# The Implications of Global Climate Change for Mountain Gorilla Conservation in the Albertine Rift

A White Paper prepared by the African Wildlife Foundation, the International
Gorilla Conservation Programme and EcoAdapt, and funded by the
John D. and Catherine T. MacArthur Foundation

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[7] African Wildlife Foundation
[8] University of California, Davis, USA
[9] University of Seoul, Korea
[10] African Wildlife Foundation

# 1.0 Introduction

## I. Purpose of the White Paper

Efforts in biodiversity conservation have long embraced the task of reducing the impacts of the stressors imposed by anthropogenic and environmental changes. In the past, most stressors have been either on-going but gradual or incremental, such as pollution or deforestation, or one-time catastrophic events, such as large oil spills, or a severe drought. The prevailing conservation principle has been to plan for a static protected area or series of protected areas, with the goal of preserving important specific habitat types, or biodiversity assemblages. The assumption has been that if properly protected, these ecosystems would remain stable (Hansen et al., 2009). Climate change has created new challenges in biodiversity conservation. While it is already changing ecosystems across the globe, it will continue to do so for decades and perhaps centuries to come, and at a faster pace than originally anticipated (Hansen et al., 2009). The current pace of change is unprecedented in evolutionary history (Barnosky et al., 2003).

Climate change is reshaping how we think about conservation. Even if fully protected from the ongoing threats imposed by human activities, the ecosystems and biota we have been protecting will not remain the same. Conservation planners must change the way decisions are made because aspects of the environment we have always considered to be relatively constant, including weather patterns, water supply, temperature extremes, even biotic communities, will be changing. This is a difficult endeavor because, not only can we not predict exactly how things will change, but we don't know when they will achieve a new stable state. We can no longer plan for stasis.

With these ideas in mind, the African Wildlife Foundation and the International Gorilla Conservation Programme have partnered with EcoAdapt to initiate the development of an adaptation framework to address climate change in planning in the continuing efforts to conserve mountain gorillas (*Gorilla beringei beringei*) in East Africa. With a grant by the John D. and Catherine T. MacArthur Foundation, a series of Climate Camp workshops in the region were held and expert research commissioned to produce this initial White Paper. The work focuses on building understanding and assessing the scope for reducing the vulnerability of mountain gorillas to regional and global changes expected to occur as a result of climate change. The goal is to reduce the vulnerability of mountain gorillas to the negative effects of climate change by understanding and accommodating its effects on their habitat, food supply, and access to water resources. The specific task of the White Paper preparation process was to carry out initial multi-stakeholder assessment of the implications of global climate change for mountain gorilla conservation in the Albertine Rift, and identify key elements of an adaptation framework, including priority adaptation strategies and actions.

## II. Regional Overview

Mountain gorillas are an important focal species for conservation in their own right, and may also bring attention to climate change impacts in the region. We present here summaries of what is known about regional climate change projections, the implications of these changes for mountain gorilla conservation and health, socioeconomic issues relevant to conservation efforts in the region, and modeled scenarios of potential climate change effects on mountain gorilla populations.

The Albertine Rift of East Africa is known for its extremely high vertebrate biodiversity and endemism, the highest in continental Africa, and has been the focus of many biological and ecological studies, as well as extensive conservation efforts over recent decades. It spans six countries, each with a unique history, political system, and ability to engage in effective conservation (Plumptre et al., 2007a). The success of conservation efforts in parts of this region has recently increased because of effective transboundary collaboration between Uganda, Rwanda, and the Democratic Republic of Congo with a focus on mountain gorilla conservation (Plumptre et al., 2007b). Regular cooperation, communication, and planning among the natural resource authorities of the three countries have helped to maximize the conservation potential of the multiple parks containing gorillas. There is some evidence that other large mammals have benefited vicariously by the success of this program (Plumptre et al., 2007b). The recently established Transboundary Core Secretariat provides an essential structural backbone for the integrated management and planning of mountain gorilla conservation for the future.

This biological wealth and conservation investment is threatened by a number of stressors, including climate change. Over the past century, according to the Intergovernmental Panel on Climate Change, the Albertine Rift region has become wetter (Figure 1). Global temperatures have increased about $1^{o}$C over the past 150 years, with an accelerated rate of increase in recent decades (IPCC, 2007). Both climate change and its effects will continue to be felt in this region for centuries to come even in the best-case scenarios. Yet the local patterns of change, not captured in the global predictions, have yet to be fully described, and we are only beginning to understand how to address these changes in conservation efforts in this region.

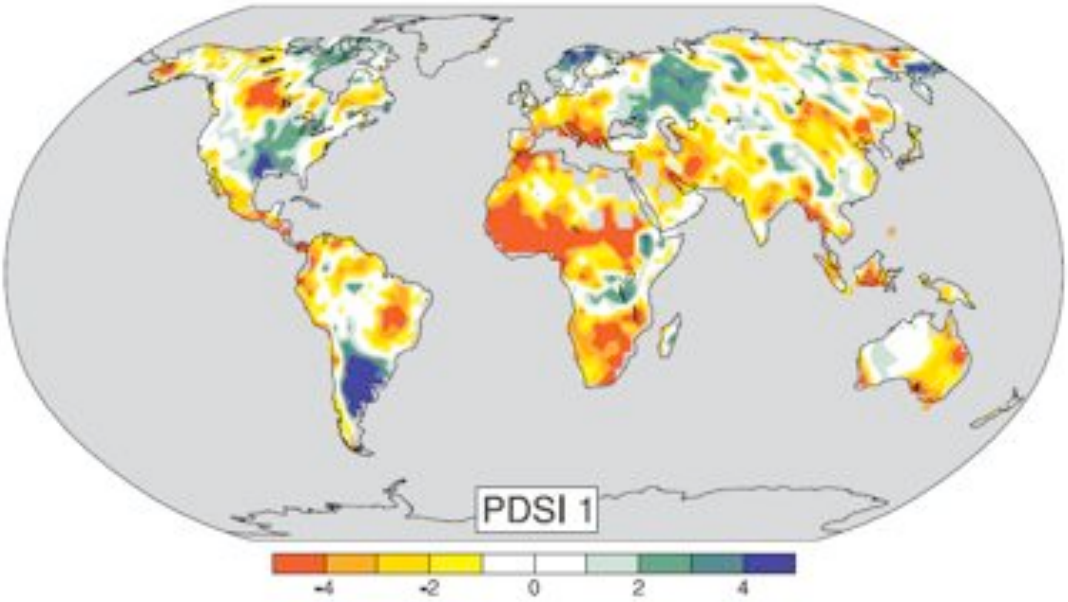

Figure 1. Overall pattern of global trends in moisture changes as captured by the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. Red and orange areas have tended to be drier than average and blue and green areas, wetter than average over the course of the century. Adapted from IPCC 2007 FAQ 3.2.

Mountain gorillas, the focus of this report, are highly threatened, with just over 700 animals in two populations. Thus any new threat to the species, such as climate change, whether it threatens the species directly or indirectly by increasing non-climate stressors, is cause for concern. Extensive efforts to study and conserve mountain gorillas have been underway for several decades. However, little is not known about the likely impacts of climate change on the mountain gorilla, nor have any climate change adaptation strategies been developed prior to this project.

## III. Principles for Climate Change Adaptation

Given the reality of ongoing climate change, the success of near- and long-term conservation will depend on the extent to which the effects of climate change are integrated into planning and management. Projected climate change effects can only be estimates based on the best available science, and as a result, taking action may seem like a risky enterprise. However, it is possible to undertake adaptation actions that are likely to produce positive results, and at the very least, buy time for biodiversity as more information is amassed, and the future unfolds. While the exact dimensions of climate change and its effects are uncertain, the reality that they will occur is not, making inaction riskier than action.

Climate change adaptation in both human and natural systems has been the subject of numerous reports (e.g., Asia Development Bank, 2005; Glick et al., 2009; Heller and Zavaleta, 2009; IPCC, 2007; Lawler, 2009; USAID, 2007). The material covered in these reports generally falls into two categories: principles for or categories of adaptation action, and frameworks for creating adaptation plans. We begin with the general principles, organized into five main tenets for adapting conservation and resource management to climate change (Hansen and Hoffman, 2010).

### 1. Protect adequate and appropriate space for a changing world.

Perhaps the most common tool used in conservation is the establishment of protected areas that confer varying levels of protection for the flora and fauna living within. These are ordinarily established in fixed locations to protect a particular species, community, or natural system, and because of this, are highly vulnerable to climate change. However, there are now known ways to integrate climate change in protected area management, including:

- *Prioritize protection of climate refugia*. These are places that are likely to maintain more stable climatic conditions for a variety of reasons. The Albertine Rift region of East Africa has extremely high topographic, hydrologic, and climatic variability, and also has the highest vertebrate biodiversity and endemicity in mainland Africa, which are commonly associated with locations that have been past refugia (Plumptre et al., 2007a). The Rift as a whole is likely to have been a climate refugium in the past, and as such, may well serve as one in the current period of climate change. Thus, the present effort to preserve mountain gorillas in the face of climate change may, in protecting a likely climate refugium, serve double duty in helping to protect against extreme biodiversity loss in the region.
- *Support connectivity and corridors along climatic gradients*. Individual animals may track favorable climate conditions, and many species will experience range shifts towards higher latitude, higher elevation, or otherwise track suitable conditions as climate change progresses. Connectivity also supports genetic exchange among populations, potentially assisting the mixing of warmer-adapted genotypes into cooler-adapted populations. In the case of

mountain gorillas, creating additional protected space where mountain gorillas may forage, or move, that has the potential to connect them to alternate home ranges, or additional specific resources, could be a good strategy for creating resilience. The risk of connectivity is that is also supports the movement of pests, diseases, and non-natives species, as well as limiting adaptation to local conditions.

- *Protect resistant or resilient populations.* This may increase the likelihood that the species of which these populations are a part will persist, as well as the ecosystem services provided by these species. In the case of mountain gorillas, only two populations exist and there are many reasons to protect both of them.
- *Protect heterogeneity of habitat, communities, and species.* Areas with many microclimates (e.g., caves, ravines, slopes facing different directions) may provide refugia for individuals, populations, or in the case of mountain gorillas, important food resources. The Albertine Rift contains many microclimates, which likely explains its extensive biodiversity and endemicity. Any space protected in this region is likely to benefit the region's biodiversity as well as human populations, for these reasons as well.
- *Maintain ecosystem functionality.* This could mean the continued existence of a wide diversity of plants and animals, or the continued existence of the benefits of nature on which people rely, such as water filtration, cloud formation, or flood control.

### 2. Reduce non-climate stressors that interact negatively with climate change or its effects.

Climate change is likely to exacerbate the damaging effects of or threats from other stressors. Conversely, other stressors may worsen some negative effects of climate change. Ecosystems or species that are already stressed or at-risk may be more vulnerable to climate change and its effects. These general statements clearly describe the case for mountain gorillas. Some non-climate stressors to consider in the case of mountain gorillas include:

- *Pests, diseases, and non-native species*. Higher temperatures may allow some pests, diseases, or non-native species to expand into the parks or into areas around the parks. Where mountain gorillas are already stressed by changing climatic conditions, they, or their critical resources, may become less able to compete with pests or non-native species, or become more vulnerable to diseases and parasites.
- *Overharvesting or overexploitation*. (of forests, fishes, water, etc.). Reducing population numbers, or severely altering their age or size distribution (in the case of trees, for example), can lead to random population crashes or alterations in the biology of the species being harvested. For example, certain fruiting trees may not produce mast-quantity fruits until they are over a certain age, and extreme reduction in the numbers of older trees could cause the fruit harvest to crash, causing a shift in pollinator density or other cascading effects in the local ecological community. In addition, overharvesting reduces the genetic diversity of any population; genetic diversity helps populations cope with changing environmental conditions both in the present and over the long term (evolutionary time). Over-extraction of water or other climate-sensitive forest resources further reduces their availability for gorillas, and may increase the rate of local or regional climatic change as well (see Tenet 4).
- *Pollution*. Changes in temperature or chemistry of soil and water can make plants and animals more sensitive to pollutants, or increase the toxicity of pollutants. Climatic changes can also affect the movement of pollutants through the ecosystem. Pollutants can also affect the sensitivity of plants and animals to climate change, for instance by increasing sensitivity to

increased temperature or changing the conditions for survival of local flora, in particular, which could adversely affect mountain gorilla resource availability. Although industrial and urban pollution has not been a major concern in the region of the Virungas and Bwindi, burning for charcoal, cooking, or clearing agricultural land creates air quality problems in some areas.

### 3. Manage for uncertainty.

Because we can neither predict the rate of greenhouse gas emissions in the future, nor all of the responses that will occur in the climate, climate projections will always be uncertain. Species distribution models, which use climate projections to model changes in species' ranges, are also uncertain since they not only build on uncertain climate models, but make assumptions about species responses to changing climatic conditions that may not always be true. Further, we cannot predict how human communities will respond to climate change or its effects. Climate change simply adds another layer of uncertainty.

Approaches to managing in the face of uncertainty include scenario planning, adaptive management, and robust decision-making. Scenario planning allows planners and managers to explore the effectiveness of various strategies across a range of plausible futures. Adaptive management puts management actions into an experimental framework, specifying what information is needed to evaluate management success and how and when it will be used to adjust management actions. Robust decisions are those that leave open a range of positive future options across a range of plausible futures rather than simply targeting a single best outcome under a single presumed future. All of these approaches will likely be important to managing conservation of mountain gorillas in the face of climate change.

### 4. Reduce local and regional climate change.

On a local or regional scale, some climatic change may be driven by local or regional factors in addition to global-scale changes. Deforestation can dramatically alter regional climate by creating more drying conditions, by removing the conditions that create cloud formation, and by changing precipitation patterns. In addition to increasing the likelihood of drought, it also increases the vulnerability of human and natural communities to both droughts and floods. In some cases, maintaining forest cover at somewhat distant locations can play a major role in maintaining stable water supplies (e.g., upriver forest cover supports downriver water supply, and potentially, downriver precipitation). Reducing deforestation regionally, not only in the location of the focal resource, in this case, mountain gorillas, is likely to slow and dampen the effects of climate change regionally. Similarly, maintaining and replanting vegetation along swamps, rivers, and streams can have impressive effects not only in terms of direct shading and cooling, but more generalized cooling effects, perhaps attributable to increased water retention in the system.

### 5. Reduce global climate change.

Climate change policy tends to place reducing greenhouse gas emissions in the category of mitigation, rather than adaptation. Yet the more we limit the rate and extent of global climate change, the greater our adaptation options.

## IV. A Framework for Action

The above tenets address the principles for action that may be taken to reduce vulnerability to climate change; developing an actual adaptation plan requires figuring out which actions to implement and how. There are five general steps to take in developing an adaptation plan (adapted from Asia Development Bank, 2005; Glick et al., 2009; Heller and Zavaleta, 2009; IPCC, 2007; Lawler, 2009, USAID 2007):

1. **Clearly identify the mission, vision, or goals of the group doing the assessment and of the assessment itself.** This may strongly influence how the assessment is carried out; a vulnerability assessment focusing on protecting a particular species, for instance, would be carried out differently than one focused on prioritizing land for further protection. Here, the focus is ensuring the survival of mountain gorillas.
2. **Assess the vulnerability of the mission, vision, and goals to climate change.** In this case, the assessment includes actual and potential effects of climate change on the focal species, the system in which they live, as well as interactions with other factors, such as existing stressors or possible changes in human resource use patterns
3. **Identify and design management, planning, or regulatory actions that address the vulnerabilities** identified in Step 2. As we describe in Chapter 8, and Appendix III, these range from adjustments in existing regulations, to changes in management approaches and priorities, to provision of substantial support for systems outside of focal species management, to important new research foci. These should be evaluated for robustness across a range of future scenarios and climate change responses by nearby communities.
4. **Design and enact monitoring programs** that assess changes in those climate and environmental parameters most important to the system in question as well as the whether adaptation measures are delivering the desired management or policy outcomes. In the case of mountain gorillas, survey, monitoring, and research programs were identified that will be critical to choosing among various management options.
5. **Create an iterative process** by which activities can be reevaluated and redesigned, if necessary. Given the large number of unknowns in the underlying biology of the system, as well as the response by human populations in the region, this will ultimately be a critical step in the ongoing adaptation of mountain gorilla conservation to climate change.

The initial White Paper process has focused on Steps 1, 2 and 3, and generated suggestions for monitoring programs addressing some variables. The White Paper summarizes the results so far, and provides guidance on going forward with the ideas generated and for developing a longer-term adaptation framework.

Specifically, good progress has been made in assessing mountain gorilla vulnerability to climate change. Because so little is documented, or studied at a regional scale, about climate in Africa, the White Paper process utilized the expertise of a climatologist involved in modeling and understanding climate dynamics in the Albertine Rift region, as well as that of modelers who applied geographic information systems (GIS) modeling approaches to develop climate change scenarios for mountain gorilla habitat during coming decades. In addition, many experts on mountain gorilla biology, ecology, and conservation participated in written evaluations and workshop discussions of mountain gorilla vulnerability under known, anticipated, and possible future conditions. As a result of these discussions, many ideas were generated that will or could reduce mountain gorilla vulnerability to climate change. Further, as part of the efforts to assess vulnerability and come up with solutions to minimize it, a number of gaps in knowledge were also identified. This generated many ideas for prioritizing and intensifying ongoing conservation actions and obtaining more information that will inform an improved vulnerability assessment in the future.

This project did not complete Steps 3, 4 and 5. Many ideas for monitoring climate and ecosystem changes were generated but the preparation of an agreed adaptation plan is not yet in place, and developing this will involve participation from the full range of stakeholders, including the regional Transboundary Core Secretariat, over the coming period. This plan will prioritize adaptation actions based on feasibility, importance and other factors and will commit the relevant parties to them. It will also involve the establishment of systems for monitoring for implementation and impact of adaptation actions. Finally, it will develop an active adaptive management approach to including climate change in long term conservation planning for mountain gorillas, as well as a mechanism by which authorities and stakeholders review and alter the adaptation and monitoring activities to reflect new information, as well as results of self-review.

Overall, this White Paper reflects the end of a first phase of assembling and disseminating what is known about mountain gorilla vulnerability to climate change. Partners and participants in the process contributed their vast, and often subtle, knowledge of the biology and conservation issues surrounding this question, and made great strides in proposing ideas to reduce gorilla vulnerability. The White Paper provides a good basis for moving forwards, and participants in the process are committed to addressing the important areas for further action identified in Chapters 7 and 8.

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# 2.0 Projected Climatological and Ecological Changes in the 21st Century Across the Mountain Gorilla's Range

## I. Introduction

In the context of biodiversity conservation, climate is a geographic endowment that exerts a strongly coercive influence on ecological system types and character, and likewise on human settlement patterns, health characteristics, livelihoods and economies, all of which impact biodiversity as well. As a consequence, long-term conservation success cannot be achieved without comprehension of present day climatic variability, and climatic changes ongoing and forthcoming. This is especially true for efforts to conserve species that are geographically constrained to particular habitats and are dependent upon continuity of established climatic patterns to sustain their habitat and favored ecology.

Such is the case of Earth's largest primate, the endangered mountain gorilla (*Gorilla beringei beringei*), whose range is geographically constrained to two tropical montane forest remnants in the Albertine Rift of equatorial Africa, the Bwindi Impenetrable Forest in Uganda and the slopes of the Virunga Volcanoes nearby, shared by Uganda, Rwanda and the Democratic Republic of Congo (DRC). The cool, moist and frequently rainy climate provides the habitat to which this species is eminently adapted and supports the rich vegetation that provides its nourishment. The mountain gorilla's range occupies a broad climatological niche defined by its elevational range; currently this extends from an anthropogenically defined (by protected area boundaries) lower margin at approximately 1,600m above sea level in Bwindi to about 4,000m, close to the higher summits, in the Virunga range. The diversity of vegetation types encompassed by this range yields a large variety of palatable plants with more than 30 species known to be consumed by mountain gorillas.

The stability of the regional climate is; therefore, a critical factor in sustaining the mountain gorilla and its viability within its native habitat. Human-influenced global climate change is of growing concern to the long-term prospects of the survival of species, especially due to the potential for climatic changes to drive vegetation shifts that may render its range less favorable for the species over time. Climate change is also likely to provoke human responses, which may in turn negatively affect the species and the long-term viability of its habitat. In this chapter we outline the basic components of contemporary climatology across the mountain gorilla's range and present climatological and ecological projections developed from global climate model output that offer insights into the future. Much of the material presented here was generated as part of the Albertine Rift Climate Assessment, a project of the Wildlife Conservation Society funded by the John D. and Catherine T. MacArthur Foundation from 2007-2009.

### *Geographic Context*

The mountain gorilla range lies in the African equatorial tropics of southwestern Uganda, neighboring northwest Rwanda and the eastern DRC close to the midpoint of the Albertine Rift (Appendix V: Figure 1). It is a complex landscape of high topographic relief and heavily modified by human activities, being characterized by densely settled agricultural regions abutting highly biodiverse protected mountain forests. Five decades of ecological research on the gorilla and its environment have produced comprehensive understanding of the species and its native habitat, and also of the intense human pressure and habitat degradation across the mountain gorilla's range related to pervasive poverty of the region's human populations. The understanding gained now underpins what is widely perceived as a successful development response, where high-priced "gorilla tourism" provides benefits such as capital influx, systematic monitoring and funded patrols, and employment opportunities to the local economies. Meanwhile, immediately outside the protected areas, high human population densities inexorably impart great pressure upon natural resources: available land for cultivation, animal protein, and timber.

The dire conservation predicament of the gorillas, which constrains them to sharply delineated protected forests abutting intensely settled farmlands, yields a high environmental sensitivity to climatic stress. Any reduction in farm output increases pressure for illegal exploitation of protein (bushmeat) both for subsistence and for income, from protected forest resources. Similarly, climate anomalies such as droughts can yield rapid environmental responses such as fire outbreaks in otherwise moist forests, highlighting the susceptibility of this region to climatic variability in the present day, and especially, the adverse impacts of climate change in years to come.

### *The Albertine Rift Climate Assessment*

Until very recently, climate change has largely been absent from consideration among priorities for biodiversity conservation in the Albertine Rift. As one of a series of measures aimed at addressing this shortcoming, from 2007-09 the Wildlife Conservation Society (WCS) conducted an initial assessment of climate change and it potential impacts along the Albertine Rift corridor and within its key protected areas in particular. The project objectives were to quantify conservative-to-extreme predictions of regional climate change across the Albertine Rift, to assess future impacts of climate change and estimate the future distribution of biodiversity in the Albertine Rift, and to develop our findings in partnership with the wider biodiversity conservation community. The Climate Assessment project's results are presented in two whitepaper reports. The first report, *Climatological Assessment of the Albertine Rift for Conservation Applications*, summarizes the state of knowledge of regional climatology (Seimon and Picton Phillipps, 2010). The companion study, *Potential Climate Change Impacts in Conservation Landscapes of the Albertine Rift***,** presents findings from environmental modeling performed for core areas of conservation focus in the Albertine Rift (Picton, Phillipps and Seimon, 2010). Selected findings and products of the Climate Assessment relevant to the mountain gorilla range are presented and elaborated upon herein.

## II. Climatological Data

Among the world's continental landmasses, tropical Africa is by far the most under-represented in term of systematic, quality controlled climate data. This void of reliable data gives cause for particular concern in contexts of global climate change. The baseline data needed as inputs to ensure that models are launched with proper representation of actual conditions as a starting point, which also serve as reference for assessing degrees of change shown in predictions that are for many regions of Africa, largely unavailable. Instead, interpolation techniques must be applied between widely separated data points greatly smoothing out local climatic detail (the detail that determines many characteristics and particularities of local ecology). Insufficient representation is especially problematic in mountains and other regions of complex topography, where both climatic and related ecological gradients are large.

Such is the case for the Albertine Rift region that encompasses the mountain gorilla's range, where a complex landscape configuration and absence of verifiable point data resulting from sparse and often inconsistent climatological observations stand as obstacles to efforts to apply models for predicting climatic and ecological futures. Furthermore, the Climate Assessment identified that contemporary understanding of Albertine Rift regional climatology conveyed in scientific literature contains notable knowledge gaps regarding the regional climatic system. In particular, prevailing perspectives tend to oversimplify the precipitation hydrology, and thus fail to represent patterns that are likely of consequence to ecological systems and that are also highly susceptible to perturbation under changing climatic regimes. Given the high degree of development interest and conservation planning focused on obtaining successful outcomes for both wildlife and people in this local region of tropical Africa, it is both surprising and disquieting to find that scientific understanding of the area's climatology remains relatively undeveloped. Therefore for this study, efforts were placed on uncovering original and unprocessed climatological observations within the protected areas covering the present-day range of mountain gorillas. Records were obtained from several research sites and ranger outposts in and around Bwindi and Mgahinga National Parks in Uganda, Volcanoes National Park in Rwanda, as well as from sites close to Virunga National Park in DRC. We offer discussion here on two of the precipitation data series with the longest periods of record obtained within mountain gorilla habitat.

### *Present Day Climate - Hydroclimatology*

In common with much of equatorial Africa, the annual climate cycle across the mountain gorilla's range is bimodal, defined by two distinct wet seasons separated by drier periods. At regional to local scales, this characteristic bimodal rainfall pattern is clearly evident in pluviograms displaying monthly means developed from daily rainfall records from the former Karisoke Research Station at 3,000 m above sea level in the Virunga region and from Ruhija at the Bwindi Impenetrable Forest National Park in Uganda (Appendix 5: Figure 2).

However, the same data plotted at higher temporal resolution (9-day running means) reveals a much more complex rainfall climatology characterized by robust intra-seasonal variability to precipitation. This is especially so at Bwindi-Ruhja, where each rainy season is revealed to be interrupted by intense maxima flanked by short-term minima (Appendix V: Figure 3). The exceptionally large-magnitude fluctuations in rainfall rate centered in early May and early September are strongly evident in the 9-day smoothed data, but entirely masked by averaging in the monthly means. Such signals are likely of considerable importance to local ecology, for example, by possibly influencing or controlling plant flowering and fruiting phenologies, yet remain invisible and undetected using conventional climatological analysis. While the significance of these climatic patterns to gorilla ecology and conservation across the range of the species has yet to be determined, their identification highlights a need to consider climate change in contexts of shorter-term phenomena than are generally considered.

