a higher gain (14%) than loss (8%) in woody cover. The gain has generally been higher within savanna protected areas and the loss in woody cover has generally been higher outside protected areas. QENP mainly registered an increase in woody cover with hardly any decrease; an indicator that the park is changing possibly due to increased rainfall as reported in section 2. If no intervention is taken, it may change from a savanna park into a dense woodland park.

The southern part of GVL registered a decrease in woody cover mainly due to volcanic activity where lava destroyed a large proportion of vegetation cover. The DRC side registered more woody cover loss than the Uganda and Rwanda side. This decrease is mainly due to small-scale agriculture expansion as well as charcoal production. The Eastern edges of the Rwenzori Mountains NP also lost woody cover. Agriculture gained 10% coverage. In Uganda, agriculture gained a lot of coverage outside protected areas but in DRC, there was agriculture coverage gain inside Virunga Park. Key drivers of these changes need to be explored.

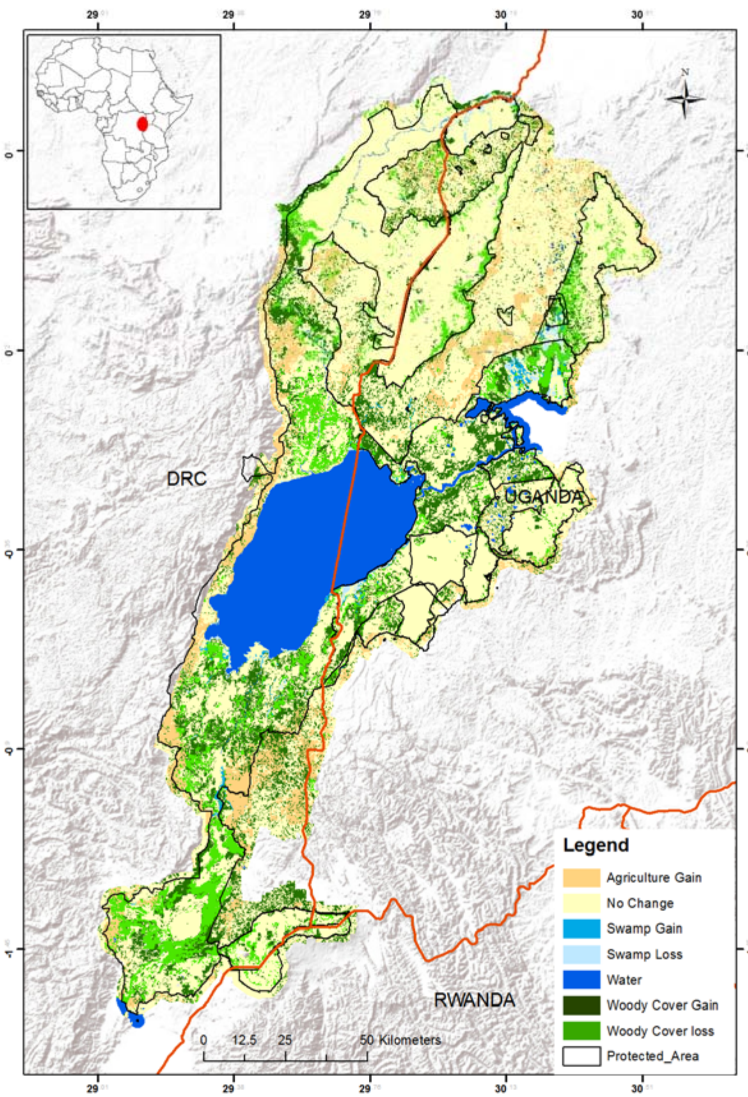


Figure 5.4 Woody cover changes gain and loss between 2006 and 2017. The map also indicates agriculture and swamp changes

6.0 Discussion and conclusions

A comprehensive analysis of the existing knowledge of changes in animal behavior in the Greater Virunga Landscape (GVL) resulting from industrial development, climate changes and other factors as well as the assessment of changes in ecology resulting from habitat changes across the GVL is a critical step toward designing and implementation of effective interventions and mitigation measures to address the negative impacts to wildlife in GVL. From the study, the results showed that climate change impacts area already being seen in the GVL, including movement upslope of birds on the mountains, increasing rainfall as predicted by climate models, and increasing temperatures. Phenology patterns in forests may also be affected by increasing temperatures, particularly for those trees where minimum temperatures may trigger flowering.