The Karisoke site is much wetter than Ruhija, with 35% more rain recorded on an annual basis (1,856 mm vs. 1,374 mm at Ruhija). While the higher elevation of the Karisoke site might explain some of the difference, almost all of the excess rainfall occurs in the February-May rainy season whereas the September-November wet seasons are close to parity. This suggests that the differences are more likely to be regional — the Virunga region being wetter overall, and the greater precipitation registered there being a product of either local topographic effects or, more likely, more favorable conditions for precipitation generation under the atmospheric circulation regime present during the first part of the year.

The complexity of rainfall behavior across space is evident in marked differences exhibited in pluviograms from different sites separated by tens of kilometers or even less. This has been demonstrated for the area around Kibale National Park in Uganda, to the north and not far from Bwindi (Stampone et al., unpublished data); this behavior is somewhat less surprising than the temporal variability since high spatial variability is an inherent characteristic of precipitation in mountainous terrain (Barry, 2008). A comparable level of analysis is not yet possible in the mountain gorilla region since clustered rain gauge observations tend to have too little temporal overlap for comparative studies.

Rainfall trends vary in observational datasets, and the predicted hydrological increases have yet to become apparent at regional scale. Some long-term records actually suggest a long-term decline is in progress. Spatial analysis of rain gauge data in Uganda from the Kibale region north of Bwindi finds disparate decadal trends in precipitation accumulation across relatively short distances (Stampone et al., unpublished data), so caution should be applied before generalizing rainfall trends identified in single site time series.

### *Present Day Climate – Temperature*

Temperature is largely a function of elevation throughout the region, with very little thermal seasonality experienced in terms of monthly mean temperatures. Nocturnal minima are lowest in the dry seasons, when radiational cooling of the highland terrain is less prone to moderation by high relative humidity. Climatic variability and seasonality in the Albertine Rift is therefore most evident in moisture variations, in cloudiness and precipitation occurrence, and is marked by fairly high degrees of both spatial and temporal variability.

The absence of long time series of climatological data within the range of the mountain gorilla makes area-specific assessment of climatic trends difficult at the present time. Most climate model projections for the Albertine Rift region centered on the mountain gorilla indicate strong increases in both temperature and rainfall across the course of the 21st century, discussed below. A thermal increase is already amply evident in observational records across eastern Africa (Cullen et al., 2006). Closer to the mountain gorilla range, the long-term temperature records from the Lwiro Research Station near Kahuzi-Biega National Park in DRC exhibit a strong and sustained multi-decadal warming trend (Appendix V: Figure 4). The net change derived by linear regression of annual temperature means of +2.1 C over 53 years is extremely rapid, and exceeds warming rates reported more widely across eastern Africa in Cullen et al. (2006). Whether this represents a response to local forcings such as deforestation, external forcings such as changing oceanic sea surface temperatures, or a combination of the two, cannot be immediately ascertained; the possibility of instrumental error or drift in measurements must also be recognized. However, the ecological impacts of a change of this magnitude should be detectable in species response, especially for thermally constrained species with habitats organized by altitudinal zonation where the warming would be expected to drive upward migrations. This pattern has already been confirmed for a tropical amphibian species assemblage in the mountains of Madagascar (Raxworthy et al., 2008).

## 3. Modeling Methodology

For this study, a suite of climatic and ecological parameter projections for several time steps into the future were generated for a 2x2 degree latitude-longitude domain centered on the Virunga range at Mt Sabinyo, which forms the triborder point of DRC, Rwanda and Uganda (Appendix V: Figure 5). This domain amply encompasses the present day range of the mountain gorilla. The source data is model output from a much larger domain generated for the Albertine Rift Climate Assessment project (refer to Appendix V: Figure 1). The modeling methodology is detailed in Picton Phillips and Seimon (2010), and summarized here.

Data from the low-resolution Intergovernmental Panel on Climate Change (IPCC) general circulation model multi-model global ensembles were extracted for the Albertine Rift region for the period 1990 – 2090. These datasets were used as input to a statistical downscaling procedure, which produced a set of medium resolution climate model data for the same period with a spatial resolution of approximately 50 km. These datasets were used in their raw state to provide predictions of climate in the Albertine Rift at 2030, 2060 & 2090, and also as input to ecosystem and crop yield modeling, performed using the Lund-Potsdam-Jena (LPJ: Sitch et al., 2003) and Decision Support System for Agro-technology Transfer (DSSAT; Thornton et al., 2009) models, respectively. To establish baseline conditions for comparison to model predictions, the project used the University of East Anglia Climate Research Unit CRU TS2.1 interpolated baseline climate gridded data (Mitchell et al., 2004) averaged over the period 1980-1999 to determine gridpoint values of monthly mean cloud cover, precipitation and temperature over the Albertine Rift project domain. Since all known mountain gorilla habitat is contained within protected areas where agricultural practices are expressly forbidden, we do not offer discussion on crop yield projections here but instead refer readers to the Albertine Rift regional discussion and figures presented in Picton Phillipps and Seimon (2010).

The climate and environmental predictions shown here were generated by the IPCC multi-model consensus under the SRES A2 greenhouse gas emissions scenario (IPCC 2000). Under this projection of global economic development and demographic trends, human population is expected to increase at a high rate, with energy consumption and changes in land use correspondingly high. Summary statistics of the climate parameters of mean annual temperature, precipitation and cloud cover averaged over the entire Albertine Rift modeling domain are presented in Table 1. The Climate Assessment also projected all variables under the more moderate B1 emissions scenario, however, the emerging consensus since the IPCC Fourth Assessment report is that such scenarios are increasingly unlikely to be representative of future conditions, hence our focus on the more severe (although not extreme) A2 scenario

Across the Albertine Rift model domain, the IPCC multi-model output projects strong and sustained temperature increases under the A2 emissions scenario, with a steepening rate of increase in the latter part of the century. Precipitation trends parallel this pattern, rising through the period but more rapidly in the latter half of the century. In the model depictions, the cloud cover remains relatively invariant over time on an annual basis. Taken together, these parameters identify the potential for a markedly different climatic environment region-wide by the last decades of the 21st century, characterized by mean conditions of warmth and wetness that would register as extreme in the present day.

**Table 1**: Summary of IPCC multi-model output statistics for the entire Albertine Rift domain for temperature (deg. C), precipitation (mm per annum) and cloud cover (percent) for the 20-year mean values centered on the years 2030, 2060 and 2090 and compared to the CRU interpolated 20-year observational data centered on the 1990 baseline year. The Maximum and Minimum values represent model gridpoint extrema across the project domain, whereas the Mean is the average of all grid points in the domain.

| | | **1990** | **2030** | **2060** | **2090** | |
|---|---|---|---|---|---|---|
| **Mean annual temperature** | *Max* | 26.0 | 27.0 | 28.1 | 29.7 | °C |
| | ***Mean*** | **22.7** | **23.6** | **24.7** | **26.3** | |
| | *Min* | 15.0 | 16.0 | 17.1 | 18.7 | |
| **Mean annual precipitation** | *Max* | 1887 | 1900 | 1968 | 2098 | mm per annum |
| | ***Mean*** | **1199** | **1233** | **1287** | **1406** | |
| | *Min* | 821 | 875 | 938 | 1057 | |
| **Mean annual cloud cover** | *Max* | 82.6 | 82.4 | 81.7 | 81.9 | % |
| | ***Mean*** | **67.2** | **67.4** | **66.9** | **67.1** | |
| | *Min* | 42.4 | 43.2 | 43.2 | 43.4 | |

## IV. Focused Model Results

For the purpose of this study we extracted model output parameters for the more focused 2x2 degree latitude-longitude box centered on the triborder region of DR Congo, Rwanda and Uganda, thus fully encompassing the mountain gorilla kingdom. The climate parameters are furthermore broken down temporally according to monthly means. A selection of bio-climatic and ecological parameters developed from the LPJ vegetation model are also presented here. Additional elaboration of the parameters generated by the LPJ model is presented in Sitch et al. (2007) and more specifically for the East Africa region in Doherty et al. (2009).

### *Temperature*

Temperature increases are projected to occur relatively uniformly throughout the year, although the mid-year months exhibit slightly stronger increases by century's end (Appendix V: Figure 6). The maximum increase is +3.9°C in May. Given that temperature change as a function of elevation in tropical atmospheres average 5-6°C per km, the net region-wide thermal increase of 3.6°C under the A2 scenario would translate to a very large upward displacement of species ranges and vegetation zones, on the order of 600-720 meters relative to 1990 levels.

### *Rainfall*

In contrast to the temperature projections, the monthly precipitation projections display marked seasonal differences as well as steepening rates of rainfall increase (Appendix V: Figure 7). Of note is that for the 20-year period centered on 2030, slight decreases in monthly rainfall are depicted for mid-year, corresponding with the longer dry season, before this reverses to rainfall surpluses. These mid-year deficits might be indicative of increasing threat of drought and forest fires, since rising temperatures would concomitantly promote stronger seasonal desiccation of the forest. By 2090, precipitation increases of 15% over the 1990 baseline values are registered on average through the modeled domain, with much of the largest increase projected in the November-March period. At present, a short dry season occurs in most years around the month of January, as can be seen in the observations from Karisoke and Ruhija in Figure 3. Should these model projections verify, the late-century rainfall increases might effectively eliminate this climatological feature, thus establishing a relatively unimodal annual rainfall pattern with potentially significant ecological impacts occurring as a result.

### *Runoff and Evapotranspiration*

The runoff parameter generated by the LPJ model assesses projected precipitation summed with the losses due to evapotranspiration, taking factors such as changes in plant functional type into account. Under the A2 scenario, the LPJ output indicates an initial slow rise in runoff that parallels the precipitation trend, and then steepens such that by century's end the runoff quantity is twice that of the 1990 baseline value (Appendix V: Figure 8 [blue line]). The net increase of +200 mm per annum is somewhat greater than the increase in precipitation (183 mm/yr), and can be explained by changes in uptake of water by vegetation, as described below.

Evapotranspiration (ET) is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants. The LPJ model output under the A2 scenario projects a somewhat surprising downward trend in ET, with a net loss of 84 mm per year projected for the year 2090 (Appendix V: Figure 8 [green line]); this occurs despite strong increases in temperature, which should greatly increase rates of evaporation, and increasing rainfall, which provides additional moisture inputs to sustain higher evaporation rates. The downward trend is most likely the result of biological, rather than physical processes, in the LPJ simulations. Under the warming and moistening climatic regime, and with an atmosphere increasingly enriched in carbon dioxide, stomatal closure in leaves, a process that limits water vapor flux from the plant to the atmosphere, can be expected to occur earlier in the day under photosynthetic conditions. This would have a net effect of decreasing the flow of water through vegetation, and thus contributing to an increasing fraction of rainfall becoming available as runoff.

The principal ecological effects of these changes would be that: (1) precipitation increases would more than offset evaporative losses, minimizing the risk of desiccation of vegetation except during relatively short-term seasonal droughts in the mid-year months; (2) the increased runoff and overall increased precipitation in this already wet environment would likely intensify erosion rates and foster conditions conducive to landslides in the steep terrain that characterizes most gorilla habitat.

### *Fire incidence*

The LPJ model generates a parameter to indicate fire occurrence, the amount of carbon lost to fire per unit area per year that reflects climatic stresses upon vegetation: actual ignition is dependent upon either natural (lightning) or anthropogenic factors. This parameter shows a strong downward trend through the century, such that by 2090 the significance of fire is projected to be half that of the baseline year of 1990 (Appendix V: Figure 9). However, a more subjective perspective suggests that over the next several decades, mid-year burning is likely to intensify due to rainfall decreases during the dry season, as discussed above, while warming enhanced seasonal desiccation of vegetation occurs. In this light, the unusual fires that occurred during July 2009 in the Virunga region might be a harbinger of more frequent occurrence of this type of activity (Appendix V: Figure 10). If so, the introduction of fire as a recurrent disturbance in mountain gorilla habitat would register some potentially significant ecological impacts upon gorilla habitat, as well as some degree of fire threat to the gorillas themselves.

*Plant functional type*

The plant functional type parameter is a characterization of the fractional coverage of vegetation according to simple classes as assessed by the LPJ model. The dominant class in the model subsection containing mountain gorilla habitat is tropical broadleaf evergreen forest (*trbe*), with small fractions of tropical broadleaf raingreen forest (*trbr*) and C4 grasslands (*c4pg*) (Appendix V: Figure 11). Little change is projected in fractional coverage for any of these classes, other than an early gain in *trbr* at the expenses of *trbe*. These results project that barring other factors related to human activity, the montane forest habitats of the mountain gorilla will remain extent for at least the next century, and thus continue to provide a haven of favorable habitat for the species.

*Net Primary Production (NPP)*

Under the CO2-enriched, increasingly warm and moist environmental conditions projected under the A2 emissions scenario, the NPP of the montane forest regions of the mountain gorilla range increase rapidly at a relatively linear rate (Appendix V: Figure 12). The LPJ model indicates this trend is already well established at present, and so should be readily detectable by monitoring growth patterns of vegetation While NPP as a parameter offers only a single diagnostic indicator for a vast assemblage of species, the increases projected might be considered as a favorable for mountain gorilla viability through the 21st century, since they suggest continued availability of foodstuffs in a vibrant forest ecosystem.

## V. Discussion

As a consequence of climate change the coming decades will undoubtedly be characterized by intensifying environmental stress to mountain gorillas and their habitat. However, mountain gorilla behavioral ecology has several characteristics suggesting strong inherent resilience to the most direct effects of climate change. The species has a relatively large thermal tolerance that is evident in the large elevational range of its habitat; it obtains nutrition from a variety of plants found over a broad elevational range; and it exhibits high degrees of mobility and is not tied to permanent nesting sites. Being highly acclimated to the cool, wet conditions of its broad altitudinal belt, the mountain gorilla would seem likely to track these conditions upwards with the expected rise in ecological zonation as climatic warming proceeds in decades to come. However, due to the upward taper of mountainous terrain as a function of increasing elevation, under this regime favorable habitat would reduce in extent inexorably. As gorilla populations are currently increasing, over time this trend might therefore intensify competition for resources and increase the potential for conflict among gorilla groups.

We posit that the more important threats to mountain gorillas as a consequence of intensifying climatic changes are likely to be indirect and largely related to novel disease introduction and the intensification of present day anthropogenic stressors related to human exploitation of forest resources. In particular, we recognize a low-risk, but high-impact threat related to climate-propelled disease introduction, from either an existing or novel pathogen, which could abruptly imperil the entire population of mountain gorillas. Under this scenario, the vulnerability of the species is greatly increased by its extremely limited range, which both increases risks of infection and offers little in the way of refugia or escape routes. The present clustered distributions thus represent a significant vulnerability of the species to disease. Community isolation would seem to be the strongest safeguard to preserve the species against invasive pathogens introduced into its range by climate change. This might therefore require assisted migration as an adaptive measure to establish of one or more communities in comparable montane habitat well outside of their present range.

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## Figure Captions

**Figure 1**: Relief map of the Albertine Rift region showing national boundaries and covering the modeled domain used for the Albertine Rift Climate Assessment Project. Darkening green and rose shades indicate increasing highland and decreasing lowland elevations, respectively. Major water bodies are shown in blue. The range of the mountain gorilla is restricted to a small region near the tri-border point of Uganda, Rwanda and the Democratic Republic of Congo.

**Figure 2**: Mean monthly precipitation rate (mm per day) at the Karisoke research station, Rwanda in the Virunga Volcanoes from 1981-1992 and at Ruhija in the Bwindi Impenetrable Forest National Park, Uganda from 1987-2006.

**Figure 3**: Pluviogram showing 9-day running mean rainfall climatology for Karisoke and Bwindi for the period 1991-2006. The high-resolution data show highly pronounced climatological behavior at sub-monthly scales that is not apparent when aggregated into monthly means according to convention as shown in Figure 2. Data provided courtesy of Dr. Katie Fawcett (Karisoke) and Robert Bitariho (Bwindi).

**Figure 4**: Annual mean temperatures and their linear regression at Lwiro, DR Congo from 1953-2006.

**Figure 5:** Two-by-two degree latitude-longitude subsection of the Albertine Rift model domain centered on Mt Sabinyo on the DR Congo-Rwanda-Uganda tri-border point used to derive bioclimatic output statistics for this study.

**Figure 6**: Mean monthly temperatures (top) and temperature changes relative to the 1990 baseline data (bottom) in degrees C for the years 2030, 2060 and 2090 within the 2x2 degree latitude-longitude model domain shown in Figure 5 under the IPCC A2 greenhouse gas emissions scenario. The thin vertical lines show the range of extreme gridpoint values within the domain, and are related to maximum and minimum elevations so display little if any variability in the output.

**Figure 7**: Mean monthly precipitation accumulation (top) and monthly change relative to the 1990 baseline data (bottom) in millimeters of rainfall for the years 2030, 2060 and 2090 within the 2x2 degree latitude-longitude model domain shown in Figure 5 under the IPCC A2 greenhouse gas emissions scenario. The thin vertical lines show the range of extreme gridpoint values within the domain, indicate considerable spatial heterogeneity in the model data, which is consistent with observational data at present.

**Figure 8**: Annual hydrological fluxes in precipitation (blue) and for evapotranspiration (ET, green) and runoff (red) from LPJ model simulations for 20-year means centered on the 1990 baseline year and for 2030, 2060 and 2090 within the 2x2 degree latitude-longitude model domain shown in Figure 5 under the IPCC A2 greenhouse gas emissions scenario.

**Figure 9**: Annual carbon loss from fire for 20-year means centered on the 1990 baseline year and for 2030, 2060 and 2090 from LPJ model simulations within the 2x2 degree latitude-longitude model domain shown in Figure 5 under the IPCC A2 greenhouse gas emissions scenario.

**Figure 10:** Fires within the boundary of Volcanoes National Park, Rwanda viewed from agricultural lands below during exceptionally dry conditions associated with a major East African drought in July 2009. (Image provided by James Kemsey, International Gorilla Conservation Program)

**Figure 11**: Plant Functional Type fractional coverage and change relative to 1990 historical baseline from LPJ model simulations in 2030, 2060 and 2090 under the A2 emissions scenario. Tropical Broadleaved Evergreen Trees (trbe) trees, indicative of perpetually moist forests are strongly dominant throughout, with low fractions of Tropical Broadleaf Raingreen (trbr) and C4 Grasslands also represented. These projections indicate that existing forest tracts would remain largely intact in their present form throughout the century providing that human-driven deforestation can be mitigated.

**Figure 12**: Net Primary Production (NPP) in grams of carbon per square meter (gC $m^{-2}$) from LPJ model simulations for 20-year means centered on the 1990 baseline year and for 2030, 2060 and 2090 within the 2x2 degree latitude-longitude model domain shown in Figure 5 under the IPCC A2 greenhouse gas emissions scenario. The strong increases, indicated as being already underway at the onset of the period, reflect both climatic conditions and CO2 fertilization from the rise in greenhouse gas content due to global anthropogenic emissions.

# 3.0 Mountain Gorilla Conservation and Climate Change

## I. Introduction

Our climate is changing at a speed much faster than is considered normal. Average global temperature is rising, regional precipitation has changed, sea level is rising, and floods, droughts and storms are occurring more frequently than before. All over the globe, animals, ecosystems, economic systems and human populations are affected and nature conservation has to face new challenges, in addition to other well-known pressures.

One impact of climate change is to create additional stress on habitats and ecosystems that are already threatened, which may result in a reduction of habitat leading to death or the large scale migration of animals. Pressures on ecosystems include high rates of change in land use and the conversion of land associated with agricultural expansion, pollution, population growth, civil wars, and the introduction of exotic species changing the integrity of ecosystems. Significant local and global extinctions of plant and animal species, many of which are important resources for African people, are projected, and if they occur, would affect rural livelihoods, tourism and genetic resources (IPCC, 2002).

Climate change may affect biodiversity, either directly or indirectly through many different mechanisms. Having a clear understanding of the expected impact of these mechanisms is essential in the evaluation of possible management actions to be undertaken. In the attempt to assess the vulnerability of mountain gorillas to climate change and then work on adaptation needs, it is necessary to begin with good quality information on the biology and behavior of mountain gorillas. Additionally, data needs to be compiled on local climate conditions, such as temperature, precipitation and the frequency of extreme events (such as mudslides and floods), and non-climatic data, such as the socioeconomic status of people living around mountain gorilla habitats, water resources, agriculture and food security, human health and biodiversity. This chapter describes the biology, ecology and conservation status of mountain gorillas and their natural habitat in the Virunga-Bwindi landscape. Along with the descriptions, the chapter highlights the known or possible vulnerabilities that mountain gorillas are susceptible to with respect to anticipated climate changes in the region.

## II. Taxonomy and Distribution of Mountain Gorillas

Current taxonomy of gorillas places the mountain gorilla (*Gorilla beringei beringei*) as a distinct subspecies of the Eastern gorilla species (*Gorilla beringei*, or Eastern gorillas), along with the Eastern lowland or Grauer's gorilla (*Gorilla beringei graueri*) (Grubb et al., 2003).

There are two populations of *Gorilla beringei beringei*, one among the volcanoes of the Virunga Massif at the border of the Democratic Republic of the Congo (DRC), Rwanda and Uganda, the other in Bwindi Impenetrable National Park in southwest Uganda on the border with DRC. Approximately 300 individuals were found in Bwindi Impenetrable National Park in Uganda in 2006 (Guschanski et al., 2009), while the other population consisting of around 380 gorillas in 2003, is found in the Virunga Massif, habitat shared by Mgahinga Gorilla National Park in Uganda, Volcanoes National Park in Rwanda, and Virunga National Park in the DRC (Gray et al., 2009). The Bwindi and Virunga gorillas appear to exhibit some morphological differences (Sarmiento et al., 1996), but these differences may only reflect a cline in diet and altitude, since the Bwindi and Virunga populations appear to be indistinguishable based on mitochondrial DNA studies (Garner and Ryder, 1996).

The relatively small size of the two mountain gorilla populations, in addition to anthropogenic stresses in and around mountain gorilla habitats of both the Virunga Massif and Bwindi, greatly contribute to the vulnerability of the mountain gorilla to climate change. To reduce the impact of climate change on the already vulnerable mountain gorilla, pro-active adaptation principles are needed rather than reactive ones. Further fragmentation of their natural habitat should be as much as possible avoided, while connectivity between protected areas or forest fragments should be provided by establishing corridors. An example of this is Sarambwe Reserve in DRC which is adjacent to Bwindi Impenetrable National Park in Uganda. In recent years habituated gorilla groups from Bwindi have periodically moved to Sarambwe; therefore, maintaining connectivity between these two forest blocks is important so that gorillas can continue to move back and forth and utilize the area. It would also be important to upgrade the status of Sarambe Reserve to that of a National Park to help ensure a higher level of protection. Buffer zones should also be established around protected areas to maintain, and even wherever possible increase, the size of the protected areas in order to increase the available habitat for the gorillas.

## III. Ecology

Ecological features of mountain gorillas are summarized in the Table 1 (taken from Robbins, 2010; Yamagiwa et al., 2003).

**Table 1**
**Ecological features of mountain gorillas**

| | ***Gorilla beringei beringei*** | |
|---|---|---|
| | **Bwindi Impenetrable** | **Virunga Volcanoes** |
| **Habitat Type** | Mountain forest | High mountain forest |
| **Altitude (above sea level)** | 1,160 – 2,607 m | 2,227 – 4,507 m |
| **Number of food species eaten** | 112 (Ruhija groups) | 36 (Karisoke research groups) |
| | 140 (Buhoma groups) | 42 (Tourist groups) |
| **Number of fruit species eaten** | 30 (Ruhija groups) | 1 (Karisoke research groups) |
| | 36 (Buhoma groups) | 2 (Tourist groups) |
| **Fallback food during fruit scarcity** | Herbs, vines (year round) | Herbs, vines (year round) |
| **Mean day journey length** | 550 -1000 m | 500 - 750 m |
| **Annual home range (km$^2$)** | 15-40 | 4 ~ 11 |

| | | |
|---|---|---|
| **Home Range Overlap** | Extensive | Extensive |

The Virunga and Bwindi gorilla populations are geographically separated in two forests blocks approximately 25km apart. The characteristic habitat of the Virunga mountain gorilla population, in contrast to the Bwindi mountain gorilla population, is high-altitude montane forest (see figure below) with a dense herb layer and low abundance of fruit (McNeilage, 2001; Watts, 1998a). Other areas frequented by Virunga mountain gorillas include open meadows and herbaceous areas, often dominated by *Mimulopsis excellens*, stands of bamboo, and ridge vegetation with abundant *Hypericum revolutum* (McNeilage, 2001). The Virunga mountain gorilla lives at higher elevation (2000-4000m) and cooler temperatures than the Bwindi gorilla population. The Bwindi gorilla population occupies transitional and Afromontane forests, living in a range of vegetation types, at warmer temperatures and is more arboreal than the Virunga gorillas (Ganas et al., 2004; Robbins et al., 2006; Robbins, 2008; Sarmiento et al., 1996). All Eastern gorillas prefer old clearings, valley bottoms, landslides, and similar areas where there is a dense tangle of ground-level herbaceous growth. The area of habitat occupied by the Virunga mountain gorilla is approximately 375 $km^2$ (Butynski, 2001); the Bwindi gorillas occupy nearly the entire southern sector of the park, an area of approximately 260$km^2$.

The geographic and altitudinal separation of the Virunga and Bwindi gorillas likely results in local adaptations to the different conditions by the different populations. This may be a potential problem if local conditions change with a changing climate, as the gorillas may not be ideally adapted for the new/different conditions. Alternatively, the very fact that two populations within the same sub-species of gorilla live under differing ecological conditions could imply that the sub-species as a whole is adaptable, and given enough time they could survive in new/different ecological conditions.

## IV. Diet

Mountain gorillas are herbivores, feeding primarily on leaves, shoots and stems, as well as bark, roots, flowers, fruit and occasionally ants (Ganas et al., 2004; Watts, 1984). There are large dietary differences between the mountain gorillas inhabiting the Virunga Volcanoes and those in Bwindi Impenetrable National Park (Ganas et al., 2004; Robbins et al., 2006). Bwindi gorillas have more tree species that produce fruit in their habitat and as a result, they consume a greater quantity of fruit (Ganas et al., 2004; Robbins, 2008). Bwindi gorillas also consume more species of fibrous foods. Ganas et al (2004) determined that the total number of food species eaten and the degree of frugivory are more similar between the Grauer's gorillas in Kahuzi-Biega National Park, eastern DRC and Bwindi, than between the two populations of mountain gorillas (Bwindi and the Virungas).

With respect to changes in diet with changes in season, there is little seasonal variation in the diet of the mountain gorilla in parts of the Virungas, probably because most of their food is available throughout the year (Watts, 1984), with bamboo shoots being the only obviously seasonally available food (Vedder, 1984; Watts, 1984). By contrast, but what is typical based on the fruiting patterns of trees, the fruit component of the diet of the Bwindi gorilla varies over the course of a year (Ganas et al., 2004; Ganas et al., 2009; Robbins et al., 2006).

As changes in climate are likely to result in the forest becoming warmer and drier (before becoming wetter), this has the potential to affect the food resources of the gorillas. The gorillas could possibly respond to such changes by altering their home ranges or possibly initiating a shift in diet to encompass different plant species. A study conducted by Vedder (1984) in Volcanoes National Park of Rwanda indicated that in response to decreases in the quantity of food available, mountain gorillas expand their range and travel further as well as alter their diet. Watts (1984) and McNeilage (2001) found that mountain gorillas in different habitats concentrate on a relatively small number of food items; however, the specific foods exploited do vary with habitat, leading to speculation that dietary flexibility is possibly the key factor in allowing them to occupy a range of different habitats within the Virungas. However, we don't know if wild gorillas learn which foods to consume while immature from their mothers or other group members, or whether they are able to easily adapt to new dietary items as adults.

Because climate change has the potential to alter the food availability for the gorillas, an understanding of how plants eaten by the gorillas respond to climate change is needed to predict the response of the gorillas, including their ranging, grouping and feeding patterns, and ultimately their patterns of reproduction and mortality. Given that mountain gorillas primarily eat herbs, what we need first is a more in-depth study of seasonal variability in availability of the herbs and how this is related to climatic factors such as rainfall and temperature. Watts (1998b) showed that there is little seasonal variation in availability of herbs in one area of the Virungas; Ganas et al. (2008) reached similar conclusions for herbaceous vegetation in Bwindi. However, both of these studies were of short duration (one year) and occurred during a period when climatic conditions were still within the 'normal' range for these habitats.

Secondly, we need additional data on major phenological events such as the appearance of buds, new leaves, first bloom and fruits for plants eaten by mountain gorillas. Along with this, we need to determine how these events relate to the weather patterns in both the Bwindi and Virunga ecosystems. Further research is also needed on the ability and willingness of gorillas to switch their diets. Related to these urgent research needs, important areas of future research include investigating how differences in food distribution between the *Gorilla* subspecies affect group sizes, habitat use, feeding competition, and reproductive strategies (Doran and McNeilage, 1998, 2001; Robbins, 2010).

### V. Ranging Patterns

In the Virungas, the typical annual home range of a mountain gorilla group is between 4–11 km$^2$ (McNeilage, 2001; Vedder, 1984; Watts, 1987, 1998a); Bwindi gorillas may use 20–40 km$^2$ in a year (Ganas and Robbins, 2005; Robbins and McNeilage, 2003). The ranging behavior of gorilla groups is mainly determined by the distribution and abundance of fruit and herbaceous vegetation in the environment (Ganas and Robbins, 2005; Robbins and McNeilage, 2003), but may also be influenced by social factors such as competition for mates (Watts, 1994).

As mentioned above Bwindi gorillas fall into an intermediate pattern of frugivory, between the Virunga gorillas and western and Grauer's gorillas. Home range size for the more frugivorous Bwindi gorillas is larger than that of the Virunga gorillas and more similar to that of other gorillas, including Western gorillas which are also frugivorous (Ganas and Robbins, 2005; Robbins and McNeilage, 2003). In contrast to the Bwindi gorillas, Virunga gorillas live in a habitat with exceptionally high herbaceous food densities, and include very little fruit in their diet, which may lead to smaller home range size. Ganas and Robbins (2005) found that gorillas in Bwindi travel further each day when they are searching for and consuming fruit. Groups also utilize a larger proportion of their home range during times of fruigivory. Rainfall has a negative impact on daily travel distance (e.g. they move less during the rainy season). As predicted, larger groups travel further each day and have larger annual home ranges than smaller groups. In sum, home range size and utilization probably depends on a complex relationship between the distribution and abundance of both fruit and herbaceous vegetation and social factors such as competition for mates (Ganas and Robbins, 2005; Robbins and McNeilage, 2003; Watts, 1994).

In general, it is anticipated that annual home range is primarily related to food resources with social factors adding another layer of complexity (Ganas and Robbins, 2005; Watts, 1998a). Changes in climate resulting in changes in fruiting and the abundance of herbaceous vegetation are likely, therefore, to affect range size, which may increase or decrease depending on food availability. This would have implications for conservation management of this critically endangered species. Even slight changes in plant quality may substantially affect the ranging behavior of the gorillas. Comparative studies of the socio-ecology of all subspecies of gorillas should include investigating links between feeding ecology, ranging patterns, and social behavior on the individual, social group, and population levels (Robbins and McNeilage, 2003; Robbins, 2010) in order to inform us about the flexibility that gorillas can exhibit and whether or not human intervention (e.g., provisioning, planting particular species or removing others, or other measures) will be needed to maintain the population.

Ranging patterns also need to be taken into account when zoning areas within the park and when looking at the conflicts that arise when gorillas range outside the forest and raid crops in adjacent fields. The national parks provide a high level of protection for gorillas that remain within park boundaries. However, when gorillas cross into the human domain, a conflict over resources (e.g., food, territory, etc.) arises, as gorillas develop crop-raiding habits and lose their natural fear of humans. This human-gorilla conflict has the potential to result in human injury, gorilla injury/death, and the transmission of diseases between these two closely related species. Perhaps more dangerous however is the long-term negative effect of the conflict on community attitudes towards conservation of gorillas and the parks, associated with crop-damage and physical attacks, with increasing negative attitudes leading to an increase in problems linked to conservation (Macfie, 2000). This conflict has the potential to increase with the effects of climate change as human populations may migrate to areas closer to gorilla habitat, leading gorillas and human populations into increasing conflict when gorillas exit the park and/or community members access the park for resources.

## VI. Social Behaviour and Population Dynamics of Mountain Gorillas

Mountain gorillas live in a stable social groups headed by a dominant male silverback. Gorilla groups may contain only one adult male, several mature males or may consist of males only (Robbins, 1995; Yamagiwa, 1987). At maturity both males and females often leave their natal group; females typically join another group or a solitary silverback, while males remain solitary until they can attract females and establish their own groups (Robbins, 1995, 2010).

Female mountain gorillas are capable of giving birth for the first time when they reach around 10 years of age (Robbins et al., 2005; Watts, 1991b), and then typically have an infant about every four years. During her lifetime, a female mountain gorilla can have up to eight offspring (Robbins et al., 2007; Watts, 1991b). Approximately 26% of infants die before they reach age three (Robbins, et al., 2007). This low reproductive rate makes this species more vulnerable to escalating threats.

The Virunga population as a whole has grown at approximately 1% annual growth rate (Gray et al., 2009). A single subpopulation in the Virungas has grown by 3-4% per year

(Robbins et al., 2009). By contrast, Bwindi has experienced lower levels of human disturbance (Baker, 2004) than many other forests in the area (Plumptre, 2002), yet its gorilla population most likely has experienced little or no growth over the past 20 years (Robbins et al., 2009). A comparison of a small subset of the Virunga gorilla population studied through the Karisoke Research Center, to Bwindi mountain gorillas done by Robbins et al. (2009), found some notable differences in the demography between the two populations. In particular, the inter-birth interval among surviving offspring (to age 3) was 17% longer at Bwindi than that in the population studied by Karisoke, while birth rates were 18% lower (Robbins et al., 2009). However, there was no difference in the rate of infant mortality. The lower reproductive rate at Bwindi can be interpreted as an indicator that the population has a slower life history, or that the population is closer to its carrying capacity. Within the Bwindi and Virunga gorilla populations, the habituated gorilla groups have a growth rate higher than that of the overall population (Robbins et al., unpublished data). This difference may be because they receive veterinary care and better protection against poachers than the rest of the population.

Possible factors that could constrain population growth of mountain gorilla populations include the availability of good gorilla habitat, disease and human disturbance (McNeilage et al., 2006). In Bwindi, suitable vegetation is found throughout most of the southern sector of the park (Guschanski et al. 2008; Robbins et al., unpublished data). New research on the quality of the vegetation and its regeneration rate, along with information on the impact of human disturbance on patterns of habitat utilization by the gorillas, and population dynamics of the gorillas will provide us with a better understanding of the number of gorillas that Bwindi could theoretically support (McNeilage et al., 2006; Robbins et al., 2009). Information on habitat availability, quality, dietary intake and use by gorillas has been used to estimate the number of gorillas that the Virungas could support, and indicates that there is considerable room for expansion beyond the current population level of around 380 individuals (McNeilage, 1995). Similarly, it is probable that there is also room for an increase in the Bwindi population.

The potential impact of climate change on the population dynamics of the mountain gorilla is currently poorly understood. Presumably if climate change has a negative impact on food availability, the population will either grow at a reduced rate or perhaps even decline. A continuation of the ongoing data collection for patterns of births, deaths, and dispersal is necessary, especially given the long life spans and slow life histories of mountain gorillas. Research/monitoring that is needed in order to help managers relate knowledge about population dynamics to the vulnerability of mountain gorillas to climate change and make the best adaptation decisions, was identified during this project and includes continued monitoring of population size, group size and composition, and growth rate and reproduction.

## VII. Threats

Mountain gorillas have been classified by IUCN as critically endangered, based on their small population size (Robbins et al., 2008), with approximately 680 individuals ranging in two isolated populations, the Virunga Volcanoes and Bwindi Impenetrable National Park (Gray et al., 2009; Guschanski et al., 2009).

Threats that have the potential to affect populations of mountain gorillas include (1) the loss or modification of habitat (e.g., deforestation, timber extraction, charcoal making, change in structure and composition of forest/availability of food); (2) killing of individuals for meat or the capture of infants (3) the effects of war and political instability; (4) diseases; (5) water collection inside the parks by communities leading to an increased risk of disease transmission and (6) loss of habitat and food from fire.

### 1. Habitat degradation and conversion

Forests throughout the area occupied by mountain gorillas are under constant threat of reduction by deforestation or agricultural encroachment by the local populations. Mountain gorillas live in close proximity to some of the highest densities of rural human populations in Africa, with up to 1000 inhabitants per km² (Bush and Ikirezi, 2010) resulting in a high demand for land and resources. The human population growth and corresponding need for natural resources cause serious and continuous pressures on the mountain gorillas. The growth of human settlements in the region is increasing the demand for resources, the impacts of which may include the degradation of gorilla habitat through illegal forest clearing for agriculture, illegal cattle grazing, firewood collection, small-scale timber extraction, and charcoal making. The result of this is a restriction in available habitat for the gorillas. Climate change has the potential to change forest composition through reduced rainfall (at least in the near term) leading to changes in the vegetation. Bamboo is an important seasonal food resource, and loss of bamboo coverage caused by changes in the climate has the potential to affect the gorillas.

Another threat directly related to habitat degradation is the huge demand for energy by communities surrounding the protected areas. Fuel wood and charcoal are by far the most heavily consumed energy sources throughout the DRC, and are the primary energy source for household cooking. Wood and charcoal provide 80 per cent of all domestic energy consumed in the DRC (Debroux et al., 2007). A study conducted in 2002 found that nearly 100% of households surveyed in the Virunga and Bwindi region used fuel wood for their household cooking needs (Plumptre et al., 2004). Currently there is no organized supply of fuel wood/charcoal in urban areas in the region and consequently a growing population continues to contribute to deforestation. In addition, during periods of conflict in recent years in eastern DRC, a number of refugee and/or internally displaced people camps have been located in or near Virunga National Park exacerbating the uncontrolled firewood harvesting, increased charcoal making and poaching.

Adaptation measures that could be put in place, or planned for, to reduce deforestation for land conversion or fuel wood include: reforestation, plantations, improved agricultural practices to increase soil fertility and crop yields and the promotion of alternative forms of energy. Alternatives to charcoal are currently being promoted by the Institut Congolais pour la Conservation de la Nature (ICCN) around Virunga National Park with a fuel briquette programme, established in July 2008, which uses discarded plant materials like rice sheaves and sawdust that can be used for cooking and heating. Response to the briquette programme has been mostly positive although there have been challenges including complaints about smoke and efficiency. ICCN is working to address these problems through retraining, repackaging, changing the ingredients of the briquettes and cutting the selling price. Other organizations are working on improved cooking stoves that use less fuel, and establishing plantations.

### 2. Hunting

Since the communities around the Virungas and Bwindi do not consume primates as bushmeat, mountain gorillas have only rarely been eaten. This gives them a degree of protection, and direct poaching of gorillas for bushmeat is not usually considered a threat (Sicotte and Uwingeli, 2001). However, gorillas have been hunted for other reasons; starting in the early 1970s, there are records of gorillas being killed and body parts (including ears, tongue and genitals) being removed for witchcraft (Groom, 1973). In the mid-1970s a trade developed for gorilla heads and hands as trophies as well as live infants for sale to zoos (Harcourt et al., 1983; Kalpers, 1992; Plumptre and Williamson, 2001). The hunting of gorillas for the sale of trophies is not considered a major threat today. However, the hunting of gorillas for the capture of a young gorilla for sale to private collectors or zoos was a serious threat during the 1970s and although it had decreased from the mid-1980's until the early 2000s, the threat has emerged again in recent years during the chaos of war. The capture of young gorillas usually implies the loss of many adults being killed in the process of trying to protect their young. A much more serious threat to gorillas from hunting, however, is the inadvertent capture of a gorilla in a snare set for another animal (such as duiker antelope or bushpig). Although not targeted by snares, mountain gorillas are often accidentally caught in snares set to capture other wildlife leaving many individuals maimed of killed from their injuries (Plumptre and Williamson, 2001).

In order to protect the gorillas, park staff in all three countries where mountain gorillas range (DRC, Rwanda and Uganda) have worked out strategies and put in place mechanisms to enhance local and cross-border surveillance and law enforcement activities. Additionally the Mountain Gorilla Veterinary Project has put in place a regional gorilla health program with their activities including the removal of snares from the gorillas (see Chapter 4 of this report for more information). In addition to these strategies there is a need to initiate discussions within the region on strategies and mechanisms for the prevention of mountain gorilla and other wildlife poaching and this could be possible with the involvement of all stakeholders including security and law enforcement agencies.

### 3. War and insecurity

Modern wars and civil strife are typically associated with detrimental effects on wildlife and wildlife habitats. One of the biggest threats to mountain gorillas is the armed struggle that has led to civil unrest and unspecified decimation of wildlife and habitat destruction in the parks the mountain gorillas inhabit (Muruthi et al., 2000). The various armed groups that have been active in eastern DRC since the Rwandan genocide of 1994 have systematically exploited the natural resource base to finance themselves or to exchange the resources for weapons. During this time a number of different armed groups have been operating within and around the mountain gorilla parks. Kalpers et al. (2003) reported that between 12 and 17 gorillas are known to have died between 1992 and 2000 in the Virungas Volcanoes Region as a direct result of military activity. Virunga National Park was placed under the World Heritage Site in Danger List by UNESCO in 1994 (UNESCO, 1994) as a result of recurring encroachments, deforestation, poaching, the high human population growth, and the refugee-related problems that have arisen due to civil unrest.

From November 2006 to late 2008, there was an escalation of violent fighting in the Virunga National Park between the DRC Government Forces against several armed groups. This fighting has been seriously threatening the fragile peace in the region and further threatening the endangered mountain gorilla population, with 10 gorillas killed in 2007 in the Mikeno sector of Virunga National Park (PNVi), a World Heritage Site (ICCN press release, January 2009).

Throughout Africa, war and other political conflicts are a serious threat to continuity in conservation programming. Armed conflict in DRC has discouraged conservation organizations, international aid agencies and government agencies from investing in affected areas, leading to the freezing of budgets, withdrawal of personnel, and reduction of anti-poaching efforts. Protecting gorillas in many areas of eastern DRC has therefore been extremely difficult and often dangerous in times of war. Such conflicts also draw attention away from longer-term conservation and development objectives to short-term objectives related to the political and security situation (Lanjouw et al., 2001). Regional resource management agreements are increasingly becoming recognized as important in ensuring environmental protection. Mechanisms enabling cooperative management of shared resources, be it water, forest, or other resources, provide a foundation for collaboration and help protect the resources from destructive utilization. Collaboration in such regional agreements potentially plays a significant role in preventing, managing and/or resolving conflict, by providing both the mechanisms and political will for cooperation. These conflicts may be exacerbated by climate change, with the potential reduction in natural resources available to community members leading to the possibilities of increased unrest in local populations. This can be addressed by sensitization of the local populations to climate change issues and working on climate change adaptation strategies together with the local communities.

### 4. Disease

Another potential threat to gorillas is exposure to human disease (Cranfield and Minnis, 2007; Graczyk et al., 2001; Graczyk et al., 2003; Woodford et al., 2002) especially for the habituated gorillas regularly in contact with humans. Gorilla tourism in the Virunga-Bwindi region regularly exposes the habituated mountain gorillas to people. Strict rules have therefore been established and must be observed with respect to regulating the time of the tourist visit and tourist numbers per group, to limit the approach of animals by humans to a maximum of 7 meters and burying human waste more than 30 centimeters depth (Homsy, 1999). As climate change is likely to create conditions where new diseases appear, diseases spread more quickly, and resources to prevent illness are reduced, it will be important that the gorilla rules are enforced more strictly and that new rules are put in place as necessary (e.g., wearing of masks during gorilla visits). It may also become necessary, as climate change progresses, for gorilla conservation organizations to become more involved in monitoring human health in the region. For further discussion of the effects of climate change on gorilla health, refer to Chapter 4 of this report.

### 5. Water

The highly porous volcanic soils around the Virunga Massif create a scarcity of surface runoff in the area. Rains that fall on the high elevation forests of the park soak rapidly into the ground and reappear primarily as sources at lower altitude, often at considerable distances from the park (Gurrieri et al., 2005). Therefore, the communities living on the highest hillsides and close to the park boundary inhabit a "dry zone" and lack sources from which to draw water. Many community members attempt to solve the problem of access to water by entering the park to draw water from springs, streams, wetlands, and lakes, causing impacts on the protected areas and threatening the survival of mountain gorilla (through disturbance to the area and the potential for disease transmission) (Gurrieri et al., 2005).

The need of the communities for water is likely to increase with climate change as temperatures are anticipated to rise and, in the short term, rain fall is also likely to decrease. The result of this will be an increase in the need to find water to supplement household and agricultural needs from rainfall. Something to consider in the Virunga-Bwindi region would therefore be livestock which require less water, and alternative agricultural crops that are more resistant to drier conditions. Provision of sources of reliable water in the "dry zone" around the

Virunga Massif is also essential if one wants to protect forest resources and the mountain gorillas as well as help communities whose health and livelihoods are threatened.

Gorillas rarely drink water as the vegetation they feed on contains enough water to sustain them. Ongoing research in Bwindi is assessing whether gorillas are drinking from open water sources more frequently than previously and if they are more likely to drink water during the dry season. Over a ten year period (2000-2010) one group of gorillas in Bwindi was observed to drink water on approximately 1% of all days (Robbins pers. obs.). The lack of open water and small streams in the area within and surrounding gorilla habitat thus could potentially become a threat to their conservation, especially if dry seasons become more prolonged and severe. The conditions that lead gorillas to drink from open water sources are not well known, so it would be useful to better understand why they drink water. For example, monitoring changes in the water content of gorilla foods seasonally would be one way of addressing this issue. Furthermore, it is important to establish a monitoring programme of the water sources in the parks, for water quality, quantity, seasonality and changes in swamps. As temperatures increase, rain becomes less predictable and available water reduces, gorillas might need to rely on a resource that is becoming scarcer. Having information on water sources in the parks, including quality, quantity, seasonality and changes in swamps, will thus be critical for developing adaptation strategies for the water that gorillas use, in the vegetation they eat or from open water sources.

### 6. Fire

Fire is another threat to the mountain gorilla population in both the Virungas and Bwindi Impenetrable National Park. A recent example of this is the forest fire that swept through Rwanda's Volcanoes National Park and Uganda's Mgahinga Gorilla National Park in July 2009, burning approximately 300 hectares. The fire was accidentally started when strong winds took hold of a flame a local beekeeper was using during honey harvesting near Volcanoes National Park, igniting grass and quickly spreading up Mt. Muhabura, which sits on the Rwanda-Uganda border. A team of 4,000 people comprised of military personnel, national park staff and neighboring communities mobilized to battle the blaze assisted by military helicopters dumping water from above.

The 2009 fire highlights the fact that mountain gorilla habitat is vulnerable to fire, and that fire is a potential threat to conservation of the mountain gorillas. Changes in climate are predicted to lead to an increased threat of fire. Additional research is needed on the significance of fire risk to gorilla habitat to better understand the extent of the threat. Some suggestions of how this can be managed include better early warning systems in the parks, better communication systems in the region about fires starting, weather monitoring, and fire mitigation techniques (including fire management plans and training in fire management for park staff).

## VIII. Conservation Status of the Mountain Gorilla

### *Democratic Republic of the Congo (DRC)*

Management of National Parks, Faunal Reserves, and Game Reserves in DRC is delegated to the Institut Congolais pour la Conservation de la Nature (ICCN), which also manages scientific research. The mountain gorilla is totally protected in DRC; owning, transport and/or trade is forbidden or regulated. People who capture or kill gorillas in a strict nature preserve face imprisonment from 1 to 10 years.

*Rwanda*

The Rwanda Development Board under the Tourism and Conservation department (formerly the Office Rwandais du Tourism et des Parcs Nationaux, ORTPN) has direct responsibility for management of National Parks and matters relating to ecotourism in Rwanda. The Volcanoes National Park therefore falls under its responsibility. The Department of Environment has overall responsibility for biodiversity conservation. The mountain gorilla is totally protected in Rwanda.

*Uganda*

In Uganda, the Uganda Wildlife Statute provides tools for the establishment of wildlife conservation areas, which fall under two categories: wildlife protected areas (national parks or wildlife reserves) and wildlife management areas (wildlife sanctuaries and community wildlife areas). It is forbidden by the national legislation to capture mountain gorillas (Uganda Wildlife Division, 2002a). As all mountain gorilla populations occur within protected areas (national parks and reserve), they and their habitat have some degree of protection.

In all three range states, political and institutional instability as well as illegal hunting in protected areas may well undermine the protection afforded by the National Parks. National laws exist in all range states for the control of hunting and capture of gorillas. Unfortunately the reality is that enforcement of the laws is often impossible due to inaccessibility of the areas and a lack of funds (Nellemann and Newton, 2002).

## IX. Transboundary Collaboration Initiatives in Mountain Gorilla Conservation

As mountain gorillas move freely across the international borders of their forested habitat in Central Africa, a regional approach to conservation is essential to ensure their survival. The conflict that has raged in central Africa over the past two decades has had a long lasting impact on regional sustainable economic development and biodiversity conservation. Despite this instability, the mountain gorilla conservation partners have worked together to increase regional cooperation and develop a landscape-level approach to conserve transboundary mountain gorilla habitat. The wildlife conservation authorities of the three countries of the Central Albertine Rift (Institut Congolais pour la Conservation de la Nature - ICCN in the DRC; the Rwanda Development Board - RDB in Rwanda; and Uganda Wildlife Authority - UWA in Uganda) together formed the Greater Virunga Transboundary Core Secretariat (TCS) in 2006. The goal of the Greater Virunga Transboundary Core Secretariat (TCS) is sustainable conservation of the Central Albertine Rift biodiversity for long-term socio-economic development through strategic transboundary collaborative management. The TCS provides a platform for constructive engagement across borders and is positioned to build on long-standing landscape management planning efforts that have been developed under the Congo Basin Forest Partnership. Transboundary collaboration within and outside of park boundaries has helped to build trust amongst government officials, park managers and staff, NGOs (conservation, development and humanitarian, etc.), research and academic institutions, and communities, allowing for improved mountain gorilla conservation, forest resource management and sustainable development.

The transboundary collaboration approach in the Virunga-Bwindi landscape has resulted in a number of notable achievements that can be attributed to the collective efforts of regional partners, and as a result of progressive regional processes leading to the creation of the Transboundary Strategic Plan in 2006. The maintenance of long-term monitoring schemes such as the ranger based monitoring (RBM) program on-going in the Virunga-Bwindi landscape is vital for the identification of conservation priorities and in providing base-line data against which to measure the impacts of climate change. In addition, such monitoring schemes are the only means by which it will be possible to detect unexpected or unpredictable impacts of climate change at their early stages. Many of these schemes are threatened by lack of resources, and a commitment to long-term support of these schemes is critical to ensure their existence and to ensure best value by utilizing existing data collection networks.

One of the suggested outcomes of this project, based on recommendations from the workshop, is the incorporation of climate change considerations within specific Agreements and Memoranda of Understanding which will provide flexibility to address particular threats to wildlife including the mountain gorillas. These should be reviewed for relevancy on a regular basis as new information becomes available.

## X. Long Term Mountain Gorilla Conservation Programs

A large number of conservation programs have focused on the mountain gorilla. Three major programs in Rwanda have been developed specifically to conserve the mountain gorillas of Volcanoes National Park. The initiatives include: the Karisoke Research Centre, established in 1967; the Mountain Gorilla Project initiated in 1978; and the Virunga Veterinary Centre formed in 1987.