Models of predicted impacts of climate change on the endemic and threatened species (108) in the GVL indicate that significant range reductions will likely occur resulting from the need to move upslope to maintain similar niches. On average species ranges have declined by 55% because of loss of habitat to agriculture and infrastructure developments in the region around the GVL and an additional 70% of what remains will be lost to climate changes by 2070, if the projected emission scenarios follow the trajectory under RCP 8.5. Fire frequency is also increasing, which may be a result of increasing fuel load with the wetter climate. These factors will likely lead to changes in vegetation composition as certain plants become more competitive with increasing moisture and fire frequency which will in turn affect animal distributions in the savannas of the GVL in particular. The areas in the GVL where the most species are likely to persist include Rwenzori national park, Mgahinga national park and Virunga volcanoes. These areas are important for the future conservation of endemic species in the GVL.

Changes in land cover land use are already happening and likely to have dramatic effects on wildlife behavior due to alteration of habitats, loss of connectivity and vulnerability and risk exposure to climate change. For example, the land cover land use map showed that most of the protected areas are still covered by natural vegetation. The north western part of the landscape, however, is under conversion to degraded forest, which is a mixture of small-scale agriculture and woodlands. Grassland cover type registered the highest net loss by 33% followed by wooded grassland at 29% and natural land cover increase was highest in woodland and tree plantation categories with 41% and 22% respectively. Woody cover of QENP registered a 25% increase between 1954 and 2006 and in terms of the entire landscape, there was a 14% increase in woody cover between 2006 and 2017, which is a slightly higher rate of loss over 11 years compared to the period of 52 years. Agriculture also gained 10% coverage within the same period. Overall, there has been a higher increase in woody cover inside protected areas due to reduced mammal densities and a higher decrease outside protected areas attributed to agricultural expansion, infrastructure development and human settlement. Savanna parks are becoming more woody, which may pose a threat to the survival of angulates that occur in GVL. The key drivers of land cover land use change need to be fully addressed by the regional governments under the transboundary collaboration framework already in place.

On the other hand, industrial developments have the potential to affect wildlife behaviour and examples are given of the impacts of oil exploration in Murchison Falls NP on elephant behaviour, impacts of the cobalt mines near Rwenzori Mountains NP on vegetation, impacts of the hydropower dam at Mpanga on Cycads and potential impacts of the proposed cable car to the top of Karisimbi volcanoe in the Volcanoes Park. Ideally, industrial developments would not take place in the GVL and all efforts should be made to avoid having a negative impact on the natural habitats and wildlife in the landscape by using directionally directed access from outside the landscape. Where avoidance is impossible and where there is no option to stop the development then the mitigation hierarchy should be followed and the key principles of this concept, that is, additionality, permanence, equivalences should be upheld. The company should go beyond simple compensation, but work toward achieving a net positive impact. This is because this is one of the most biodiverse places on Earth, has three World Heritage Sites and 10 Key Biodiversity Areas. We noted that poaching pressure on wildlife will also have an impact on where animals range and we showed that poaching pressure varies across the landscape using ranger patrol data from SMART in Uganda and DRC. Snaring is often found near the park boundaries, but killing of larger animals such as elephants, hippos and buffalo occur in the central areas of the parks because they have been extirpated near most park boundaries. According to the study by Nampindo (2014) that assessed the impacts of climate change on elephants in GVL, it was noted that climate change did not show immediate direct impacts on the elephant population, but thermal and latent heat effects were likely occurring. These effects could be mitigated, if improvement in habitat management, particularly reducing fire risks through biomass suppression, encroachment reduction and degradation due to extraction of resources by local communities and extractive industries are controlled.

Declines of species to small populations is of real concern and the case of the “Tree climbing lions of Uganda” is highlighted as they have fluctuated greatly between 10-33 individuals over the time they have been monitored. Given that wild animals will continue to move out of protected areas into the communities either as part of their normal movement and dispersal routine, running away from extractive industries activities taking place inside the parks or simply responding to availability of food outside protected areas, a comprehensive human-wildlife conflict plan needs to be developed and communities living adjacent to these protected areas need to be supported in order to be part of the conservation agenda. As such, a performance-based reward system needs to be developed in order to incentivize communities to participate in conservation.

6.1 Recommendations for mitigating impacts

Any development projects within the GVL are going to exacerbate the ongoing changes to the landscape due to climate change as well as the natural changes in habitat as large mammal numbers fluctuate and plant species distributions change. The landscape has already lost large areas of land to agriculture and settlement leading to large loss of suitable habitat for many of the endemic and threatened species. The human pressure on the protected areas is also leading to habitat losses with almost 10% of land in Virunga Park converted to agriculture over the past 15 years. So we would urge that as much as possible industrial developments be discouraged from the GVL which contains three World Heritage sites and a Ramsar site and likely qualifies for Key Biodiversity Area status under criterion C (one of the best examples of remaining habitat in the Albertine Rift Ecoregion). However, if developments are to move ahead, we would want them to follow the mitigation hierarchy and adapt the World Bank and International Finance Corporation standards, particularly Performance Standard 6 and work toward achieving No Net Loss goal.

6.2 Mitigation hierarchy

The mitigation hierarchy follows a four step approach for any development namely

1. Avoidance
2. Minimisation of impacts
3. Restoration of impacts
4. Offsetting residual impacts
5. Additional conservation actions

These steps aim to minimize the impacts of development at a site and are summarized in figure 6.1.

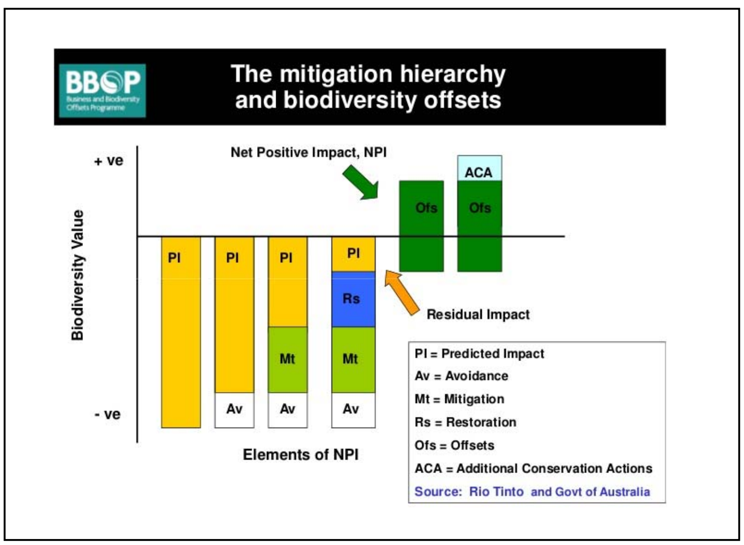


Figure 6.1. The Mitigation hierarchy as proposed by the Business and Biodiversity Offsets Partnership

We describe the specific actions that should be considered under these four steps below.

6.2.1. Avoidance

In the first instance any company should aim to avoid operating in the GVL. This is one of the most biodiverse landscapes in the World with many endemic and threatened species and should not be impacted further. Options for operating outside the landscape and accessing resources under the ground using tunnels/directional drilling should be considered at first.

If the decision is made to move ahead with a development inside the GVL then it should aim to avoid sensitive areas in the landscape. These include:

1. The mountain areas of Rwenzori massif and Virunga Volcanoes including afroalpine moorland, giant heather, bamboo and montane forest habitats
2. Montane/high altitude forest areas in Bwindi Impenetrable and Kibale National parks as well as Kasyoha-kitomi Forest Reserve
3. Lake shores and wetlands in the landscape which are particularly sensitive to impacts (Plumptre et al. 2016b)
4. Corridor areas that link protected areas and allow movement of animals, particularly across the international borders between Uganda, DR Congo and Rwanda.

The savannas are important for threatened large mammals and as these are also important for tourism income they need to be managed carefully. However, savannas are fairly resilient to impacts and can be restored more easily than most other habitats. Where developments occur they should target parts of the savanna habitats where many of the threatened and key tourism species are uncommon or where the vegetation is dominated by scrub or spear grass which is not consumed by large mammals except when young shoots.