In February 1990, Fauna and Flora International, in partnership with the African Wildlife Foundation and World Wide Fund for Nature expanded the Mountain Gorilla Project to form the International Gorilla Conservation Programme (IGCP). The aim was to support conservation work throughout the range of the Eastern Lowland and Mountain Gorilla in DRC, Uganda, and Rwanda, promoting cooperation between these three countries through the provision of financial and technical assistance. The International Gorilla Conservation Program (IGCP) works in close partnership with the governments of Rwanda, Uganda and DRC to conserve mountain gorillas (*Gorilla beringei beringei)* and regional afromontane forests. Specifically, IGCP works together with the protected area authorities (PAAs) within the region: Rwanda Development Board (RDB); Uganda Wildlife Authority (UWA); and Institut Congolais pour la Conservation de la Nature (ICCN). IGCP's unique partnership operates through a regional landscape-level approach, promoting integrated collaboration and capacity building, and an adaptive program strategy centered on four core components: a) Strengthening the protection of mountain gorillas and their habitat through transboundary collaboration; b) Establishing a strong information base to understand the dynamics between human populations and wildlife; c) Working with local communities to create livelihood opportunities that are complementary and contribute to conservation; d) Advocating and strengthening supportive policy and legislation for conservation. IGCP is supporting the development of a regional mountain gorilla conservation policy through transboundary collaboration between the three mountain gorilla range states while working with local communities to reduce their dependence on park resources, minimizing human-gorilla conflicts and support a more equitable distribution of the benefits from gorilla tourism. The IGCP is also conducting new research to better understand the effect of climate change on mountain gorilla populations and their natural habitat

The Dian Fossey Gorilla Fund International is dedicated to the conservation and protection of gorillas and their habitats in Africa. The Fossey Fund operates the Karisoke Research Center in Rwanda, which was officially created by Dian Fossey in 1967, as she established her research camp in Rwanda between Mt. Visoke and Mt. Karisimbi. Although her original focus was on study of the mountain gorillas, she soon realized that if they were to survive, they would require protection as well. Among the threats were poachers who set snares in the forest (in the Virungas this was mainly for other animals such as antelope), cattle grazing, and human encroachment into the forest. Karisoke's facilities were built and destroyed a number of times throughout the years, and today have been moved to the nearby town of Musanze (formerly Ruhengeri), with outposts in the forest where needed. In recent years, Karisoke has also added programs geared toward education and health in local communities. Today, the Karisoke Research Center employs some 80 staff members, with more than half of these in research, protection and monitoring of the gorillas. Other staff includes education, health, and administrative staff. The Fossey Fund also works with community-based reserves and national parks in the Democratic Republic of Congo, and is building a rehabilitation center there for gorillas rescued from poachers.

The Mountain Gorilla Veterinary Project (MGVP)'s mission is to improve the sustainability of mountain gorilla populations using an integrated, or "one-health," approach that combines health care, research, capacity building, information sharing, and strategic partnerships. The project monitors the health of wild mountain gorillas, treats trauma and illness, researches significant issues in gorilla health, and develops protocols and partnerships to support the Mountain Gorilla One Health Program in the Virungas and environs. The project works in close partnership with the governments of Rwanda, Uganda and the Democratic Republic of the Congo and other gorilla conservation organizations to achieve mutual goals, and its work is shared to strengthen wildlife conservation efforts around the world. The Mountain Gorilla One Health Program is a partnership between the MGVP and the University of California, Davis, Wildlife Health Center. The Mountain Gorilla One Health Program investigates the disease threats facing mountain gorillas, helps expand medical care for the humans working in and around the gorilla parks, and improves the health and well-being of livestock to benefit the families who depend on them for nutrition and income.

In Uganda there are a number of conservation programmes that have been established for conservation of the gorillas in Bwindi Impenetrable and Mgahinga Gorilla National Parks. Established in 1991 the Institute of Tropical Forest Conservation (ITFC) is a conservation-oriented research institute of Mbarara University of Science and Technology (MUST). It is located on the edge of Bwindi Impenetrable National Park (BINP), a World Heritage site in South West Uganda. ITFC has carried out, often with partners, a range of biological and socio-economic research and monitoring, aimed at addressing the key conservation challenges in the region.

Conservation through Public Health (CTPH) works to promote conservation and public health in Uganda by improving primary health care to people and animals in and around protected areas. The programme is designed to prevent and control disease transmission where wildlife, people, and their animals meet, while cultivating an attitude to conservation and public health in local communities.

## XI. Potential Impact, Long Term Monitoring and Adaptive Measures

Acording to the Congo Basin Forest Partnership (CBFP), and the Central African Program for the Environment (CARPE), endemic species such as mountain gorilla are highly at risk from minor climatic changes (CBFP/CARPE, 2005). Since the mountain gorillas are confined to a relatively small habitat within a high altitudinal range, minor climate changes causing changes to the habitat may have a severe impact on the population, particularly if the habitat changes through degradation and fragmentation to such an extent that it can no longer support the population. In addition to direct impacts on the vegetation within the parks, increased climate variability and the occurrence of extreme climate events are likely to have an impact on surrounding communities that depend on natural resources for their livelihoods. An example of this is an increase in soil erosion problems caused by more intense rainfall and changes in rain fall patterns which will put pressure on both subsistence and cash crops grown around the mountain gorilla parks (SEI, 2009). A reduction in these crops will directly increase the stress on communities who will have fewer resources and feel they have no option but to enter the parks to obtain resources, potentially threatening the gorillas.

The current effects of climate change on montane forests of the Congo River Basin are not fully understood because a lack of functional meteorological stations hinders weather forecast and calibration of global and regional climate models. It is likely that extreme rainfall events will increase by the end of the century, but there is no concensus between the models on the likely changes in the severity of the dry events. Temperature will increase and observed trends show a change in the seasonal pattern of rainfall (Rose, 2009). To address this need, IGCP has recently launched a long term monitoring program in the Virunga-Bwindi landscape to follow the trends of changes of climate parameters and their impact on the mountain gorilla behavioural ecology.

To better understand the local climate variability and its impact on gorilla food availability, a network of weather micro-stations has been set up by IGCP and the three park authorities (UWA, RDB, and ICCN) in mountain gorilla habitat. Systematic observations of a number of key climate parameters, including temperature, rainfall relative humidity and atmospheric pressure, are carried out daily by trained park rangers at standard preset times. Several botanical transects have also been established to monitor plant phenology and therefore assess the spatio-temporal availability of gorilla foods in relation to climate variability. The seasonal timing of such plant life-cycle events can be critical to the survival and reproduction of animals relying on these plant items in their diet with changes having potentially serious consequences both for plants and the animals which rely on them (Moza and Bhatnagar, 2005). It is therefore important to keep tracking plant life-cycle events from year to year, and determine how they relate to the weather patterns and how the presence or absence of items eaten by mountain gorillas affect their ranging pattern in the Virungas and Bwindi. Plant phenology is being monitored daily in the Virunga Massif and in Bwindi. Over the long term this data will be used to look at changes in plant phenology together with changes in climate, to assess the impacts of climate change on gorilla food distribution and availability. While these projects will generate important information, the project in the Virungas is new and it will be at least a year before data will be available for analysis.

Obviously, changes in the mountain gorilla habitat may not only lead to the extinction of this emblematic species, but could also negatively affect livelihoods of the surrounding human population. The mountain forests offer a number of ecosystem services including the regulation of rainfall run-off, soil retention capacity and water supply. If these services are disrupted by climate change, then the communities around the forests will become vulnerable to soil erosion, a shortage of water, flooding and other climate related risks (McNaughton, 2008).

An example of the disruption of ecosystem services caused by changing climate patterns took place recently in the Virunga Massif. On the night of Saturday 15th May 2010, uncommonly heavy rains hit parts of Mt. Karisimbi resulting in mudslides of two meters height and over five meters width. This mud flow destroyed two hundred and thirty-two (232) houses, fields of crops and even livestock. Nineteen people were reported dead and twenty-seven others missing (probably killed also). This is an unfortunate example showing some of the negative impacts of extreme weather events, a likely outcome of an ongoing changing climate. The heavy rainfall also affected the gorilla population in Parc National des Volcans, Rwanda. Park management reported that four mountain gorillas including one female adult and three infants in the research groups in Volcanoes National Park (VNP) died. At the time the group was ranging at high altitude (above 3,500m); the cause of death is suspected to have been exposure which was caused by severe weather following the heavy rains.

In response to these concerns it is important to integrate climate change issues in the general management plans of all the protected areas so that all activities undertaken at the park level take into consideration the issue of climate change, bearing in mind that our actions are likely to increase or help to accommodate climate change effects. Interactions with local communities are also very important and local communities should be involved as much as possible in planning adaptation strategies, particularly those strategies that may lead to large-scale changes in land-use.

At the policy level, effective adaptable conservation policies are necessary to manage mountain gorilla habitat. Possible policy actions identified during the stakeholder workshop for this project include 1) limiting land subdivisions; 2) upgrading the status of Sarambwe Reserve in eastern DRC; 3) defining a clear legal land tenure system; 4) ensuring that national policy for adaptation is complementary to conservation funding; 5) reviewing current General Management Plans for all mountain gorilla parks to take into consideration climate change: and 6) reviewing existing national policy and legislation, particularly tourism and environment in relation to climate change.

It will be important to provide efficient mechanisms of communication on climate change issues which could include establishment of a climate change adaptation working group to set priorities for action, divide up tasks and disseminate information. Strategies also need to be developed to improve the capacity in the region to adapt to climate change; including sensitization for local communities on climate change; and training of park staff, conservation partners, governments and communities on adaptation measures.

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# 4.0 Mountain Gorilla Health Considerations

## I. Background

Mountain gorillas, a subspecies of the Eastern gorilla, exist in only two populations, the Virunga population, straddling three contiguous countries and national parks, and the Bwindi population dwelling in the Bwindi Impenetrable Forest in Uganda. Together, these populations number approximately 680 animals.

This chapter summarizes common health threats to mountain gorillas, and impending threats from anticipated emerging threats to humans and other wildlife, with special consideration to climate change predictions for the region.

### *Mountain Gorilla Health Monitoring*

*Gorilla* is one of only four genera in the family Hominidae, a young family that diverged from its ancestors 10 to 15 million years ago. As such, it is very closely related to humans. In addition to being threatened directly by human hunting and violence, and indirectly by human encroachment on its habitat, gorillas are threatened by many, if not most, of the same infectious disease risks that threaten human populations. The Mountain Gorilla Veterinary Project (MGVP) was established out of efforts initiated in the early 1980s by Dian Fossey and her research team's studies of gorillas in Rwanda. As part of ongoing mountain gorilla conservation efforts, it has been providing wild mountain gorilla veterinary care for over 25 years. It recently has become part of a "One Health" program based at the University of California, Davis, Wildlife Health Center, which explicitly seeks to study and monitor the connections between human, gorillas, other wildlife, domestic animal, and ecosystem health. Humans coming into contact with gorillas and other great apes, even in the service of conservation, may be increasing the risk of infectious disease in gorillas (MGVP, 2009).

The World Health Organization and multiple authors claim that climate change has and will increase the rate of spread, severity, and geographical ranges of many diseases (e.g. McMichael et al., 2006; WHO, 2009). For this reason, a climate change vulnerability assessment of the mountain gorilla should include not only the known health threats to the two mountain gorilla populations, but also looming threats that may accompany new risks to human health in the region.

### *Small Population Risk*

In addition to their vulnerability attributable to genetic relatedness to, and contact with, humans, the remaining mountain gorilla populations constitute, by any criteria, a small population. Small populations have been shown theoretically, and empirically, to be subject to additional risk of extinction. Although mountain gorillas do not differ from other small populations in this regard, it is important to remember the added vulnerability that comes with this status (Soule, 1987). Specifically, to conservation biologists, small population concerns include:

- increased risk of stochastic catastrophic losses,
- increased risk of catastrophic losses due to disease outbreak,
- reduced genetic variability, which in turn could lead to:

- reduced native resistance to a variety of illnesses and problems (inbreeding depression) and,
- reduced ability to adapt genetically to a changing local environment.

Given the small size of the two remaining populations, and their concentration in relatively small reserves, an obvious concern is that catastrophic losses to population numbers could occur. These could come about as a result of an extreme weather event, or of another threat resulting from a primary or secondary effect of climate change, such as a severe fire or refugee episode, or a disease epidemic.

It seems likely that the mountain gorilla's generalist dietary and environmental needs and strong social structure have allowed it to compensate behaviorally for numerous stressors, including, for example, local environmental changes, encroachment and competition within its habitat, and periodic slaughters and population disruptions. Their general resilience and behavioral plasticity is the likely explanation for this. However, the apparent resilience of mountain gorillas in the face of multiple regional and population changes over the past century does not preclude the possibility that the dramatic reduction in mountain gorilla numbers has caused some reduction in genetic variation in the existing populations, although a reduction in genetic variation in the remaining mountain gorilla populations has not been shown empirically. These potential concerns underlay considerations of health threats to gorillas in the face of climate change.

## II. Snare Injuries and Hunting-Related Threats

It is evident from the MGVP data (Tables 1, 2 and 3) that mountain gorillas are susceptible to ensnarement and gunshot wounds (in rare cases). Snares are set by bushmeat hunters, who are most often targeting forest ungulates, and can injure the hands and feet of mountain gorillas if they are caught in them (Ferris et al., 2005). Gunshot wounds have resulted from people who are targeting gorillas in retaliation (although this is speculative and has never been proven), or to eliminate protective adults in order to take infants into captivity, though these events have been extremely rare in recent years. Hunting within the national parks is illegal in all three countries. While this deters some hunting, it does not prevent these activities entirely. Habituated gorilla groups may be especially vulnerable to both of these threats because they are not automatically afraid of humans. Non-lethal wounds incurred by snares, or other such devices, may or may not be life threatening to gorillas. If wounds are superficial, and the snare does not remain attached to a limb, for example, gorillas appear to heal quickly. Even when snares cause deeper wounds, restricting and sometimes causing loss of a limb or digit, some gorillas have been observed to recover and function well. However, particularly in young or weak individuals, or in cases of tightly restrictive snares, infections are known to set in and if not treated, gorillas may die of sepsis.

### *Anticipated Impact of Climate Change*

These types of injuries are the result of indirect human conflict with gorillas, caused by illegal encroachment into the parks for subsistence (meat) or livelihood (bushmeat market, gorilla infants). If human populations around the parks have more limited access to food and sources of income as a result of climate-change-induced crop or livestock failure, infrastructure damage from extreme weather events, or other climate change effects, more individuals will be willing to undertake illegal activities in order to survive. It is anticipated that poaching activities will increase if food-access conditions become severe in the local human communities.

Greater enforcement of park boundaries, as well as potential establishment of multiple-use/buffer zones in areas outside the parks, where hunting or gathering of other forest resources may be possible, may help to alleviate this pressure, or at least to prevent it from worsening. Prioritizing and intensifying work with local communities to increase farming efficiency and to establish alternative sources of livelihood may also help.

### III. Fight Wounds and Infanticide

Wounds of non-specific origin are also observed and treated in mountain gorillas when they are human induced or considered life threatening. Many of these are thought to be the result of fighting among gorillas, either within or between groups. Generally, fighting between gorillas is known to occur when a silverback dies or is killed, and/or when subordinate males seek access to females within groups. New silverbacks will often kill infants sired by the former silverback (Ferris et al. 2005). Wounds from fighting are sometimes mortal or become so if they become infected.

While this type of fighting is inherent in mountain gorilla social structure, humans may have played a role in increasing its frequency. For example, if a poacher mortally injures a silverback, this has the potential to cause the type of disruption in a group that leads to fights and infanticide.

#### *Anticipated Impact of Climate Change*

If poaching or other forest encroachment increases as a result of increased survival pressures on human communities living near the parks attributable to climate change, this might indirectly cause increased social disruption and fighting among gorillas.

Alternatively, if food, water, or other gorilla resources become limited or more widely dispersed in the region, gorillas may begin to forage further, or move home ranges, potentially forcing increased contact among gorilla groups. It is possible that these spatial movement changes could lead to increased gorilla conflicts. Habituated gorilla movements are closely monitored and all gorilla groups are located and counted in a regular census. However, these data have not been well evaluated to look for patterns and changes in gorilla individual and group densities across the current ranges. New studies of group movements, space use and inter-group encounters as climate change progresses could help with anticipating possible inter-gorilla conflict trends and with the design of monitoring and adaptation mechanisms.

### IV. Respiratory Illnesses

Human-origin pathogens have been shown to be the cause of respiratory disease in chimpanzees, and are thought to be an important cause in mountain gorillas as well (Palacios et al., unpublished data). Observed signs and symptoms of respiratory illness in mountain gorillas are commonly mild, and include runny noses, sneezing, and coughing. In less common cases, gorillas become very ill with more severe respiratory symptoms, lethargy and loss of appetite. Rarely, they develop secondary bacterial pneumonia which can be fatal. Respiratory disease in general has been observed in gorilla individuals from habituated groups, but it is unknown whether or how prevalent it is in un-habituated groups. This knowledge could inform future understanding of the etiology of this type of illness. Sometimes several individuals are sick; other times entire groups or multiple groups will develop symptoms in succession (MGVP, pers. obs.). Although the infectious agent involved in any given outbreak cannot always be determined, individuals with severe symptoms may be treated with antibiotics for a presumed secondary bacterial pneumonia, which has improved the health of the sick gorilla.

In the past nine years, respiratory illnesses have been the second most frequent reason for clinical interventions (after snare removal) and the second leading cause of death (Tables 1, 2 and 3). Although this has not yet been examined statistically, there is no obvious pattern showing an increase in the occurrence of respiratory illness from year to year, or an increase in severity. MGVP veterinarians are currently working to summarize past respiratory outbreaks in gorillas and results to date suggest it is critical to look at seasonal weather patterns, and upper respiratory disease in people living in the area, as well as in the gorillas (Spelman et al., unpublished data). This is an important area of study in the interest of long term potential health risks to mountain gorillas. New occupational health and gorilla conservation standards have provided strong incentives to rangers and others that come into contact with habituated gorillas to stay away from work if ill in any way (Ali et al., 2004). MGVP has recently recommended that all visitors to wild gorilla groups wear surgical masks to help mitigate risk of disease transmission; these guidelines apply to all: tourists, guides, trackers, researchers, and veterinarians should wear masks if within 30 meters of gorillas (MGVP, pers. comm.). This is also in line with the IUCN Best Practice Guidelines for Great Ape Tourism which recommends that all tourists and staff who are likely to approach habituated apes to within 10 meters should wear a surgical quality N95 respirator mask for the duration of their one-hour visit (Macfie and Williamson, 2010).

### *Anticipated Impact of Climate Change*

Although the actual optimal conditions for increases respiratory illness are unknown, investigations are under way to further explore possible links between respiratory outbreaks, seasonality, and proximity to humans (Spelman et al., unpublished data). Because these factors are unknown, it is not possible to know, at this time, the effect that climate change might have, directly or indirectly, on the prevalence of this kind of illness.

Although the relationship between respiratory illness and climate or weather patterns is undetermined, attempts to avoid potential problems may include increased surveillance to further enforce restrictions on contact between humans and gorillas, and to implement and enforce the occupational health policies of the MGVP. It will also be important to build the capacity of the park authorities to develop their occupational health policies to prevent contact between ill employees or tourists and gorillas. In addition, the MGVP have indicated the continued importance of regular and prolonged monitoring of individual gorilla groups in order to observe the more subtle signs of illness onset in order to maximize the effectiveness of interventions. Simultaneously, it is important to support ongoing investigations of the relationship between human illness, gorilla illness, and environmental conditions.

## V. Malnutrition

The exact nutritional requirements of mountain gorillas are unknown. Primary dietary components and some indication of foraging preferences have been described in both the

Virunga and Bwindi populations (e.g., Ganas et al., 2009, Rothman et al., 2007). These indicate that, in general, mountain gorillas will forage for herbaceous and fruit food primarily among the most abundant sources, but in proportion to their nutritional needs. The MGVP has documented only four cases of malnutrition as the cause of death in mountain gorillas, out of 95 deaths in 8 years, but it is difficult to determine the cause in these cases (MGVP, unpublished data).

Studies of precise nutritional content of the very distinct diets of the two populations are ongoing within the habituated groups. Some additional studies have shown that gorillas seek specific nutritional or health elements in certain food items. For example, bamboo is high in protein and its shoots are highly sought-after when they are abundant (Ferriss et al., 2005). The stems of stinging nettle are a common food item in the Virungas. The same plant is sought as an anti-diarrheal by humans in the region. Researchers showed that it has antibacterial activity against at least the enteropathogens *Salmonella B, Shigella flexneri and Escherichia coli* (Nahayo et al., 2008). In another study, Rothman et al. (2006) showed that gorillas will often seek, store, and consume decaying wood, and that the woods actively selected by gorillas contain high sodium levels compared to other food items and to wood that is not eaten. Mountain gorillas have also been observed to consume insects, subsoil sediments, and dung (Ferriss et al., 2005), though nothing is known about the nutritional needs these items might meet. It is likely that there are many other components of mountain gorillas diets that meet specific nutritional and health requirements for the species, about which little is known.

### *Anticipated Impact of Climate Change*

Predictions suggest that climate change will increase the local temperature monotonically and local rainfall significantly, with a possible long or severe intervening drying period. These changing conditions are very likely to alter vegetation within the two forest regions containing mountain gorillas. Because the changes will take place very rapidly, plant species may not be able to adapt evolutionarily or physiologically to the new conditions. If temperatures increase without an increase in precipitation, even for a couple of decades, it is possible that some tree species will senesce and stop growing, fruiting or reproducing as they appear to have done in some other regions (e.g., Jump et al., 2006, van Mantgem et al., 2009). Others may die off completely. New or rare species may rapidly move into the area or become the dominant vegetation. Mountain gorillas are known to have flexible diets and be willing to forage widely to meet their dietary needs (Ferriss et al., 2005). However, it is possible that while basic nutritional dietary components, such as calories, fiber and fat, will be obtained, other nutritional and health needs, ordinarily met by rare dietary items, will not be easily met by readily obtained items. Possible activities that would help to prevent malnutrition include making supplemental sources of trace nutritional elements or food available within the parks. Over the long term, making sure that naturally growing vegetation is able to provide for gorillas' needs, for instance by establishing nurseries and planting programs for food species expected to do well under future conditions, would be more sustainable.

Continuing the research that is currently ongoing to determine gorilla nutritional needs in the wild could provide important information towards this end. Specifically, further focused nutritional research would enable supplemental nutrient programs to be more effective. This might include new research on the nutritional content and palatability of potential food plants likely to do well under the predicted climate changes. Further, ongoing monitoring of the forests including stand ages and growth rates, fruiting and flowering phonologies, and species compositions would allow confirmation or refutation of these suggested changes, and permit early response if necessary. Related research could include monitoring for evidence of phenotypic plasticity and evolutionary potential in currently important plant species, in relation to climate change predictions.

## VI. Parasites, Gastrointestinal Bacteria and Dermatological Illness

The presence of endo- and ectoparasites or dermatological disease in and on individual gorillas can go undetected, and, if present at a large scale, can contribute to that individual's susceptibility to infectious illness, nutritional deficiencies, opportunistic septicemia, or other health challenges.

Several studies have sought to identify gastrointestinal parasites in mountain gorillas. Most of this work has been carried out on Bwindi gorillas, so less can be said about the Virunga population. Rothman et al. (2002) found strongylid eggs in many individuals, suggesting these represent *Trichostrongylus, Oesophagostomum, Hyostrongylus, Impalaia, Paralibyostrongylus* or, *Murshidia*. They also found the larvae of a pinworm, *Probstmayria*. No evidence of human parasites was found in this study. The liver round worm, *Capillaria hepatica*, was found in rodents in Bwindi; this worm is known to be found in many mammal hosts, including some primates (Makanga et al., 2004), and has been diagnosed in mountain gorillas at necropsy (MGVP). Several bacterial infections were identified in fecal samples from Bwindi gorillas, including *Campylobacter* spp., *Salmonella* spp., and *Shigella* spp (Nizeyi et al., 2001). All of these are known to also occur in humans, and the prevalence of the bacteria in gorillas increased in members of habituated groups. In another study, the prevalence and type of *Escherichia coli* in fecal samples of gorillas, livestock and humans around Bwindi Impenetrable National Park was estimated. This study showed that not only did the prevalence increase in gorillas that were near infected livestock and humans, but the *E. coli* found in livestock and humans were more genetically similar to those found in geographically proximate gorilla groups than in those found in more distant groups. Further, many of the strains found in habituated gorillas were antibiotic resistant. The presence of multi-antibiotic-resistant strains in gorillas strongly implicates nearby livestock as a source of infection, as the livestock are commonly administered many and large doses of antibiotics (Rwego et al., 2008).

While these studies and cases are not conclusive, there are strong implications that contact with and proximity to humans and livestock increases the prevalence of endoparasites and bacterial infections in gorillas. If the *E. coli* study is indicative of other bacteria, many of the infections are antibiotic resistant, which increases the risk to gorillas.

### *Anticipated Impact of Climate Change*

If poaching or other forest encroachment increases as a result of increased survival pressures on human communities living near the parks, then it is very likely that the potential for cross-infection of all of these and other infectious agents will increase between gorillas and humans or livestock. Climate conditions that favor specific parasites or bacteria may be available in the parasitology and bacteriology literature; however, if changes occur such that any one of these parasites or bacteria is favored, the rate and severity of infection could increase, resulting in nutritional, metabolic, or immune stress on the infected gorillas. This, in turn, could increase the gorillas' susceptibility to any other illness or infection. Attempts to alleviate this potential threat could include increased surveillance of the parks to minimize or avoid illegal contact between humans and gorillas, to carry on or increase the occupational health policies of the

MGVP to prevent contact between ill employees or tourists and gorillas, to build the capacity of the park authorities to develop their occupational health policies to prevent contact between ill employees or tourists and gorillas, and to simultaneously support monitoring of parasites and bacterial infections in gorillas, humans, and livestock.

## VII. Cancers, Genetic Disorders, and Organ Failure

MGVP has documented rare cases of death by cancer, organ failure, or genetic disorder. In humans, cancer has various etiologies including but not limited to virus, toxin, and can be heritable. This is likely true for gorillas as well. Heritable tendencies for cancer, organ failure, or other genetic disorders are expected to increase in small, inbred populations. Remarkably, in spite of the low population numbers of mountain gorillas, which have been sustained for at least half a century, signs of inbreeding depression are not obvious in these gorillas.

### *Anticipated Impact of Climate Change*

It is possible that recessive genetic predisposition for cancer or genetic disorders may be thinly disguised by the current favorable conditions for population growth. Under the conditions of climate change a range of factors including dietary stress, increased non-lethal assault by viral, parasitic, and bacterial infections, or other disruptions could potentially weaken the immune systems of mountain gorillas. Under such conditions, the consequences of genetic predispositions for disorders of various types could become apparent. If there are underlying genetic weaknesses in these populations which will be challenged and exposed by changing environmental and health conditions, little can be done to change this. It is possible that the best practices continue to be efforts to limit contact with humans and livestock, provide veterinary support where possible, and monitor the populations.

## VIII. Other Threats: Filoviruses, Ebola and Marburg

Ebola and Marburg are viruses that cause hemorrhagic fevers in humans and non-human primates. Besides severe impacts on human populations, several outbreaks of the Ebola virus since 2000 are thought to have killed thousands of great apes in western Central Africa. To date, the mountain gorillas have not been affected. There is only one species of Marburg virus, genus *Marburgvirus*, known from the region of Lake Victoria. There are five known species of the genus *Ebolavirus*. The most recent species, *Bundibugyo ebolavirus*, was isolated from an outbreak in Uganda (CFSP, 2009). The most common carriers for these filoviruses are bats which appear to infect primates sporadically, although the viruses have also been found in small non-flying rodents and insectivores. The mortality rate varies for a variety of reasons, thought to include at least viral strain and environmental conditions, but some infections have had up to 90% mortality. Incubation periods can range from 2 days to 21 days, and symptoms often appear in 2 to 10 days. The viruses are shed in all bodily fluids and sick individuals can be infectious for months (at least in the case of the *Zaire ebolavirus*).

### *Anticipated Impact of Climate Change*

Although there has not been an outbreak among mountain gorillas, the proximity of at least two species of filovirus to the parks indicates that it is a potential threat. There is some promise of the development of a class of vaccines that could work on a whole suite of filoviruses

(Swenson et al., 2008). Although specific links between climate and the transmission, mutation rate, or virulence of filoviruses is unknown, it is possible that it could have an influence on these factors.

## IX. Other Human Infectious Diseases

Tuberculosis and other infectious agents have the potential to cross over to mountain gorillas, given the genetic similarity between gorillas and humans. These diseases and others known to reach epidemic proportions in humans, especially under stressed, overcrowded, malnourished, or other conditions, could become an imminent threat to gorillas. Further, although gorillas are not susceptible to human immunodeficiency virus (HIV), for example, an increase in HIV infection among local human populations will mean an increase in rates of infection by various opportunistic pathogens of humans that could potentially spread to gorillas.

*Anticipated Impact of Climate Change*

Indirectly, if human health conditions were to decline as a result of climate change stressors, then the rate of HIV or other infectious disease spread among local human populations could increase. Although also unknown, it is possible that climate change stress will cause a large increase in human encroachment on the forest, which would increase the potential for transmission of infectious agents to gorillas. The best preventative actions may be ongoing monitoring of gorillas, humans, and the regional scale health situation. In addition, intervening where possible to both minimize contact between humans and gorillas, and maintain general health of the gorilla populations will be the best defense against new disease challenges.

## X. Summary Comments

Although every possible health consideration cannot be anticipated or controlled, the overriding conclusion of this review is that there currently seems to be little evidence for strong links between climate change and gorilla health. There are plausible connections between climate change and some health issues—namely viral diseases, malnutrition, and any issues related to human incursion into the parks—suggesting that these issues may deserve particular attention in monitoring programs. In light of clear-cut concerns, the MGVP One-Health approach is to ensure the health of humans and livestock coming into contact with gorillas, and to monitor and follow up on emerging problems perceived in gorillas. This seems a good approach to limiting overall vulnerability of gorillas and identifying emerging health concerns in a timely fashion. In addition, monitoring of regional health issues of humans, livestock, and other possible reservoir species could provide a clearer picture of links between climate and infectious disease in these other species, as well as some warning before infections reach the vicinity of the gorillas.

The MGVP is serving as the Uganda and Rwanda country leaders for a 5-year grant awarded to the UC Davis Wildlife Health Center (WHC) by the US Agency for International Development's Emerging Pandemic Threats (EPT) program. The EPT is aimed at pre-empting or combating new zoonotic diseases in wildlife that could spark future human pandemics. The WHC has been tasked with implementing the EPT's PREDICT project, which will conduct surveillance in 24 countries around the globe for newly emerging diseases in high-risk wildlife (especially primates, bats and rodents) that could pose a major threat to human health in 24 countries around the globe. The emphasis of field activities will be on sampling and testing wildlife at high-risk interfaces, such as places or situations where people and wildlife come into close contact. This program will not only generate important data for preventing human pandemics, but will also increase capacity in all countries for wildlife disease surveillance. MGVP's Dr. Benard Ssebide will serve as PREDICT country coordinator in Uganda; and new MGVP veterinarian Dr. Julius Nziza will serve as PREDICT country coordinator in Rwanda.

On the preventative side, work that is currently ongoing to understand nutritional requirements, trace needs, and potential vegetative changes within the parks will undoubtedly help to provide guidance to conservation teams. Taking measures to maintain adequate natural food supplies (e.g., by breeding more heat- or drought-tolerant strains) as the climate changes is preferable in the long term to artificial supplements. Maintaining the general good health of individual gorillas will go far to minimizing the possible negative effects of climate change.

**Table 1**
**MGVP Interventions in Virunga and Bwindi from 2000 to 2009 (MGVP, unpublished data)**

| | **Park** | | |
|---|---|---|---|
| **Reason of intervention** | **Bwindi** | **Virunga** | **Grand Total** |
| Recover infant | | 3 | 3 |
| Rescue | | 4 | 4 |
| **Respiratory** | **1** | **20** | **21** |
| Return orphan | | 1 | 1 |
| **Snare removal** | **2** | **24** | **26** |
| Surgery | | 1 | 1 |
| Treat illness | 1 | 10 | 11 |
| Treat infant | 2 | 11 | 13 |
| Wound care | | 15 | 15 |
| **TOTAL** | **6** | **89** | **95** |

**Table 2**
**Recorded mountain gorilla deaths from 2000 to 2009 (MGVP, unpublished data)**

| | **Park** | | |
|---|---|---|---|
| **Year** | **Bwindi** | **Virunga** | **Grand Total** |
| 2000 | 1 | 4 | 5 |
| 2001 | | 3 | 3 |
| **2002** | **3** | **14** | **17** |
| 2003 | | 6 | 6 |
| 2004 | 4 | 7 | 11 |
| 2005 | 3 | 11 | 14 |
| 2006 | | 11 | 11 |
| **2007** | **4** | **11** | **15** |
| 2008 | 1 | 7 | 8 |
| 2009 | 4 | 6 | 10 |
| **TOTAL** | **20** | **80** | **100** |

**Table 3**
**Cause of Death (MGVP, unpublished data)**

| | **Park** | | |
|---|---|---|---|
| **Cause of Death** | **Bwindi** | **Virunga** | **Grand Total** |
| Cardiac | | 2 | 2 |
| Developmental | | 2 | 2 |
| Disappeared | | 2 | 2 |
| **Gun shot** | | **9** | **9** |
| Hypo-nutrition | 1 | 3 | 4 |
| **Infanticide** | **1** | **6** | **7** |
| Liver failure | | 1 | 1 |
| Metabolic | | 1 | 1 |
| Neoplasia | | 1 | 1 |
| Neurological | | 1 | 1 |
| **Respiratory** | **2** | **11** | **13** |
| Scabies | 1 | | 1 |
| Septicaemia | 1 | 1 | 2 |
| Snare | | 1 | 1 |
| Still born | | 1 | 1 |
| **Trauma** | **4** | **13** | **17** |
| **Unknown** | **10** | **25** | **35** |
| **TOTAL** | **20** | **80** | **100** |

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# 5.0 Climate Change and Socio-Economic Issues in the Albertine Rift

## I. Introduction

The impacts of climate change will increase the challenge of ongoing poverty alleviation efforts in the concerned areas of Uganda, Rwanda and the Democratic Republic of Congo (DRC). Communities with close dependence on natural resources and natural-resource based livelihoods will be the hardest hit. Particularly high vulnerability can be expected among the most climate sensitive livelihood systems, namely agriculture (crops and livestock), forest products and fisheries. Within these systems, groups already marginalised and least able to adjust (e.g. through migration, changing livelihood sources) will be at highest risk, notably women, children, the elderly and the disabled.

This Chapter of the White Paper summarises some of the key articles available in the literature, addressing questions raised and discussed at the Climate Camp workshops held in September 2009 and February 2010. It looks at linkages between mountain gorilla conservation, climate change and human well-being, but does not claim to provide a thorough or technical review of the subject; as such a review was beyond the scope of the White Paper process.

## II. Background

A great deal of socio-economic research has been conducted over the past decade in the mid-Albertine rift area. However, only some of this data has been available to the project team, and we recommend that a further collection and assessment of data would be valuable. This chapter presents our initial findings, based principally on three important research papers, augmented where possible from additional sources. The three papers are:

- Bush et al., 2004
- Hatfield and Malleret-King, 2007
- Plumptre et al., 2004

These studies tell us much about the livelihoods of people living close to mountain gorilla habitat, about their perceptions of and attitudes to conservation efforts and the pressures they are under. Though none of these studies directly assesses vulnerability or adaptation to climate change, they do go some way towards indicating possible socio-economic impacts and responses.

The studies indicate that uses of biodiversity in the mountain gorilla ranges are both consumptive (food, fibres, fuel, shelter, medicinal, wildlife trade) and non-consumptive (ecosystem services and the economically important gorilla tourism). They also highlight that the principal recent driver of biodiversity's vulnerability to climate change is the reduced area of forest habitat, driven principally by continued growth in demand for agricultural land. Various analyses have tried to establish the goods-and-services values that these forests deliver locally, nationally and internationally, in order to ensure the policy framework takes these into account. While the full socio-economic value of forests in the mountain gorilla ranges is generally understood to be high, many of the benefits from forests are difficult to quantify, particularly the ecosystem services of soil, water and climate protection, and this complicates our ability to assess the socio-economic impacts of climate change and potential adaptation priorities.

A study for the Wildlife Conservation Society (WCS) (Bush et al., 2004) estimated that the total economic value of Rwanda's forests was more than $267 million per annum (p.a.), with the bulk of this accounted from carbon, and highlighted the need for additional, more detailed valuation studies, particularly given the need to differentiate among international, national and local costs and benefits. Hatfield and Malleret-King (2007) estimated that the opportunity cost of the forest in terms of farming income is in the order of $50-$140 million p.a. They found that 90% of total annual net benefits of $200 million p.a. derived from the mountain gorilla forest system is attributed to 'international non-use values,' namely the forest benefits (of biodiversity, carbon, existence) delivered to the international community (and therefore potential future revenue streams), and that most of the remaining 10% flows from gorilla tourism. They conclude that the forest should be protected, because the international and national values of their conservation greatly exceed the local costs, but that local benefits must be increased (Hatfield and Malleret-King, 2007).

**Valuing the Mountain Gorilla Forests**

It is common belief in many circles that the long-term interests of not only global but national and, in particular, local society will be better served by conserving rather than converting these forests. As such, they remain undervalued.

One reason for this is that forests tend to be undervalued on a global scale. It is increasingly recognised that forests provide significant benefits which to date have received little attention, either due to lack of knowledge or difficulty in quantification. Primary amongst these is the value of the ecological services provided by the forests – for example, the benefits to agricultural production of climate control; regulation of water flow; and soil retention; or the wider benefits of atmospheric pollution control. Other less obvious but highly-valued benefits include amongst others: biodiversity value (including flora, fauna, and invertebrates); aesthetic value; value to future generations; and ethical value.

A second reason involves the social context within which the forests exist. Since the relationship between economic and ecological systems is necessarily dictated by human perception, the value of a resource is subject to the socio-political-economic landscape – the forces of which can mitigate in favour of, or against, conservation both in the short-term and the long-term. The social context surrounding the Virunga and Bwindi forests does not favour long-term conservation. The challenge for conservationists is to explore mechanisms that meet conservation goals while gaining long-term approval within the social and economic context.

Source: Hatfield and Malleret-King, 2007

Each of the following questions is considered in light of its relevance to mountain gorilla conservation.

- Will climate change lead to increased pressure on park boundaries?
- What impact will climate change have on gorilla tourism, and in turn, on funds generated for gorilla protection?
- What impact will climate change have on crops and husbandry techniques, and could this create increased pressure on the parks and mountain gorillas?
- How will climate change affect human population and settlement patterns, and would new patterns affect parks or mountain gorillas?

- How will forest-dwelling ethnic minorities such as the Batwa be affected differently if climate change affects the forests shared with mountain gorillas?
- How will use of forest products and water resources be affected by climate change, and how might changes in use affect mountain gorillas?

For the purpose of this chapter, the following are identified as the main socio-economic parameters affected by climate change:

- Demographic trends – population growth and migration
- Human settlements and infrastructure
- Human health

In turn, the following are the main natural-resource linked livelihoods activities affected by climate change:

- Agriculture – crop and livestock production
- Gorilla tourism
- Forest use
- Fresh water and fisheries

In the sections below we discuss, for each of these parameters and activities, what is known about the current baselines in the target area, the likely impact of climate change as modelled by the project scientists, the possible adaptation responses and areas of further research needed. We then add a section on policy responses to address issues of transboundary management, planning processes and land tenure. The final section presents some conclusions.

## III. Projected Climate Change

Essentially, as recorded in Chapter 2, climate models predict that target area is expected to experience increasing temperatures and lower rainfall for the next two decades, followed by steadily increasing temperature and rainfall through the rest of the 21st century. However these trends will vary greatly between local areas, and more detailed forecasts will shed more light on likely socio-economic adaptation trends.

## IV. Demographic Trends

The Albertine Rift is among the most densely populated regions in Africa due to its fertile soil and climate that favours farming; even the regions abutting the mountain gorilla protected areas have very high population density (Figure 1). An estimated 1.3 million people live in the region. The high density reflects the ongoing need for post-genocide resettlement in Rwanda and the impact of refugees from war in DRC. For instance, Kabale district in Uganda is estimated to have a population density of 290 people/km$^2$ (Plumptre et al., 2004). Rwanda, Ruhengeri and Gisenyi provinces are estimated to have a population density of 537 people/km$^2$. Bwisha (in DRC) is estimated to have a population density of 254 people/km$^2$. The net effect of these high population densities has been excision of forested/conserved land and high land fragmentation, with growing pressure on natural resources leading to over exploitation.

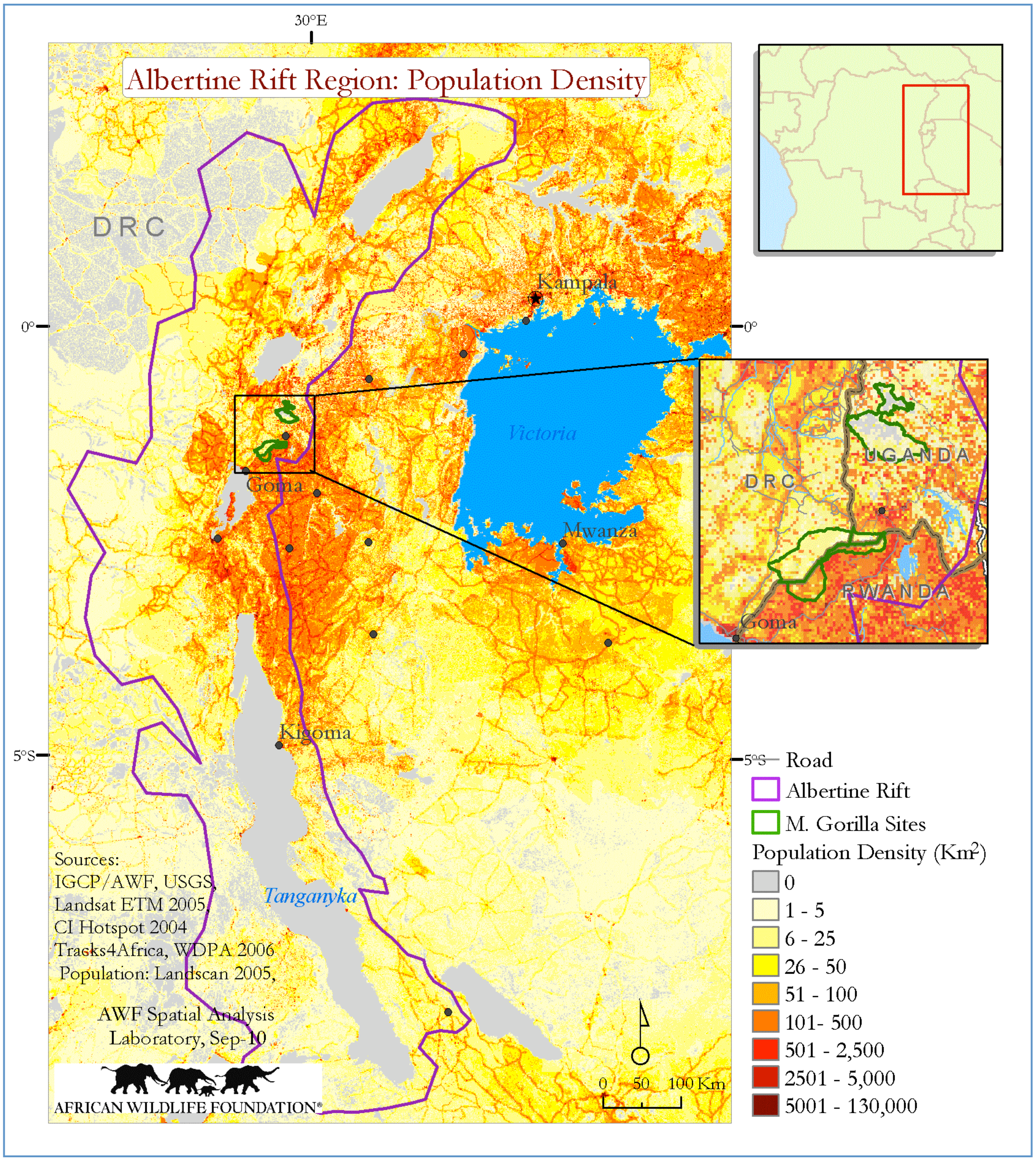

Figure 1: Albertine Rift – Human Population Density Map, adapted from Dobson et al., 2000.

A common assumption among social scientists working in the region is that increases in population density have led to a decrease in average farm size.

The intense need for agricultural land in this area has been the main threat to mountain gorilla habitat and, over time, has forced the remaining gorillas higher up the volcanoes. In Rwanda land scarcity has resulted in the excision of various tracts of conservation land over the past thirty years including the degazettement of 30% of Volcanoes National Park in the 1970s for European Union- sponsored pyrethrum production, and, more recently, allocation of large parts of Akagera National Park for post-genocide resettlement.

Surveys performed this decade of the socio-economic status of people living within ten miles of the mountain gorilla forests in Rwanda, Uganda and DRC showed high mortality (attributable to poor health care access and high HIV infection rates) and high emigration rates

(Plumptre et al., 2004). These communities have little capacity to engage in conservation activities such as soil and tree management. The Batwa communities were found to be similarly affected, though with even higher mortality rates given very limited access to or use of modern health care (Bush, 2005). The socioeconomic surveys found the demographic structure of communities indicated that many people were living below the poverty line. These people tend to bear the costs of protected areas and conservation activities without having access to the benefits, for example, from gorilla tourism. They, therefore, develop negative attitudes towards conservation when forest access is restricted (Plumptre et al., 2004). Park-edge households do not plant trees as they believe this creates a habitat for animals leaving the parks and raiding crops in adjacent fields. However, where buffer zone plantations create resource use or employment opportunities (e.g. around Nyungwe National Park, Rwanda), local communities had a more positive attitude toward conservation. Poverty is the biggest underlying threat to forest conservation in the mountain gorilla range states, with rural development and poverty alleviation activities the primary intervention needed as identified by governments, conservation and development organisations alike (Bush, 2005).

Poverty in the region is disproportionately concentrated among households whose primary livelihood activity is agriculture, with 40% of the poorest households in Rwanda owning less than 0.2ha of land and the majority of poor households having no alternative livelihood source (reported by Bush et al., 2004 as taken from EICV results). Landholdings in Uganda are typically larger on average (Hatfield and Malleret-King, 2007). The Batwa have no access to agricultural land because of a tradition of forest-dwelling, and are among the poorest.( Bush, 2005) The poorest are particularly vulnerable to climate change, and tend to be excluded from efforts to improve benefits – "even the most grassroots community based organizations have been found to exclude the poorest people" (Plumptre et al., 2004). High poverty levels constrain the scope for climate adaptation.

Conservation strategies adopted by government and partner agencies reflect widespread understanding of these structural demographic constraints, with heavy emphasis on improving agricultural livelihoods, strengthening access to alternative livelihoods and addressing the issue of land scarcity. Predicted warming and drying over the coming two decades is likely to increase incentives for outmigration, depending critically on its impact on agricultural productivity.

## V. Human Settlements and Infrastructure

Climate change will have significant impacts on human settlement patterns and on infrastructure. Past and future forest clearance to allow space for human settlements increases the risk of landslides in periods of heavy rainfall. Higher rainfall is likely to exacerbate management problems relating to pollution, sanitation, waste disposal, water supply, public health and infrastructure as reported in Kundzewicz et al. (2008). Excessive precipitation is likely to have serious negative effects on the road network in Central Albertine Rift, making roads periodically impassable due to floods and landslides. This will affect local and national economies. Remote local communities will be more frequently cut off from each other, increasing vulnerability to disease and food shortages and leading to escalation in prices of basic goods and services.

The Albertine Rift, home to many refugees following wars in the region, is likely to see further migration resulting from climate change. As with the large numbers of conflict-displaced refugees living in the Gishwati forest region, the pressure for use of forested areas is likely to increase with climate change, either slowly or rapidly following an extreme climate event such as floods or drought. The risk of rapid future deforestation is a grave threat to mountain gorillas.

## VI. Human Health

Climate change is thought to have already had direct and indirect impact on disease in the wider region, notably on the climate sensitive diseases of malaria, tuberculosis and cholera and other diarrhoeal diseases. A case in point is the 1997-1998 El Nino event which led to an outbreak of malaria, Rift Valley fever and cholera in East Africa (Desanker and Magadza, 2001). Kundzewicz et al. (2008) projected that climate change will lead to pathogen load increase due to more heavy precipitation events in areas without good water supply and sanitation infrastructure.

Rising temperatures in the mountainous parts of Central Albertine Rift will change the geographical distribution of disease vectors. For instance, malaria mosquitoes may migrate to the mountainous parts, exposing malaria to a population that was previously not exposed to malaria infections. Lieshout et al. (2004) have shown that climate-induced changes in the potential distribution of malaria are projected in the poor and vulnerable regions of which the Albertine Rift is part.

In addition to malarial, as well as numerous unknown potential risks to human health posed by new environmental conditions brought on by climate change, the connection to mountain gorilla conservation is direct. Because of their close relationship to humans, gorillas are known to be susceptible to most human illnesses. Proximity to new disease vectors, as for humans, will increase risks to gorillas (see Chapter 4 for further discussion of this issue). In addition, the increased likelihood of human incursions into protected forests and of human settlement within forest areas implies increased contact between gorillas and humans, thereby directly increasing the threat to the health of gorillas.

## VII. Agriculture

The three studies on which this Chapter is based contain much detail about agricultural practices across the communities living close to mountain gorilla habitat. Farms in Rwanda average less than one hectare of land, with subsistence farming still the main land use. Farms in Uganda are larger on average. In all three countries communities cite lack of non-agricultural livelihoods as a serious constraint to both poverty reduction and conservation (Hatfield and Malleret-King, 2007). Crops include food staples such as beans and sorghum, supplemented by sweet potatoes, cassava and peas. Coffee and tea are important cash crops. Access to rural credit is constrained (Plumptre et al., 2004). Few poor households sell any of their agricultural produce (none in the poorest quintile), with food storage as the basic form of food security for most households.

The progressive conversion of pasture into cropland has caused a reduction in average household livestock production, and a parallel decline in the amount of manure available for improving soil fertility (Plumptre et al., 2004). Hatfield and Malleret-King found that more than 70% of households in Rwandan communities have livestock, compared with less than 50% in DRC communities, in spite of the fact that on average, households make five times more net income from crops than from livestock. They estimate an overall average annual net income of

$436/hectare for forest-adjacent communities from crops, livestock and woodlots (Hatfield and Malleret-King, 2007).

Production of food crops is mainly for subsistence use with the surplus sold to neighbouring towns. Arable land sub-division has led to insufficient food production, despite more than 90% of the population practising agriculture as the main activity. In fact, the period October-November and April-May of each year are characterized by food shortage, malnutrition and low income among the local population (Plumptre et al., 2004). Land is rarely left fallow due to scarcity of arable land.

Climate change is likely to have widespread and potentially catastrophic impacts on agricultural systems. Forecasts of steadily increasing temperatures, lower overall rainfall in the near term, and more variable rainfall with more frequent storms threaten this region of high poverty and climate vulnerability. There will be shorter growing seasons and lower yields, as well as a general decline in the production of most subsistence and cash crops, though it is possible that faster adapting and better adapted crops can be introduced. Following this dry period, overall rainfall will increase far beyond present levels, which is likely to increase erosion of the newly dried hillsides, and cause new and further stress on whatever crops have persisted to that point.

Increase in temperatures threatens the production of high altitude and cool temperature crops such as tea. According to Desanker and Magadza (2001), increases in local temperatures will have detrimental effects on sensitive development stages such as flowering, thereby reducing grain yield and quality.