6.2.2. Minimise impact

Where a development is authorized to take place then impacts need to be minimized as far as possible. The footprint in the landscape should be as small as possible and this can be achieved by using several methods such as:

1. Locating all staff outside the GVL and transporting them in to the site during the day
2. Minimizing the length of access routes to a site and ensuring that the access route is controlled to prevent other users accessing the region, particularly those that may poach wildlife or harvest timber.
3. Ensuring that transportation moves outside the boundaries of the GVL in a short distance so that it doesn't impact the feeling of wilderness for tourism or the species that may be killed on the roads
4. Ensure that all traffic moves at slow speeds (30-40km/hr max) to minimize risks of hitting wildlife or people and vehicles should not be allowed to move after dark.
5. Accessing the resources by directional drilling from one footprint site rather than developing multiple sites
6. Keeping all infrastructure out of line of site to maintain the 'wilderness' experience
7. Ensure sites are not placed near steep slopes where erosion can impact the site around the development.
8. Managing in-migration of people looking for work in an area so that they do not all settle at the edge of the GVL and start harvesting resources from within the site

6.2.3. Restore impacted areas

Where a project footprint will be developed it should plan to remove topsoil and gather seed of the native plants found at the site and store them so that at the end of the development the site can be restored carefully as far as possible. Restoration of drill sites in Murchison Falls National Park has been successful at many sites and it is difficult to assess where some of these sites existed now. However, at some sites, which were poorly sited, there have been major impacts from erosion and the site has not been restored to its original state.

6.2.4. Offset residual impacts

The impacts of the development need to be measured and plans for offsetting to occur. It is not possible to find habitat that is similar to that in the GVL elsewhere that can be protected as an offset site, as it is either protected already in the Albertine Rift or has been lost to agricultural development. Therefore, the only types of offset that can be considered are a “net gain” to the management of the GVL and to the species found here. Options for net gain might include:

1. Strengthening the management of the protected areas by providing training and resources to manage the sites well – particularly the ability to enforce the law and stop degradation of the landscape as well as generating incentives within the local community to support conservation such as tackling human-wildlife conflicts.
2. Supporting initiatives that increase the populations of species of conservation concern in the GVL - such as assessing options for compensation for livestock losses to large carnivores as well as better husbandry of livestock to prevent losses
3. Supporting the conservation of the corridor habitat linking Virunga Park to Mt Hoyo Reserve north of Virunga which is likely important for the chimpanzee and Okapi populations in Virunga Park.
4. Providing financing in the form of a trust fund that can ensure long-term financial support to protected area management of the sites

6.2.5. Additional Conservation Actions

Given the global importance of the GVL we believe that an additional step that BBOP terms “additional conservation actions” (figure 6.1) should be required of any company to develop anywhere inside the GVL. This would ensure that they not only offset residual impacts, and provide substantial support to the conservation of the landscape, as well as deter ‘cowboy’ investors who would not manage their footprint seriously. The types of actions could include those that might be developed for biodiversity offsets but would go beyond the compensation of residual impacts and ensure additional conservation measures are achieved.

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The data analyses were made in the WCS Uganda Country Office.

[1] Recommended Citation: Plumptre, A.J., Nangendo, G., Ayebare, S., Kirunda, B., Mugabe, H., Nsubuga, P., & S. Nampindo (2017). Impacts of climate Change and Industrial Development in the Greater Virunga Landscape on the long-term Changes in Wildlife Behavior. Report submitted to GVTC-ES. November 2017

References

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.

Babweteera, F., Plumptre, A.J., Adamescu, G.S., Shoo, L.P., Beale, C.M., Reynolds, V., Nyeko, P., & Muhanguzi, G. in prep. The ecology of tree reproduction in an African medium altitude rainforest. *Biotropica*

Bahati, G. (2003). Geothermal energy in Uganda, country update. International Geothermal Conference, Reykjavík, Sept. 2003 Session #4

Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, et al. (2011) Has the Earth's sixth mass extinction already arrived? Nature 471: 51–57.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. Ecology Letters. http://doi.org/10.1111/j.1461-0248.2011.01736.x

Byrne, J.G.D. 2016. *The importance of biotic interactions and climate change on avifaunal range limits of the Albertine rift*. Unpublished MSc. Thesis, University of York.