Climate change is likely to reduce the quality of grazing and increase animal diseases, leading to a reduction in numbers of livestock. Areas that are currently marginal could become unsuitable for agriculture in the near future. However, with proper planning for heat resistant grazing fodder and retention of topsoil, the following wet period could prove to restore grazing potential to the region.

## VIII. Gorilla Tourism

The Plumptre et al. surveys (2004) found that gorilla tourism was perceived as very useful to the national economy, but of limited value locally, possibly in part attributable to high population densities diluting benefits. Limited connection was made between tourism and other park benefits such as revenue-sharing. Hatfield and Malleret-King agree. They find that the bulk of the estimated value of the mountain gorilla forests – of $200 million p.a. – is due to ‘international non-use values’ (ecosystem services provided internationally through protection of carbon, biodiversity etc.) and gorilla tourism. They estimate the value of mountain gorilla tourism using the travel cost method as over $21 million p.a. in total (including internationally) with net income of $3.7 million p.a. in Parc National des Volcans, $6.9 million p.a. in Bwindi and $3.0 million p.a. in Mgahinga (2005 figures), of which about $1 million p.a. accrues to local communities (through payments, employment, other benefits), clearly not enough to balance local costs of conservation. Structured interviews with community members generated lists of costs and benefits associated with gorilla tourism, with the two main concerns identified as the creation of a new landless class (those who had sold their land for tourism facilities), and the need for better planning to ensure protection of the poor and good long-term planning of development activities at community level (Hatfield and Malleret-King, 2007).

A growing examination of biodiversity-poverty linkages helps inform the level of local vulnerability to climate change. In a recent presentation, Sandbrook (2010) stated that conservation organisations use gorilla tourism as one of several integrated themes to address conservation-poverty linkages, with others include community-based natural resource management activities, health and family planning, law enforcement, strategies to reduce human-wildlife conflict, working with the forest industry and payments for ecosystem services (notably forest carbon sequestration). While some of these activities reduce or alleviate poverty, others (e.g. law enforcement) can exacerbate it. He emphasises the difficulty of impacting poverty through conservation activities when human population levels and densities are so high.

Rising temperatures and rainfall variability in combination with other stressors such as deforestation could result in shifting of ecological zones and of species, including the mountain gorilla. It is speculated that a reduction in winter rainfall or increase in summer rainfall would alter the fire regime which is critical to the life cycle of these species, as well as to preservation of forest, per se. Any reduction in or migration of the mountain gorilla population would have serious economic impacts nationally and locally because of the loss of tourism dollars.

## IX. Forests and Protected Areas

There is a wide literature assessing the impacts of protected areas on local communities. Vulnerability of local people increases with levels of poverty and the degree of dependence on natural resources, and are highest for forest dwelling people. People living close to protected forests tend to use them as part of the local resource base available for securing livelihoods. This is particularly true of communities living in isolated areas with limited access to markets and infrastructure. One study (Bush and Mwesigwa, 2007) found that less than half of those interviewed thought that Bwindi Impenetrable Forest National Park had a beneficial impact on them, despite largely agreeing that it did protect ecosystem services (notably rainfall) and bring NGO investment and better healthcare. The study found that problems of crop-raiding, lost access to resources and outmigration as a result of deteriorating opportunities more than outweighed any benefits for most respondents.

According to the Congo Basin Forest Partnership (CBFP), over 168,000 people have invaded Virunga National Park over the last seven years, thereby degrading 90,000 ha (van de Giessen, 2008). Although a number have been relocated elsewhere, 50,000 people still live in the Kilolirwa area and 30,000 on the western shore of Lake Edward inside Virunga National Park. Although this situation is highly understandable from the viewpoint of the internally displaced people in the region, it is a major threat to efforts to protect the biodiversity in the Central Albertine Rift. Around Bwindi Impenetrable National Park (Figure 2), the current situation is much more stable, as arrangements have been made between the Ugandan park authorities (Uganda Wildlife Authority, UWA) and the local communities. People are allowed to gather products from the forest in some areas of the park; this can be done in the so-called Multiple Use Zones (MUZs). The products that can be extracted in these zones are medicinal plants, craft materials and seed collection for on-farm planting outside the park. In addition, some farmers are allowed to use the park for placement of beehives for honey collection. These MUZs are only accessible for those surrounding communities that have signed a Memorandum of Understanding with the UWA.

Evidence suggests that in these mountain gorilla ranges, forest resources are vital for filling the 'hungry gap' between running out of home produce and collection of the next harvest (Bush et al., 2004). A study of household use of protected forest in Uganda showed a significant positive correlation between the time of year when the forest is used most and when cash/food is needed most (Bush et al., 2004).

**Assessing social perceptions of forest conservation – discussion from 2003 surveys of communities in Rwanda, Uganda and DRC**

It is clear from the study results that people living around these forests derive benefit from the use of the forests. A consistent desire to have access to the forests and harvest forest products was expressed by all people but in particular by the Batwa communities. The problem the conservation community faces is that granting access to everyone living around the forest will lead to the degradation of the forest. These are some of the most biologically rich forests in Africa and as such are globally important for conservation. Where people are allowed access to the forest and where law enforcement is low, in Echuya (2 guards for the forest), 74% of households and 100% of the Batwa living there admitted to harvesting products from the forest. Law enforcement at the other sites combined with education has reduced the percentage of households admitting to accessing the forest to 13-22%. Around Bwindi and Mgahinga a reasonable number of households had practiced on-farm substitution, having been encouraged by development projects but elsewhere few households practiced this. Many people cited lack of land and the fact that they would have to reduce the food crops they planted as a reason not to practice on-farm substitution.

Many hundreds of thousands of dollars have been put into Integrated Conservation and Development Projects (ICDPs), a trust fund and other activities to improve community relations around Bwindi and Mgahinga forests and yet the percentage of people admitting to accessing the forest illegally in these two (13-19%) was not very different to other areas (Nyungwe, PNV and Virunga) where law enforcement has occurred (14-22%). Working with communities bordering the forest may not completely reduce the illegal activities but may lead to better relationships with the protected area authorities, which allows less aggressive tactics in dealing with illegal activities. It would be expected therefore that Mgahinga and Bwindi would have more respondents claiming that relations between themselves and the protected area authorities have improved and this is the case. However, there were also more people around these two protected areas who believed that relationships had deteriorated than around the other protected areas where they believed the relationships to be stable. This should be of concern to those development projects that have been working in this region. It is possible that people may see their neighbours benefiting from the projects associated with the park and perceive they are losing out, even though in reality they may be better off than forests where no such projects occur. It is also possible that the effects of law enforcement activities are considered more important than the benefits this group of people receive around these forests. It is also possible that people living in this region have been given the possibility of voicing their concerns about the park and tend to be more outspoken than in Rwanda or DRC as a result or because they perceive that by complaining they may receive more benefits in future.

Failure to enforce park and forest protection regulations for political, social and economic reasons means that local people are used to being able to access protected forests to use resources, and protected forests are threatened by this failure to restrict access. Rwanda has acute national fuelwood shortages, for example. Deforestation has increased fuelwood costs, reduced supply of non-wood products, negatively impacted watershed and soil protected and reduced biodiversity availability, each of which has negative socio-economic impacts (Plumptre et al., 2004). Hatfield and Malleret-King found that, with the exception of Mgahinga, the majority of communities consulted had woodlots, though many (40% in Rwanda) still depended on buying fuelwood.

Pressure on forest resources in the area continues to grow despite the actions of governments and NGOs to intervene in forest dependency for the western section of Virunga National Park in DRC. Population growth and poverty levels are such that dependency on fuelwood and forest foods for the 'hungry gap' is increasing. Climate change is likely to increase pressure on forest resources in the area, particularly as pressure on agricultural systems increases.

It is not known what impacts climate change will have on forest resources themselves. The heat, drought, and moisture tolerance of most forest species of both plants and animals are unknown. Much of what is expected to change are not only the temperature and rainfall minima and maxima, but the timing and duration of rainfall events, and resulting cloud formation. Studies are underway to begin to monitor pollination and phenology of key forest resources in limited locations, and more are recommended (see Chapter 3 of this report).

## X. Fresh Water and Fisheries Resources

Pressure on freshwater systems has increased, with high demand for fish and water. Plumptre et al. (2004), report that swamps have been drained to reclaim agricultural land. Intensive crop production has increased erosion from farms causing more sediment transport to the lakes and rivers. The volcanic geology of the area means that water runs off quickly and the forests play an important role in maintaining a steady supply of surface water. However, in drier months the parks become home to permanent water sources which are in high demand locally; with local people entering parks to access water with the tacit approval of parks authorities.

Ruckstuhl (2009) has reported conflict arising from the competing fishing interests in the region, notably fishing access rights of Nyakakoma village on Lake Kivu in DRC (Ruckstuhl, 2009); a decreasing per capita availability of fish due to over-fishing, and water scarcity due to climate variability.

Climate change has serious implications for water resources and regional development in the area. A rise in temperature will lead to higher evaporation, unless the rivers are compensated by increased precipitation. High evaporation reduces runoff leading to increasing water scarcity and stress with a subsequent potential increased risk of water conflict over declining water volume, water quality and fish in rivers and lakes. A reduction in water volume would curtail hydropower generation from rivers and increase household dependency on fuelwood, which is one of the causes of forest degradation.

## XI. Policy Responses

Putting in place transboundary management arrangements and institutionalising them has been a major policy success story in the region. The three protected area authorities - the Uganda Wildlife Authority (UWA), Rwanda Development Board (RDB) and Congolese Institute for Nature Conservation (ICCN) – have, with IGCP's support, created the combined Greater Virunga Transboundary Collaboration (GVTC) as their co-ordination mechanism with the Transboundary Core Secretariat as one of its main implementing institutions. The Secretariat is now a legitimate entity which seeks to ensure a harmonized approach to wildlife conservation in the area, develops strategies for transboundary natural resource management, plans, evaluates and monitors transboundary projects, and secures stable and sustainable financing for biodiversity conservation and management of the local protected area network. It is therefore a critical institution in the assessment of mountain gorilla vulnerability to climate change and for encouraging appropriate adaptation.

Planning processes in all three countries differ greatly. In Rwanda the rapid move towards decentralisation and positive engagement with the private sector as a means of promoting locally driven economic growth may increase vulnerability to climate change, for example through unplanned gorilla tourism development and a failure to address the problems of agricultural land scarcity and forest and land degradation.

After very long deliberations, the Rwandan Parliament in 2003 approved a Land Reform Decree that provides for individualized rights to property. This policy was followed, in 2005, by passage of the Land Law. The Land Law abolishes all customary forms of tenure. In their place, the government issues titles for 99-year leases of land. The government claimed that this new tenure system would contribute to enhancing food production, social equity and cohesion and the prevention of conflict. Land has always been a very important and highly contested resource in the region. As noted in many earlier studies, land has been closely related to politics and conflict for at least four decades. Although the conflicts in Rwanda of 1959, 1963, 1973, 1980, 1990, and the genocide of 1994 were all politically motivated by politicians, evidence has shown that fertile land was a large factor behind social tensions before these erupted into violent conflicts. The same holds true for the conflicts in the Ituri region and, to a lesser extent, the Kivu provinces in DRC.

The struggle for land is very intense and land scarcity is increasing. Therefore, in order to prevent further social and violent conflicts, improving land security is one of the most urgent agenda points for the Rwandan and DRC governments. In keeping with the goal of protecting mountain gorillas through the predicted extreme transition period, continued protection of gorilla parks and any additional land deemed critical for gorillas to survive the shift in their resources, should also be an urgent agenda item for these governments.

## XII. Conclusion

The people of the region are some of the poorest in Africa. Significant numbers of them depend on forest resources, particularly for energy. High human population densities have led to a situation where almost every piece of available land is in use, including steep hill slopes and swamps, which are drained and transformed into farmland. Livelihoods strategies are focused on survival, with little time or inclination to invest in conservation activities. Demographic trends indicate worsening conditions for the poor even without climate change. Efforts to increase agricultural productivity and food storage, as well as access to markets, may help reduce household dependence on forests to fill the ‘hungry gap’, but the impacts of climate change on agricultural strategy options at household level are unknown. Poor access to clean water remains a problem and is likely to get worse given the projections for reduced (initially) and more variable rainfalls. Existing coping strategies of insecure rural populations make them more vulnerable to the impacts of climate change on water, food production and health through current trends of forest degradation, intensive land use for agriculture and use of marginal lands including steep slopes for farming.

To enable workable and effective adaptation measures, governments and NGOs must consider integrating climate change in the planning and management in all decision-making. One step needed is to integrate seasonal climate forecasts, whose predictability potential in the region is rated high (Cooper et al. 2008), into agricultural and resource management practices. Already, the Eastern Africa region has the IGAD Climate Prediction and Application Centre (ICPAC) as the main agency of generating and disseminating forecasts. However, applying the forecasts at local levels such that households understand the implications and their response options remains a huge challenge. Another step is to integrate protection of natural resources, including adequate habitat for mountain gorillas, into the national adaptation planning process of each government, with the goal of securing some of the international adaptation funding available for such protection.

Climate change is likely to spur local, and intra-state, migration in response to droughts and flooding. The level of resource conflict is likely to increase as pressure on forest, agriculture, water and fisheries resources grows. Both these trends will negatively affect prospects for mountain gorilla conservation, and we conclude that efforts to enable local people to improve their livelihoods and reduce their vulnerability to climate change should be intensified, accelerated and extended.

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# 6.0 Modeling Species Distribution under Several Climate Change Scenarios for Mountain Gorillas

## I. Introduction

Species are expected to respond to climate warming in a variety of ways. These responses can be classed as direct and indirect effects. Direct effects include being physiologically affected by changes in temperature and moisture, which can lead to shifts in the geographic range of the species, since the location where suitable environmental conditions are found may have shifted. Under global warming, species are generally expected to shift towards higher latitudes and elevation. They may also find refugia within the extent of their current range. Refugia are locations that, because of a combination of environmental factors, retain their suitability for the target species. Direct effects may also include changes in the timing of life cycle events, such as when plants change the timing of their flowering.

Indirect effects are a generally broader category of impacts, and may include changes in many of the trophic interactions that species are involved in. These changes may also be attributable to causes or environmental alterations other than global warming. Indirect effects can include: changes in the amount or quantity of available food items, changes in the populations of pathogens, predators and parasites; changes in the distribution or quality of other species that provide habitat; and changes that provide better conditions for invasive species, which in turn can alter ecosystems in a variety of ways that can affect the target species.

The mountain gorilla (*Gorilla beringei beringei*) is a species of tremendous conservation concern, a charismatic large mammal that is closely related to humans. It ranks among the most important flagship species in conservation, and the story of its protection to date has served as a lesson in conservation biology for many other efforts, particularly in tropical and equatorial regions (Fossey, 1983; Schaller, 1964; Vedder and Webber 2001). Confined as it is to a much smaller range than it originally occupied, and hemmed in on all sides by a growing tide of humanity, the mountain gorilla already requires a high degree of management to ensure its continued existence. There are four national parks in three countries (Democratic Republic of Congo, Uganda, and Rwanda) that contribute to mountain gorilla conservation. These parks face ongoing pressures, predominantly from political instability and growing human populations. For example, the Parc National des Volcans, in Rwanda, has lost over half its extent between 1958 and 1979 (Rwanyiziri and Kayijamahe, 2005).

While the total area of habitat available to mountain gorilla has declined because of the incursions of ranching and farming, actual numbers of gorillas have increased in recent decades. The population increase is attributable to the improved management of the parks in which they reside, education, financial incentives to local populations and governments from a valuable tourism trade, and an ongoing research effort that continues to involve a dynamic community of scientists. The emergence of global warming concerns has led to the need to apply research methods that assess species climate change vulnerability to the mountain gorilla. The goal of this Chapter is to lay out an initial effort to assess the possible vulnerability of mountain gorilla to the emerging threat of climate change. The description is meant to provide technical details of our procedures, with justifications; the results are meant to generate discussion of the possible dimensions of global warming impacts to mountain gorillas, their habitat, and the ongoing efforts to preserve them.

Several themes are addressed in this chapter:

1) *Species range dynamics*. This is commonly addressed in climate change studies, and is the main focus of this paper. Species range dynamics are developed by mapping the historic, current and expected future areas that a species can occupy, and measuring the level of disruption that a species may face, as a result of having to move. Two important sub-themes of this topic are the assessment of what environmental variables are the most important in predicting the distribution of a species, and whether already-protected areas that are not currently occupied by mountain gorillas are suitable to be occupied or not.

2) *Secondary effect*. Namely, climate change effects on the landscape. An important corollary to this is whether there are areas near the parks that could be restored to forest. This considerable expense might be justified if it successfully expands the habitat of gorillas, but the funds might be better used to improve park management, if climate change is going to make the potentially restored areas unsuitable for forest restoration.

3) *Managed relocation*. This is the idea that under some circumstances, it may be necessary to move a species into a new area if it is to survive. This is done either when the old range is found to no longer be climatically suitable, or in the most desperate situations, when a species will likely be extirpated if it is not moved, because of hunting, infectious disease or other emergency. At this point no-one is proposing to relocate any mountain gorillas from their natural range, as the risks would currently outweigh the known benefits, but this option is still considered in this Chapter as a matter of good practice.

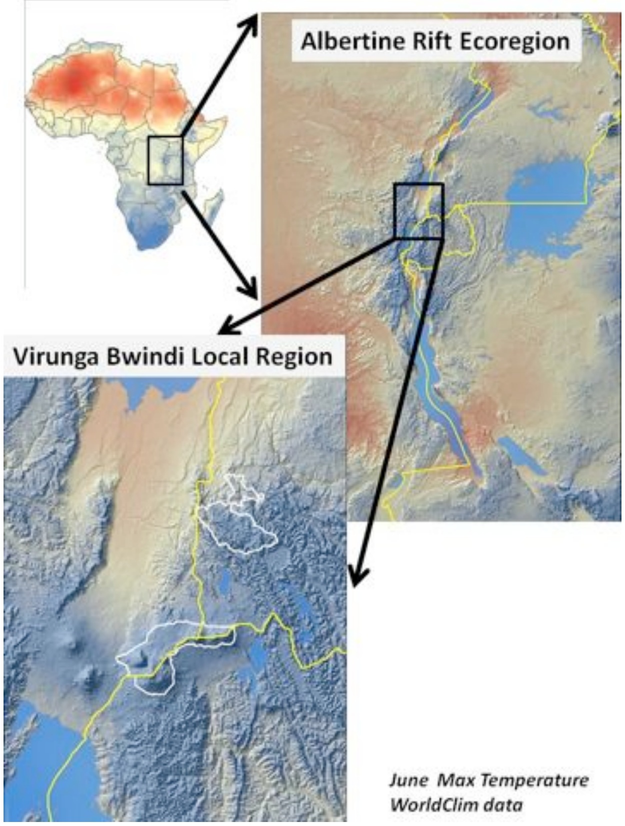
## II. Climate Projections in the Albertine Rift – Predictor Variables

*Setting of the study boundaries*

We selected two spatial study boundaries, to permit an ecoregional and a more localized view of mountain gorilla range. The Albertine rift ecoregion was first selected by a box of 1100x1600 km. A box containing the two mountain gorilla regions – the Virunga Volcanoes and Bwindi Impenetrable Forest are represented by a box 180x180 km that contains within it the reserves covering 325 km$^2$ for Bwindi and 551 km$^2$ for the Virungas (Figure 1). For both the ecoregional and local regional study areas, we used an operational grid size of 1x1 km.

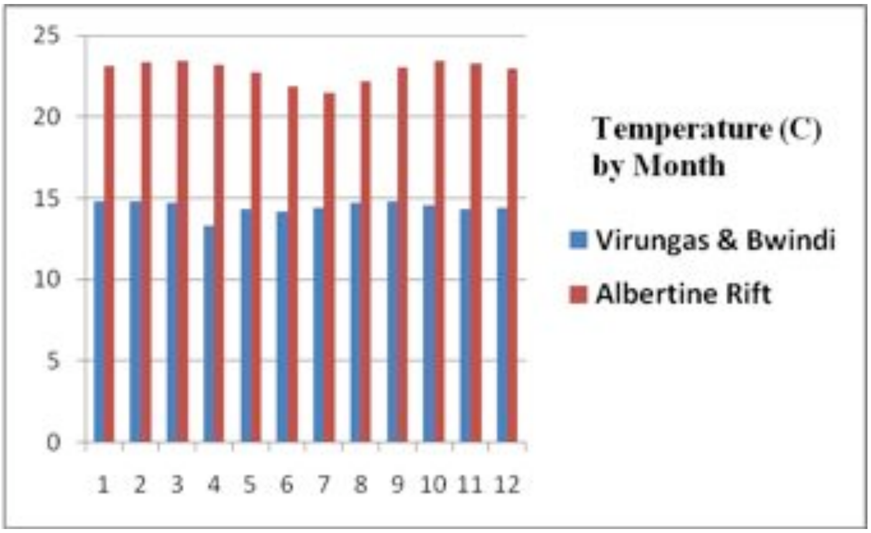
A 1 km$^2$ grid for the portrayal of climate data (particularly future climates) would be considered extremely fine-scale by climatologist standards. However, the scales at which General Climate Models (GCMs) are generally developed (e.g., 100x100 km) are so coarse that the much more fine-grained biotic response by animals and plants would be lost. Therefore landscape ecologists prefer to use downscaled models of climate. One of the most widely used downscaled climate models is WorldClim (http://www.worldclim.org/; Hijmans et al. 2005), which offers 1 km grid climate surfaces for the globe. The WorldClim dataset consists of monthly temperature values – $T_{min}$, $T_{mean}$, $T_{max}$ and precipitation, which were rendered into 1x1 km grid maps from many hundreds of weather stations around the globe. It is a widely used climate dataset. Dr Hijmans kindly also downscaled three climate future scenarios for this effort. The downscaling involved taking the gridded outputs from a GCM, applying those values to all the smaller grid cells on a per grid cell basis, and adjusting the GCM value in each smaller cell by the proportional difference between cells, as measured in current time in the WorldClim map; this is a method to approximately translate a forecast to a spatial resolution that is finer than that of the original forecast.

We used WorldClim values to portray the current climate conditions of the Albertine Rift ecoregion and the parks region containing mountain gorilla. Current temperature differs markedly between the Albertine Rift as a whole, and the two mountain gorilla parks (Virungas and Bwindi), with the protected mountain gorilla parks being at least 6° C cooler in every month of the year (Figure 2a). The protected areas are also wetter (varying and up to about 50 mm more) than the rest of the Albertine Rift Ecoregion as a whole in every month of the year except July and December (Figure 2b).

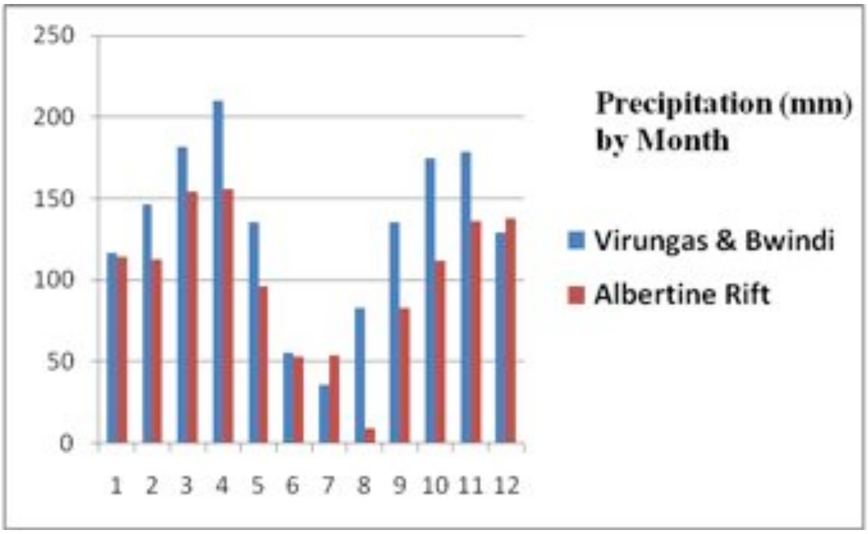


*June Max Temperature*
*WorldClim data*

Figure 1. The ecoregional and local region extents used for the modeling work in this chapter. The two park regions are visible outlined in white, the countries are in yellow. Current June maximum daily temperature is shown draped over a topographic relief map in the background.



**a.**



**b.**

Figure 2. a. The current mean temperature by month (C◦) and b. the current mean precipitation (mm) by month for the mountain gorilla parks (in Blue), and for the Albertine Rift ecoregion as a whole (in Red).

*Review and Selection of Climate Futures for use in Modeling*

Future climate scenarios are defined by several important criteria. First and foremost, the concentrations of $CO_2$ in the atmosphere are represented by a series of policy scenarios. The higher the concentration of $CO_2$, the less effectively humans have managed to alter their lifestyles to control the emissions of greenhouse gases (IPCC 2007a). The codes used to define the different levels of emissions are the:

A1 series: This series represents continued globalization of markets, with a heavy economic focus. Expected 1.4-6.4 C° increase in temperature.

B1 series: This series also reflects rapid globalization, but with more focus on environmental sustainability. Expected 1.1-2.9 C° increase in temperature.

A2 series: This series reflects a regional, rather than global economic expansion. Expected 2.0-5.4 C° increase in temperature.

B2 series: This series reflects a regional expansion but with consideration for local environmental sustainability. Expected 1.4- 3.8 C° increase in temperature.

For this study, we selected the A2 and A1B scenarios (Figure 3), which are among the more extreme in terms of the assumption of future $CO_2$ levels (Ganguly et al., 2009; Maxino et al., 2008; Williams et al., 2010). We felt the use of these scenarios was justified because the trajectories of $CO_2$ concentrations have already surpassed the levels represented in some of the lower emissions scenarios. The key assumptions of the two selected scenarios follow.