Carr, J.A., Outhwaite, W.E., Goodman, G.L., Oldfield, T.E.E. and Foden, W.B. 2013. *Vital but vulnerable: Climate change vulnerability and human use of wildlife in Africa's Albertine Rift*. *Occasional Paper of the IUCN Species Survival Commission No. 48*. IUCN, Gland, Switzerland and Cambridge, UK. xii + 224pp.

Chapman, C.A., Chapman, L.J., Struhsaker, T.T., Zanne, A.E., Clark, C.J. & Poulsen, J.R. 2005. A long term evaluation of fruiting phenology: importance of climate change. *Journal of Tropical Ecology*, 21, 31-45

Chapman, C.A., Chapman, L.J., Zanne, A.E., Poulsen, J.R &. Clark, C.J. 2005b. A 12-Year phenological record of fruiting: implications for frugivore populations and indicators of climate change. In: J. L. Dew and J.P. Boubli (eds.), *Tropical Fruits and Frugivores: The search for strong interactions.* Pp 75-92. Springer. Printed in The Netherlands.

Chapman, C.A., Chapman, L.J., Ghai, R., Hartter, J., Jacob, A.L., Lwanga, J.S., Omeja, P., Rothman, J.M. & Twinomugisha, D. 2012. Complex responses to climate and anthropogenic changes: an evaluation based on long-term data from Kibale National Park. In: A.J.Plumptre (ed). *The Ecological Impact of Long-term Changes in Africa's Rift Valley.* Nova Science Publishers, New York. pp 73-94.

Clarke L, Edmonds J, Jacoby H, Pitcher H, Reilly J,Richels R (2007).CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations.U.S. Government Printing Office.Washington, DC

Edroma, E. L. 1977. Population structure and management of grassland types in Rwenzori NP, Uganda. *Geo-Eco-Trop.* 4: 277-294.

Edroma, E. L. 1981. Some effects of grazing on the productivity of grassland in Rwenzori NP, Uganda. *African Journal of Ecology,* 19: 313-326.

Edroma, E. L. 1984. Effects of burning and grazing on the productivity and number of plants in QENP, Uganda. *African Journal of Ecology* 22: 165-174.

Elith, J., Phillips, S.J., Hastie, T., Dudı´k, M., Chee, Y.E. & Yates, C.J. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions, 17, 43–57.

Elith, J., & Leathwick, J. R. (2009). Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. *Annual Review of Ecology, Evolution, and Systematics*, *40*(1), 677–697. http://doi.org/10.1146/annurev.ecolsys.110308.120159

Eltringham, S. K. 1976. The frequency and extent of uncontrolled grass fires in Rwenzori NP, Uganda. *East African Wildlife Journal* 14: 215-222.

Fielding, A. H. and Bell, J. F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation, 24, 38–49.

Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko, 2007: Ecosystems, their properties, goods, and services. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof,P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272.

Hanley JA, McNeil BJ The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology. 1982; 143:29-36

Hijioka Y, Matsuoka Y, Nishimoto H, Masui T, Kainuma M (2008) Global GHG emission scenarios under GHG concentration stabilization targets. J Glob Environ Eng 13:97–108

IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy,S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

IPCC. 2013. Climate Change 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G. K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley(eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC. 2007. Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2000. Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Jaksic-Born, C. 2009. *Effects of anthropogenic disturbances on the distribution and abundance of large herbivores in Queen Elizabeth National Park, Uganda.* Unpublished PhD Thesis, University of Basel, Switzerland.

Jetz W, Wilcove DS, Dobson AP (2007) Projected Impacts of Climate and Land-Use Change on the Global Diversity of Birds. PLoS Biol 5(6): e157. https://doi.org/10.1371/journal.pbio.0050157

Laurie, R. O. W. 1974. Habitat Utilization by hippopotamus in the Mara River. *East African Wildlife Journal,* 12: 249-271.

Laws, R. M. 1968. Interactions between elephant and hippo populations and their environment. *East African Agricultural and Forestry Journal* 33: 140-147.

Laws, R. M., Parker, I. S. C., & Johnstone, R. C. B. 1975. *Elephants and their habitats: The ecology of elephants in north Bunyoro, Uganda.* Oxford: Clarendon Press.