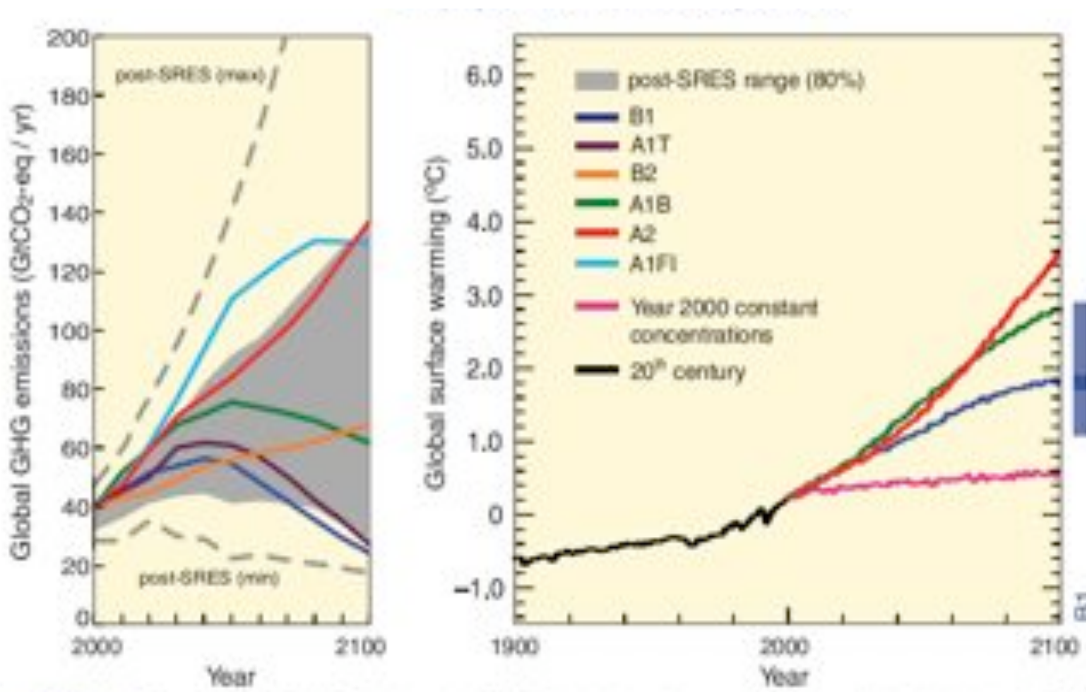


Figure 3. Schematic from the IPCC 2007 report (IPCC 2007b) showing the estimated warming from different greenhouse gas emissions scenarios.

***A1B Emissions Scenario***

*Key Assumptions*: A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.

***A2 Emissions Scenario***

*Key Assumptions*: A very heterogeneous world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

*Use of WorldClim Data and Downscaling of Future Climate Scenarios*

The next step in our selection of climate models was to select which of the modeling groups to use from among the various modeling groups that produce future climate maps based on IPCC greenhouse gas policy scenarios. There are over 12 research groups around the world with the capacity to generate spatial models of future climates. They are large research consortia which frequently have access to substantial computing power such as super computers. Each group's approach differs slightly. The most significant differences have to do with interpretations of how global circulation patterns operate interactions between different levels of the atmosphere, and the amount of moisture projected to be in the system. We picked three modeling groups, and used their outputs for the two emissions scenarios (A1B and A2), to compare in the mountain gorilla study. Here are the modeling groups' codes for which of their model outputs we used for the A1B and the A2 scenarios:

Miroc- a Japanese consortium.
Scenarios
mi = 'miroc3_2_hires' (A1B)
mr = 'miroc3_2_medres' (A2)
BCCR – the Bergen Centre for Climate Research (Norwegian).
Scenarios
bc = 'bccr_bcm2_0 (A1B and A2)
IN- the Institute for Numerical Mathematics, a Russian group
Scenarios
in = 'inmcm3_0' (A1B and A2)

We use the following variables from these model projections:
tn = min temperature C°
tx = max temperature C°
pr = precipitation mm
month: 1:12; 1 = Jan: 12 = Dec

*Time scales*

General Circulation Models (GCMs) are produced at varying time steps. Dr. Hijmans prepared 5 time slices for our purposes.

Time periods:
1: 2001-2020
2: 2021-2040 - mean 2030
3: 2041-2060 - mean 2050
4: 2061-2080 - mean 2070
5: 2081-2100 - mean 2090

There are advantages and disadvantages to using the longer-term projections. The more near-term projections are likely to be more accurate with regards to changes in temperature and precipitation, because they are closer (in time) to the actual trends in weather that are being measured. However, biotic response to changes in climate is more likely to be captured across longer time periods, because the change in any given 20-year interval may not be enough to effect the species, and because there may be inherent lag in some of the biotic responses, particularly with regards to shifts in its range. We focused on 50 and 90 year projections, to limit data interpretation and to be able to see the most extensive changes that may occur to mountain gorilla range.

*Other variables considered - Topographic and Net Primary Productivity*

In addition to climate variables we wanted to see whether other predictor variables could be used to project suitable mountain gorilla habitat. To this end we extracted two topographic variables from a digital elevation model; 1. elevation, and 2. topographic roughness. The latter is a measure of the degree of elevation change in any given grid cell. Topographic variables were derived for 1 $km^2$ cells from the Shuttle Radar Topography Mission (SRTM; http://srtm.usgs.gov/index.php; Farr et al., 2007) global digital elevation models which were provided at 1km2 and 90m grid cell sizes.

Dr. Hijmans also provided a conversion of the climate values related to plants, an estimate of net primary productivity (NPP) by month. NPP derivation calculations have been published and were constructed from the climate variables for current future scenarios according to Leith (1975) and Adams et al. (2004). The NPP is presented in kilograms carbon per meter$^2$ per year, and in gm/m2/month throughout this paper. This measure can potentially be used to portray where plant productivity might be high enough to support gorillas under future climates.

## III. Biological Data Developed – Response Variables

*Assembly of gorilla data, standardization*

The gorilla observation data were provided to us mostly in Excel spread sheet form by the International Gorilla Conservation Programme (IGCP). The records came from three countries, 4 national parks (Bwindi Impenetrable Forest, Mgahinga National Park, Parc National des Volcans, and Volcanoes National Park), two regions, and had been collected by multiple individuals and patrols, likely most associated with daily visits. The observation records frequently recorded family group and date, as well as location, and how many gorillas were seen. These data represent about 10 years of "ranger based monitoring" data collected operationally by rangers and park employed tourist field guides. These data may be considered an exhaustive sampling of gorilla movements within the park segments that are represented. Several population censuses are known, which would capture the locations of gorilla individuals and groups not regularly monitored by rangers. Data from these censuses were not incorporated in these results since the records were either not digitized or available at the time of analysis. We strongly recommend these records be added to the digital repositories over time.

We standardized the format of each dataset as follows, and compiled the records. The surveys provided included over 40 separate files or tabs and contained over 80,000 individual records. The observation records often included a spatially identical entry for each member of a family group on a given date. While records of individuals have value for other types of research, for species distributional modeling, only one record per locality was required. Multiple individual records with a single XY location were therefore reduced to a single record of presence at that point. This resulted in a reduction to 44,780 points, which represent daily observation values from both regions (Bwindi Impenetrable Forest and the three national parks in the Virunga Volcanoes). Of the varied original data we retained:

Date ¦ X coordinate ¦ Y coordinate ¦ Group Name ¦ Vegetation Type

Of these records the X and Y locations were required and date was highly desirable. Only 29 records with no date were accepted. Once the data had been cleaned and compiled, it was possible to view all the observations at one time (Figure 4).

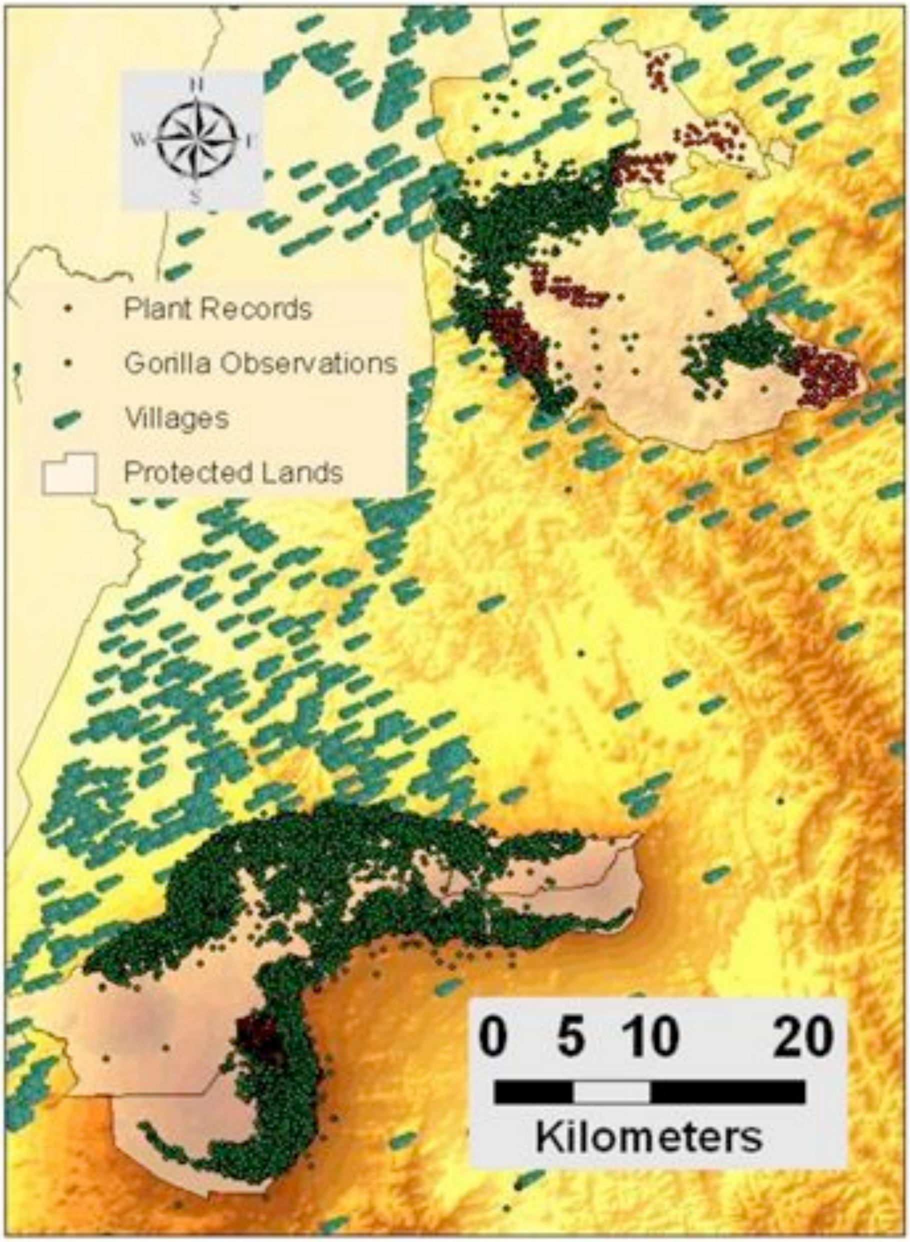


Figure 4. Bwindi (upper right cloud of points) and the Virungas (lower left cloud of points) with 44,780 gorilla observation points, shown in green. Villages (all light green shapes outside the protected areas) and records of gorilla plant food (red dots inside parks) are also shown. The map is shown overlaid on a topographic hillshade, where yellow is low and brown is high. Protected areas are partially transparent so that major topographic features are visible behind.

To let the gorilla data dictate the grain of the analyses, family group records were examined over time. The distance between records within day, between day and over 2 days was taken for the >40 family groups that were accounted for in the records.

Gorilla within-day movements averaged 222m (SD 537.78 m, N = 11,829); daily movement averaged 600m (SD= 806.33 m, N= 24,3238), and the 2 day movement average was 1099m (SD= 1196.49, N= 1,102). Elevational distribution of gorillas varied between the two park regions. Mean elevation for the Virunga populations is 2751m (SD 311, N= 37,970, min 2000m, max 3822m). Mean elevation for the Bwindi populations is 1722m (SD 202, N= 6630, min 1373m, max 2802m). This analysis confirmed that our base scale of analyses could be a 1x1 km grid, which represents a 2-day movement by mountain gorillas. We used this grid scale for both the ecoregional analysis and the regional (180x180 km) work.

*Assembly of plant data*

Plant species data records were made available by Dr. Andy Plumptre for the Virunga mountains and by Dr. Martha Robbins for the Bwindi region. Dr. Plumptre's data was from his dissertation, and represents an elevational transect on the Rwanda side of the Virunga mountains. Dr. Robbin's data was collected for a gorilla edible plants study, and represents clustered sampling from a variety of locations throughout Bwindi (Figure 4). As such, these data do not represent an exhaustive sampling of plants, or even all known edible plant species throughout the gorillas' range. However, they provide an expertly generated sample in both regions.

The Virunga plant data set is composed of vegetation plot data with a format as follows:

X coord | Y coord | date | Species 1 | Species 2 | Species 3 | Species 4 | etc.

This format is very useful for species distribution modeling (SDM), because if a species is not recorded at one location, this means that you can assign an absence to that location for that species. There are 978 locations for which 23 species or genera are recorded (Table 1). However, because the location of the plots is limited to one, relatively narrow location within the park (Figure 4), the records do not lend themselves well to projecting the expected distribution of the plant species in the park.

The Bwindi plant data are more widely dispersed, and 20,851 individual records were taken at different locations, that identify 357 plant taxa. Of those, 4941 records are of edible plants for gorillas (Robbins, *personal communication*; Table 1). While these records were more widely dispersed, and hence better suited as inputs for species distributional modeling, there were few records for some of these species, and no absence records. Nevertheless, the Bwindi data represent a broader sampling of the landscape (Figure 2). The format of the Bwindi plant records was:

X coord | Y coord | date | Species Name

Gorilla food plants recorded in these two datasets (Table 1) represent only a small fraction of the plants that gorillas eat, although many of the most commonly eaten species are listed.

**Table 1**
**The list of plant species for which spatial records have been recorded within the region of the mountain gorilla**

| **Virunga Plant Species** | | **Bwindi Plant Species** |
|---|---|---|
| *Afrokrania volkensii* | | *Basela alba* |
| *Carduus kikuyorum* | | *Bridelia micrantha* |
| *Carduus nyassanus* | | *Chrysophyllum sp + C. gorungosanum* |
| *Carex bequaertii* | | *Clitandra gymulosa* |
| *Carex johnstonii* | | *Ficus capense + multiple other + F. sp.* |
| *Cyperus spp* | | *Ficus natalensis* |
| *Discopodium penninervum* | | *Ipomea sp* |
| *Droquetia iners* | | *Laportea sp* |
| Galium spp mass | | *Maesa lanceolata* |
| Giant heather ( *Erica*) stem number | | *Mimulopsis arborescens* |
| *Hagenia abyssinica* | | *Mimulopsis solmsii + M. sp.* |
| *Helichrysum formosissimum* | | *Momordica calantha* |
| *Helichrysum globosum* | | *Momordica foetida* |
| *Hypericum revolutum* | | *Myrianthus holstii* |
| *Lobelia giberroa* | | *Myrica salicifolia* |
| *Lobelia mildbraedii* | | *Mystroxylon aethiopicum* |
| *Lobelia stuhlmanii* | | *Palisota mannii* |
| *Peucedanum linderi* | | *Piper capense* |
| *Peucedanum linderi* | | *Piper guineense* |
| *Prunus Africana* | | *Podocarpus milanjianus* |
| *Rubus runsorrensis* | | *Psychotria mahonaii* |
| *Senecio johnstonii* | | *Rubus sp* |
| *Stephania abyssinica* | | *Symphonia globulifera* |
| *Urtica massiaca* | | *Syzygium guinense* |
| *Usnea spp.* | | *Syzygium cordatum* |
| *Zehneria scabra* | | *Tabernaemontana holstii* |
| | | *Tabernaemontana odoratissima* |
| | | *Teclea nobilis* |
| | | *Triumfetta sp + T. rhomboidea* |
| | | *Urera sp + U cameronensis* |
| | | *Xylopia staudtii* |
| | | *Xymalos monospora* |

Since the records for individual plant species were scant we elected to combine all the gorilla plant species from both surveys, to see whether a combination could provide a basis to model suitable habitat. Modeling from this line of inquiry led to unsatisfactory results in the form of 'food plant' ranges that did not cover the protected areas, particularly for the Virungas, so further processing of the plant data is not presented here.

*Recommendation for future efforts*

It is highly desirable to collect the locality data for important food species and habitat plants. This would permit the addition of considering food and habitat plants in future climate vulnerability studies for the mountain gorilla. We note that setting up the surveys would not appear to be a difficult challenge, given that there are many park managers and researchers continually in the parks. Comprehensive surveys are not necessary for plant modeling to provide useful contextual information, but a better geographic distribution of samples than is currently available would be helpful. It might be useful to identify the dominant habitat plants, the major food plants associated with each elevation zone, and a suite of plants used by mountain gorillas that are present in one or both protected areas, and to have these be added to a target list of plants to record during additional surveys.

## IV. GIS Framework and Model Development

Once the climate, environmental and biological data were prepared, the next step was to use a spatial grid framework, which is the basis upon which the modeling is done, to sample all the variables.

*Integrating predictor and response variables*

We used a 1x1 km grid for the local region modeling, determined to be suitable, as described earlier, from the gorilla movement data, and also because this was the scale at which many of the grids were available. The analysis grid was aligned with and had the same projection coordinates as all the climate data grids. The 44,780 unique-locality gorilla observations were dropped onto this grid, and the cells that contained one or more records were designated with a 1 (presence); empty cells were given a 0 value (absence). This resulted in 538 1x1 km grid cells with a presence value. We also used a 1x1 km grid for the ecoregional modeling, leaving the same number of gorilla presence cells for use at the scale of the Albertine Rift ecoregion.

A similar exercise was conducted for each plant species. Each climate grid layer- from current and future climates- was then sampled and the values found at every grid point that had either gorilla or plant presences was recorded to a table in preparation for the modeling. The stack of climate, as well as topographic and NPP variables extracted in this manner became the predictor variables for species distributional modeling, while gorilla presence points (or plant presence points) became the response variable. These predictor and response variables are used in species distributional modeling to determine what combination of predictor variables is most influential on the pattern of distribution of the target species, in this case the mountain gorilla.

*MAXENT Species Distribution Modeling*

There are many types of species distribution models (e.g., Elith & Leathwick, 2009). Given that we are considering a very restricted species with a high amount of data, we used an approach that is direct and easy to implement called Maxent. Maxent is a modeling approach that does not require absence points to be part of the data used (they are essentially selected at random by the program, in the context of a background extent set by the user. Maxent is widely used in the climate research community, and can rank the relative influence of any given predictor variable on the pattern of the target species. Like any statistical model, Maxent will not be able to identify important variables if they are not included among the predictor variable options.

We used Maxent (http://www.cs.princeton.edu/~schapire/maxent/l; Phillips et al., 2006) to examine a series of predictor variable combinations in current time, before setting out to model future climate scenarios. At first we examined topographic variables, climate variables, and NPP, each, in independent runs. We then combined the 4 highest performing climate variables with the two topographic variables, and the four highest performing NPP variables with the two topographic variables. We also examined a composite, single variable of NPP, which represents an annual value of plant productivity, combined with the 2 topographic variables. All model runs were examined in map form. For part of this analysis, we derived a set of 19 BioClim (from 35 possible) variables (http://fennerschool.anu.edu.au/publications/software/anuclim/doc/bioclim.html; Busby, 1986), using a method that combines climate values to provide compound predictor values such as 'the mean temperature of the coldest quarter', and 'rainfall in the wettest quarter' (Table 2).

Once the weightings of predictor variables were developed for the current time period, those weightings were used to project the expected range under future climate scenarios (Figures 5 & 6). Results from these current and future climate modeling are presented as a series of ecoregional maps and regional or 'local' maps.

Table 2. The list of BioClim Variables. BioClim uses monthly or weekly values to determine the above bioclimatic variables. The ones shown in *italics* were used in some versions of the modeling.

| |
|---|
| *P1. Annual Mean Temperature* |
| *P2. Mean Diurnal Range(Mean(period max-min))* |
| *P3. Isothermality (P2/P7)* |
| *P4. Temperature Seasonality (Coefficient of Variation)* |
| *P5. Max Temperature of Warmest Period* |
| *P6. Min Temperature of Coldest Period* |
| *P7. Temperature Annual Range (P5-P6)* |
| *P8. Mean Temperature of Wettest Quarter* |
| *P9. Mean Temperature of Driest Quarter* |
| *P10. Mean Temperature of Warmest Quarter* |
| *P11. Mean Temperature of Coldest Quarter* |
| *P12. Annual Precipitation* |
| *P13. Precipitation of Wettest Period* |
| *P14. Precipitation of Driest Period* |
| *P15. Precipitation Seasonality(Coefficient of variation)* |
| *P16. Precipitation of Wettest Quarter* |
| *P17. Precipitation of Driest Quarter* |
| *P18. Precipitation of Warmest Quarter* |
| *P19. Precipitation of Coldest Quarter* |

| |
|---|
| P20. Annual Mean Radiation |
| P21. Highest Period Radiation |
| P22. Lowest Period Radiation |
| P23. Radiation Seasonality (Coefficient of Variation) |
| P24. Radiation of Wettest Quarter |
| P25. Radiation of Driest Quarter |
| P26. Radiation of Warmest Quarter |
| P27. Radiation of Coldest Quarter |
| P28. Annual Mean Moisture Index |
| P29. Highest Period Moisture Index |
| P30. Lowest Period Moisture Index |
| P31. Moisture Index Seasonality (Coefficient of Variation) |
| P32. Mean Moisture Index of Highest Quarter MI |
| P33. Mean Moisture Index of Lowest Quarter MI |
| P34. Mean Moisture Index of Warmest Quarter |
| P35. Mean Moisture Index of Coldest Quarter |

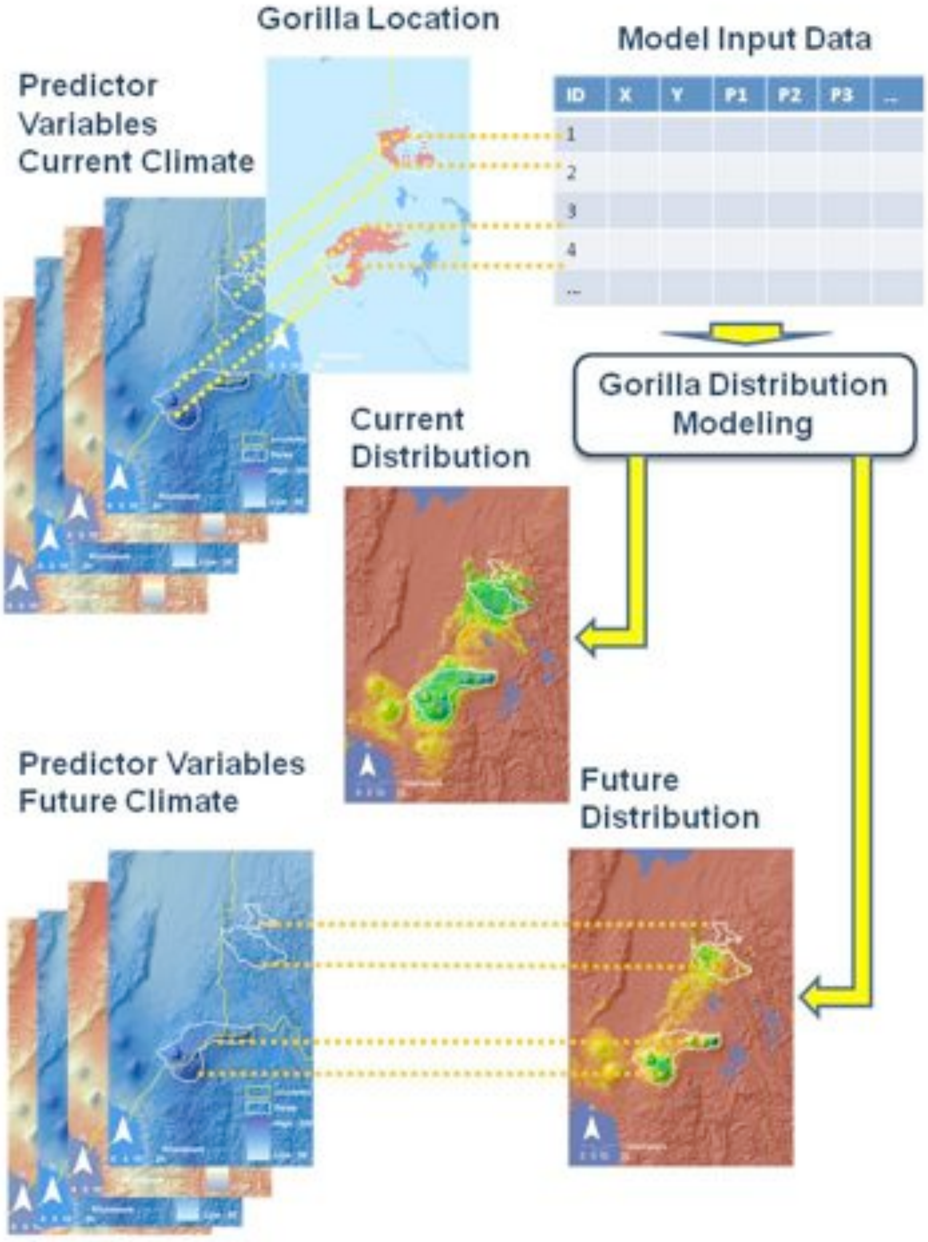


Figure 5. This image shows the general approach taken for the species distribution models. Gorilla observations are used to sample background climate and other predictor variables (upper left), which are compiled into a table of predictor and response variables (upper right). This table is used to generate SDMs for the current time period (center). The weightings derived under current time are then used to assess where range may be found under future climates (lower panels).