Lock, J.M. 1972. The effects of hippopotamus grazing on grasslands. *Journal of Ecology* 60: 445-467.

Lock, J. M. 1977a. The vegetation of Rwenzori NP, Uganda. *Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie,* 98: 372-448.

Lock, J. M. 1977b. Preliminary results from fire and elephant exclusion plots in Kabalega National Park, Uganda. *East African Wildlife Journal,* 15: 229-232.

Lock, J. M. 1985. Recent changes in the vegetation of Queen Elizabeth National Park, Uganda. *African Journal Ecology,* 23: 63-65.

Lock, J. M. 1988. *Vegetation studies in QENP*. Kampala: Uganda Wildlife Authority.

Lock, J.M. 1993. Vegetation change in QENP, Uganda: 1970-1988. *African Journal of Ecology* 31: 106-117.

Lock, J. M., & Milburn, T. R. 1971. The seed biology of *Themeda triandra* in relation to fire. In E. Duffey & A. S.Watt, (Eds), *The Scientific Management of Animal and Plant Communities for Conservation.* London: Symposium of the British Ecological Society 11.

McGahey, D.J., Williams, D.G., Muruthi, P., Loubser, D.I., 2013. Investigating climate change vulnerability and planning for adaptation: learning from a study of climate change impacts on the Mountain Gorilla in the Albertine Rift. Natural Science 5, 10–17. http://dx.doi.org/10.4236/ns.2013.55A002.

Nampindo, S. (2014). Age-class specific elephant population dynamics: influence of climate, wars, and poaching. Chapter 4, pp 168-304 *in* Integrated modeling of land use and climate change impacts on multiscale ecosystems of central african watersheds. A Ph.D. Dissertation Presented Submitted to the Graduate School of the University of Massachusetts Amherst, MA, USA, September 2014.

Nyombi, H. 2015. *Tree fruiting phenology: Implications on primate foraging patterns in and around Budongo Forest Reserve, Uganda*. Unpublished MSc Thesis, Makerere University. 106pp.

Olupot, W. & Plumptre, A.J. 2010. *Conservation Research in Uganda's Forests: a review of Site History, Research and Use of Research in Uganda's Forest Parks and Budongo Forest Reserve.* Nova Science Publishers, New York.

Olupot, W., Parry, L., Gunness, M. & Plumptre, A.J. 2010. *Conservation Research in Uganda's Savannas: A Review of Park History, Applied Research and Application of Research to Park Management.* Nova Science Publishers, New York.

Pacifici, M., Visconti, P., Butchart, S. H. M., Watson, J. E. M., Cassola, F. M., & Rondinini, C. (2017). Species' traits influenced their response to recent climate change. *Nature Climate Change*, (February). http://doi.org/10.1038/nclimate3223

Pearson, R.G. 2008. Species' Distribution Modeling for Conservation Educators and Practitioners. Synthesis. American Museum of Natural History. Available at http://ncep.amnh.org.

Phillips SJ, Anderson RP, Schapire RE. Maximum entropy modelling of species geographic distributions.Ecol Modell. 2006; 190: 231–259

Phillips SJ, Dudik M, Schapire RE. A maximum entropy approach to species distribution modeling. Proceeding of the twenty-first international conference on machine learning. New York: ACM Press,Banff, Canada; 2004. pp. 655–662.

Phillips SJ, Dudík M. Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. Ecography (Cop). 2008; 31: 161–175

Picton Phillipps, G. & Seimon, A. 2009. *Potential climate change impacts in conservation landscapes of the Albertine Rift*. Report to MacArthur Foundation.

Plumptre, A.J. 2012. *The Ecological Impact of Long-term Changes in Africa's Rift Valley.* Nova Science Publishers, New York. 308pp.

Plumptre, A.J. and Roberts, C. (2006). *Attractions of Queen Elizabeth National Park: Perceptions about development of a golf course.* Unpublished report for UWA.

Plumptre, A.J., Kirunda, B., Mugabe, H., Stabach, J., Driciru, M., Picton-Phillipps, G., Ayebare, S., Nangendo G., and Laporte, N. 2010. *The impact of fire and large mammals on the ecology of Queen Elizabeth National Park.* Report to WCS.

Plumptre, A. J., Pomeroy, D., Stabach, J., Laporte, N., Driciru, M., Nangendo, G., Wanyama, F. & Rwetsiba, A. 2012. The Effects of Environmental and Anthropogenic Changes on the Savannas of the Queen Elizabeth and Virunga National Parks. In: A.J.Plumptre (Ed.) *The Ecological Impact of Long-term Changes in Africa's Rift Valley.* Nova Science Publishers, New York. Pp 95-116

Plumptre, A.J., Ayebare, S., Segan, D., Watson, J. & Kujirakwinja, D. 2016a. *Conservation Action Plan for the Albertine Rift*. Wildlife Conservation Society Report to Governments of Uganda, Rwanda, Burundi, Tanzania and Democratic Republic of Congo

Plumptre, A.J., Prinsloo, S., Ayebare, S. & Nangendo, G. 2016b. *Documentation of existing and potential oil/geothermal projects, mapping their likely adverse negative effects on the biodiversity conservation and community livelihoods in the Greater Virunga Landscape.* Unpublished report to Greater Virunga Transboundary Collaboration.

Riahi, K., Rao, S., Krey, V., et al. (2011) RCP 8.5—A Scenario of Comparatively High Greenhouse Gas Emissions. Climatic Change, 109, 33-57. https://doi.org/10.1007/s10584-011-0149-y

Sekercioglu, C agan H., Primack, R. B., & Wormworth, J. (2012). The effects of climate change on tropical birds. *Biological Conservation*, *148*(1), 1–18. http://doi.org/10.1016/j.biocon.2011.10.019

Seimon, A., Asefi-Najafabady,S., Lawrence, D. and Lawrence, P. 2017. Watersheds of the African Great Lakes 21st Century Changes in High-Stress Climatic Conditions. Presentation made at the African Great Lakes Conference, Entebbe, Uganda, 2-5 May 2017.

Seimon, A. & Picton Phillipps, G. 2012. Regional climatology of the Albertine Rift. . In: A.J.Plumptre (ed). *The Ecological Impact of Long-term Changes in Africa's Rift Valley.* Nova Science Publishers, New York. pp 9-30.

Taylor, K. E., Stouffer, R. J. & Meehl, G. A. An overview of CMIP5 and the experiment design. Bull. Am. Meteorol. Soc.93, 485–498 (2012)

Thorne, J. H., C. Seo, A. Basabose, M. Gray, N. M. Belfiore, and R. J. Hijmans. 2013. Alternative biological assumptions strongly influence models of climate change effects on mountain gorillas. Ecosphere 4(9):108. http://dx.doi. org/10.1890/ES13-00123.1

Thornton, D. D. 1971. The effect of complete removal of hippo on grassland in the QENP, Uganda*. East African Wildlife Journal,* 9: 47-55.

Travers, H., G. Mwedde, L. Archer, D. Roe, A. J. Plumptre**,** J. Baker, A. Rwetsiba and E. J. Milner- Gulland (2017). *Taking action against wildlife crime in Uganda.* International Institute for Environment and Development (IIED).

van Vuuren D, den Elzen M, Lucas P, Eickhout B, Strengers B, van Ruijven B, Wonink S, van Houdt R (2007) Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Clim Chang 81(2):119

van Vuuren, D.P., Kriegler, E., O'Neill, B.C. et al. 2014. A new scenario framework for Climate Change Research: scenario matrix architecture. Climatic Change 122: 373. doi:10.1007/s10584-013-0906-1

WCS (2012). *Attractions of Murchison Falls National Park: Perceptions about the Development of a Golf Course*. Unpublished report to Uganda Wildlife Authority.

Wise M, Calvin K, Thomson A, Clarke L, Sands R, Smith SJ, Janetos A, Edmonds J (2009a). The Implications of Limiting CO2 Concentrations for Agriculture, Land-use Change Emissions, and Bioenergy. Technical Report. [PNNL-17943]

Wise M, Calvin K, Thomson A, Clarke L, Sands R, Smith SJ, Janet OSA, Edmonds J (2009b) Implications of Limiting CO2 Concentrations for Land Use and Energy. Science 324:1183-1186