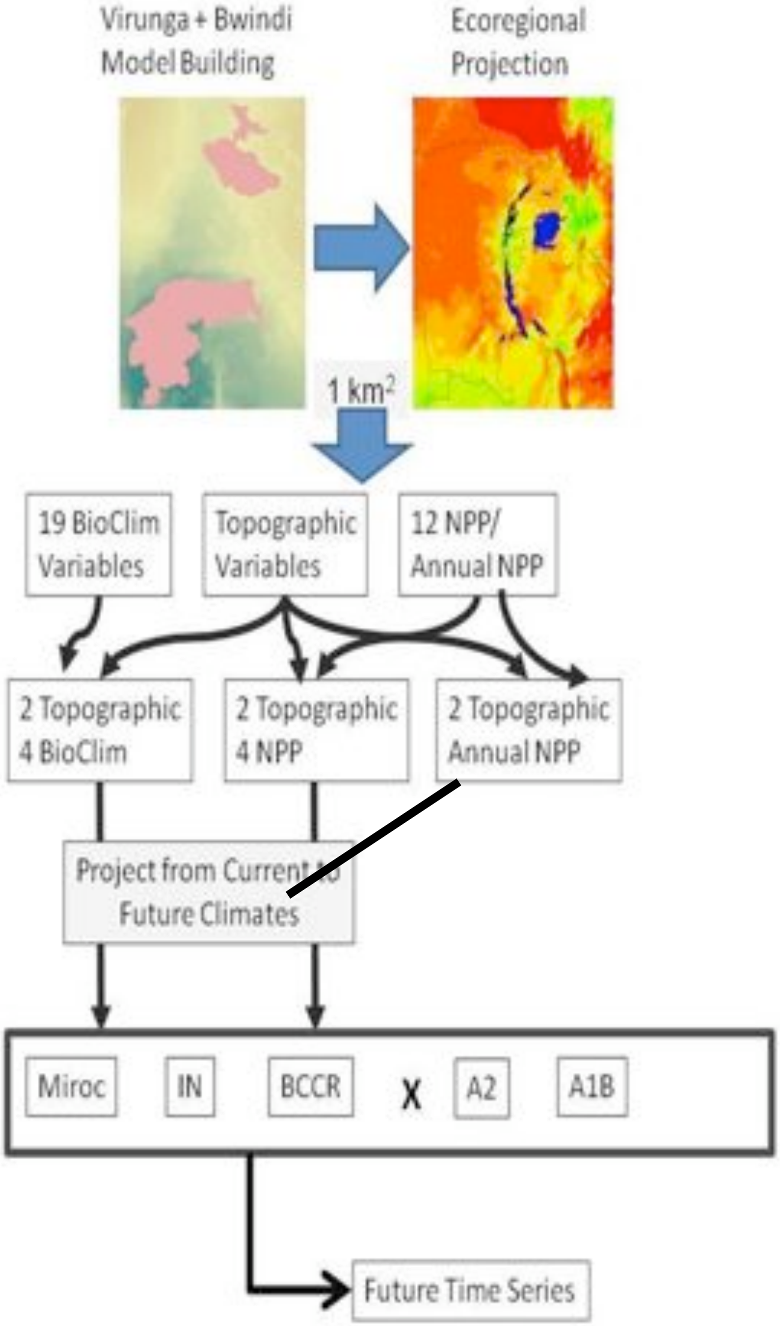


Figure 6. This image shows the work flow we used to examine different species distribution modeling parameters for mountain gorilla. Local and ecoregional extents (top) were used in modeling using three base sets of predictor variables (row 2). Combinations of the best performing variables were then used in another round of modeling (row 3). From the results, the two best performing models in terms of area selected in current time were used to project future ranges (row 4), according to three modeling groups' climate surfaces for the A2 and A1B scenarios (row 5).

## IV. GIS Model Results

*Current time*

Comparison of predictor value weighting among the initial models in current time identified the four BioClim variables (temperature seasonality, mean temperature wettest quarter, annual precipitation, and precipitation of the driest quarter) and four NPP months (April, June, September, and November) that had the highest predictive value for mountain gorilla. Model performance is reported as measured by the Receiver Operator Curve (ROC, where a value of 1 is perfect performance of the model). Model performance varied depending on which set predictor variables was used, with ROC values ranging from 0.873 for use of only topographic variables, to 0.973, and also depending on how the model outputs were tested (Table 3, Figure 7); all of these are very high scores of model performance. We tested all model outputs in three ways: 1. by using the same input observation points as used to run the models for the test; 2. by holding out 20% of the observations, seeing how well the other 80% predicted those 20%, and repeating the process five times (a five-fold validation); and, 3. for the Virungas, using a mountain gorilla census obtained after the model building, to see how well the model predicted completely independent observations of gorilla localities.

The topographic-only model identified the broadest area as suitable for mountain gorilla. Elevation explained 73.3% and topographic roughness 26.7% of the pattern of gorilla presences. The areas that contain gorillas contain considerably more elevation gain, and relief, than the rest of the Albertine Rift ecoregion in general (Figure 8 a, b). Relative contribution of every predictor variable to each model run is presented as percentages in Table 4.

Table 3. Receiver Operator Curve values obtained with each type of test of model outputs (ROC: a value of 1 is perfect performance of the model), with each combination of predictor variables, as shown in the 1st column. The third approach, a subsequently obtained mountain gorilla population census from the Virungas as a completely independent data set of gorilla observations, is most robust, although from only a sub region of the local modeling extent.

| | **Receiver Operator Curve Values (0-1)** | | |
|---|---|---|---|
| **Predictor Variables** | **Training and test using all data** | **5-fold validation** | **Test using an independent population census survey from Virungas** |
| **Topo 2** | 0.873 | 0.867 | 0.973 |
| **Topo 2 + Bio 4** | 0.964 | 0.964 | 0.973 |
| **Topo 2 + NPP 4** | 0.963 | 0.963 | 0.971 |
| **Topo 2 + NPP 1** | 0.93 | 0.927 | 0.965 |

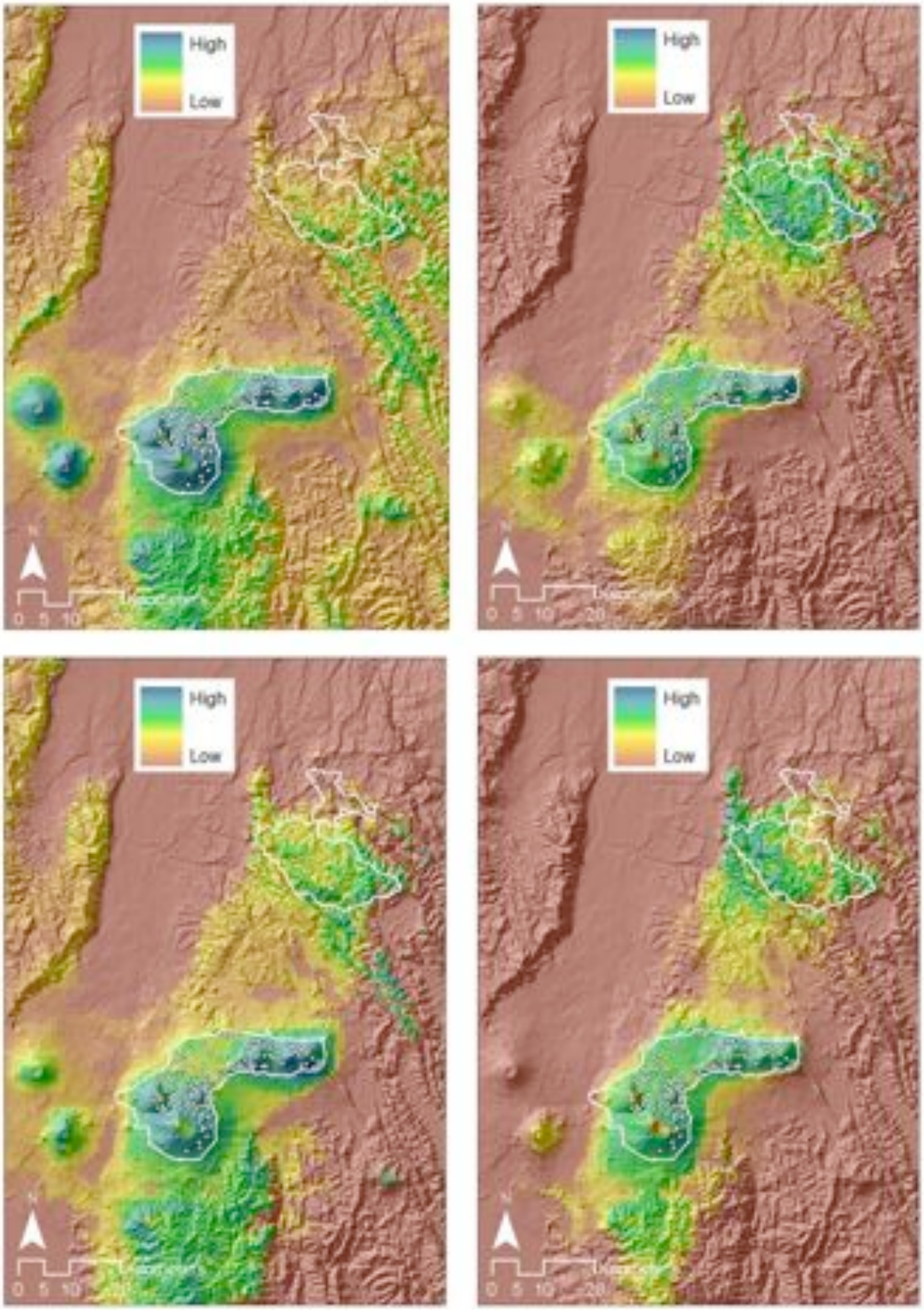


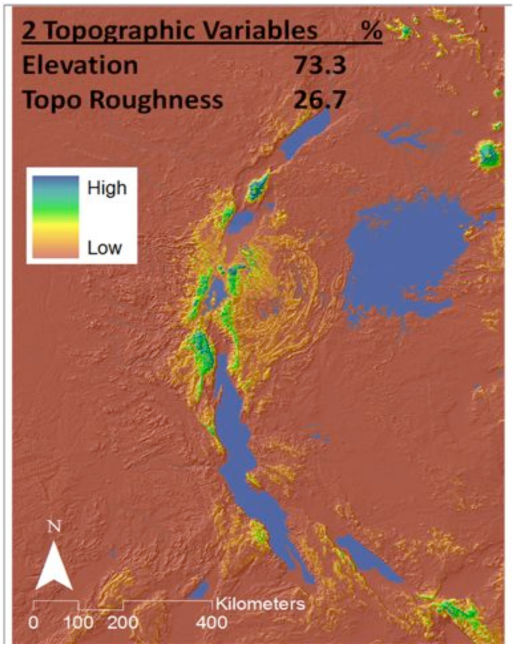
Figure 7. These images show the location of mountain gorillas from population census records obtained after the Species Distribution Models were run, in the Virunga Volcanoes. The census data, shown as white dots, were used as a completely independent test of model performance (as shown in Table 3). These images represent that test, with the census data overlaid on top of the

model outputs for, from top left in clockwise rotation: 2 topographic variables; 2 topographic variables and 4 BioClim variables; 2 topographic variables and four NPP variables; and 2 topographic variables and a yearly summary of NPP. All four model outputs scored high, with the lower left panel (2 topographic and annual NPP predictors) scoring the lowest, with the model correctly identifying only 96.5% of the census locations as suitable habitat for mountain gorillas.

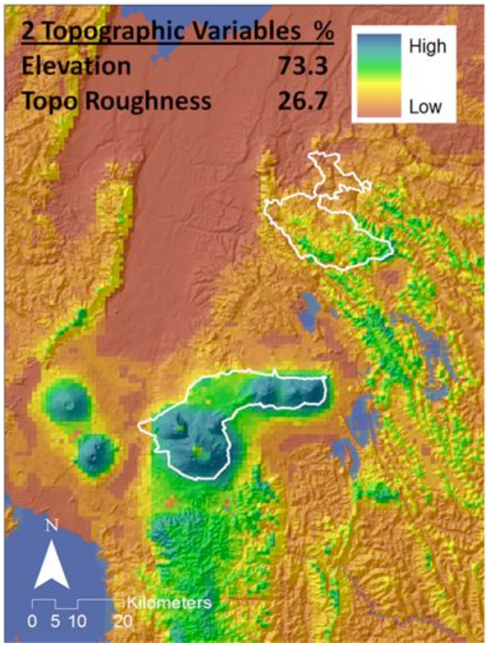
The **topographic-only model** identified the broadest area as suitable for mountain gorilla. Elevation explained 73.3% and topographic roughness 26.7% of the pattern of gorilla presences. The areas that contain gorillas contain considerably more elevation gain, and relief, than in the rest of the Albertine Rift ecoregion on average (Figure 8 a, b).

The top four **BioClim** predictor variables are: precipitation in driest quarter (16%), annual precipitation (17.5%), temperature seasonality (7.7%), mean temp in wettest 1/4 (7.9%). Generally, the climate-based BioClim modeling approach identified only a very few locations that currently have similar climate to the Virungas and Bwindi, the primary one being Mt. Elgon to the far east and north (Figure 8 c, d). We produced a comparison of current temperature and precipitation that confirms that most of the Albertine Rift is much warmer, but has lower rainfall than the gorilla protected areas (Figure 2).

The **NPP-only view** is an attempt to identify where plant productivity could be suitable to gorillas (who are primary consumers). NPP may also allow us to gain insight into changes in drought period. The NPP analysis identified months 4, 6, 9, and 11 (16.2%, 28.6%, 13.8%, and 15.5% respectively), as the most important to patterns of gorilla presence. The NPP-based maps identified considerably more range than the BioClim variables, but far less than the Topographic variables (Figure 8 e, f).



a.



b.

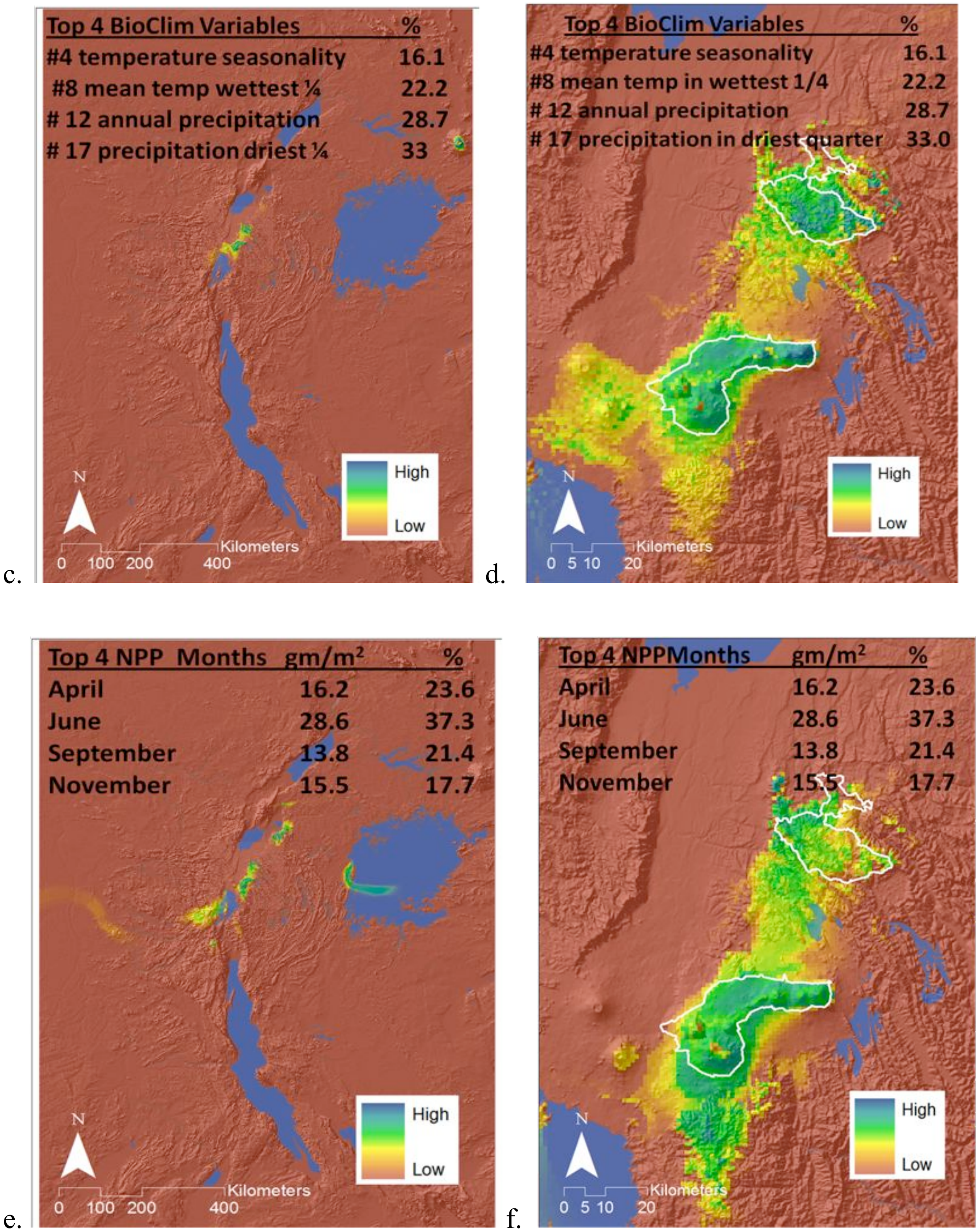


Figure 8. Ecoregional and local maps of mountain gorilla range as predicted by 2 topographic variables (a, b); by the top 4 BioClimatic variables (c, d); and by the top 4 monthly Net Primary Productivity (e, f) variables for the current time period.

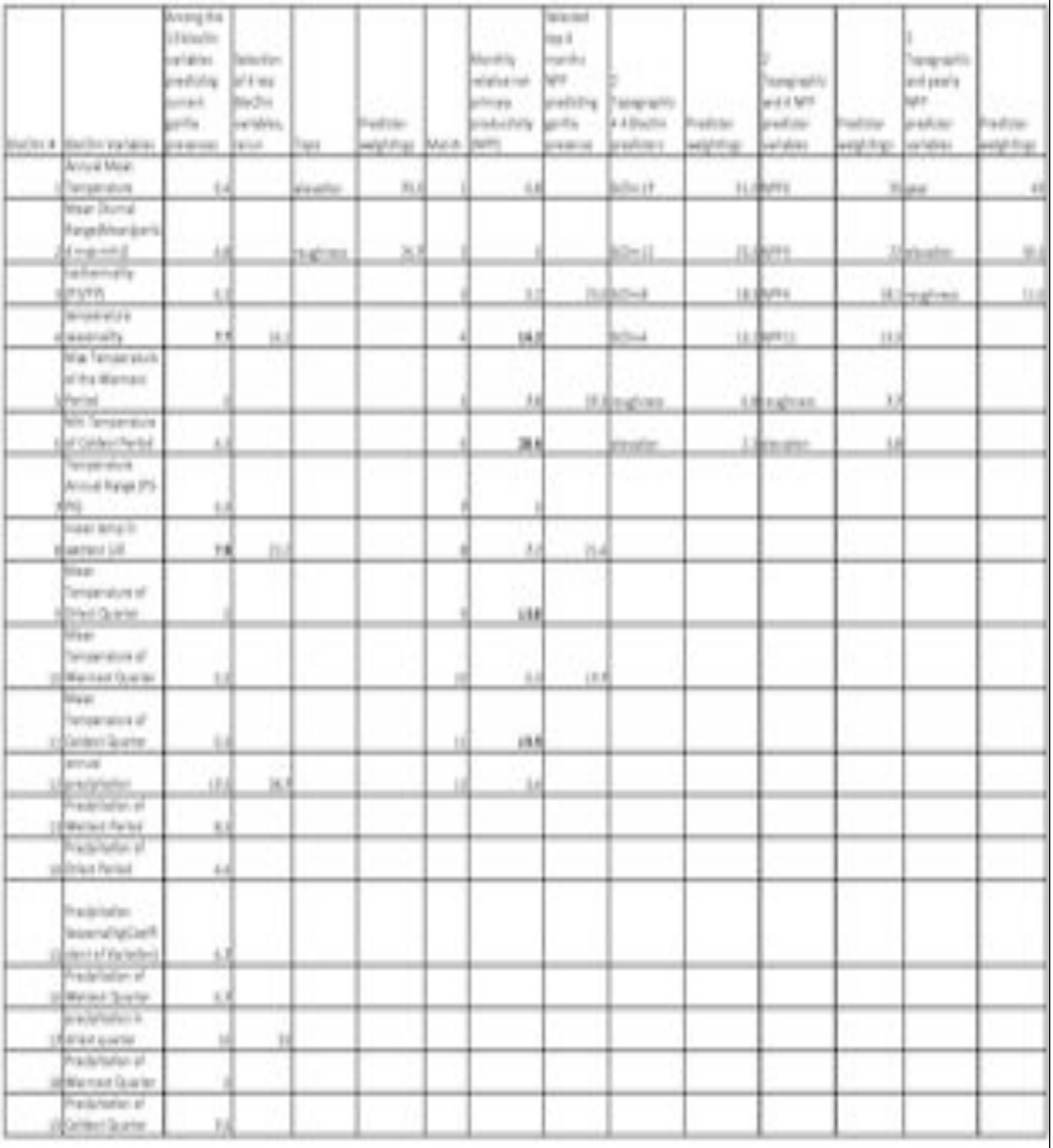
*Question to consider:*

While model performance was high across each type of predictor variable, is one of the projections more correct than another?

The output maps from the various predictor variables do not fully agree, although they all identify the two regions currently inhabited by mountain gorilla. Topographic variables alone identify a wide range of areas around the Albertine Rift ecoregion that have similar topographic conditions to the rugged mountains and hills currently occupied by mountain gorillas. Possible reasons for the much smaller ecoregional range predicted by climate is that the climate-based approach identified the highly restricted environments found in the upper elevations of the Virungas, for which there are very few other suitable locations. This could be compounded by the fact that mountain gorillas have been increasingly constrained in their range by growing human populations and endeavors. Human activity has caused loss of habitat, which in turn means that the available records of gorilla activity are restricted to a much smaller area than they might actually be physiologically capable of occupying. Under the climate predictors, only Mt Elgon, on the border of Uganda and Kenya has suitable conditions for a possible managed relocation. The NPP predictors identify a set of low mountains to the north of Bwindi in Uganda (not the Rwenzori), and also some areas west of Lake Kivu as currently suitable for mountain gorilla.

Another recommendation, in the light of these findings would be to convene a group of experts to examine palynological and other data showing historical forest extents, to assemble historical accounts of gorilla distribution and observations, and to assemble on-the-ground knowledge of historic gorilla range for the Mountain gorilla, for use in future modeling efforts.

Table 4. The relative weightings of predictor variables for each set of predictor variables tested. Selected predictors are presented in columns, with the predictor named to the left of the weighting for each combination.



*Combine current predictors*

We combined the two topographic predictor variables with the 4 best BioClim and 4 best NPP variables. These combined predictor sets were the final ones used with the future climate projections (Figure 9). Also included for comparative purposes, but not projected under future climates is the combination of two topographic variables with the annual NPP. This annual NPP projection captures the majority of the range of the sister subspecies, the eastern lowland gorilla (*Gorilla beringei graueri*), which is located to the west of the mountain gorilla range, on the eastern end of the Congo river basin, and just across the edge of the rift (Figure 9).

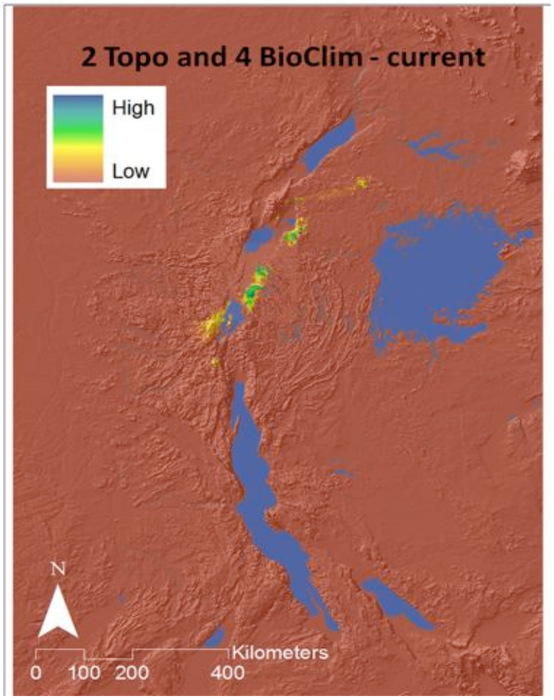
For the combination of two topographic and four BioClim variables, precipitation in the driest quarter was the most important, accounting for 31.9% of the projected spatial pattern, while the topographic variables account for an additional 9.1 %.

Using the 4 NPP predictors and two topographic variables model, June emerges as the most important month for plant productivity, accountable for 35% of the model, while the two topographic variables account for an additional 11.5%. All relative predictor weightings values for the models are shown in Table 4.

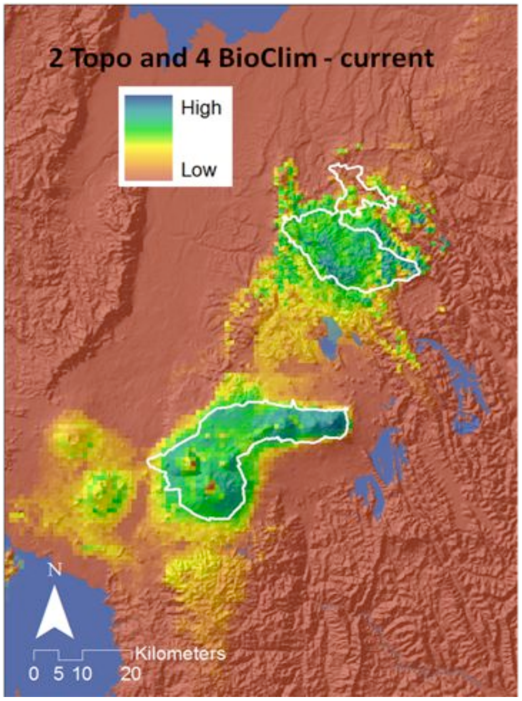
In addition to the model performance and the proportion of model weighted on the predictor variable combinations, the overall extent of (current) suitable range identified is an important consideration. Figure 9 illustrates what the extent of range looks like for the topographic variables combined with the 4 months of BioClim, the 4 months of NPP, and the annual NPP values.

The topography + annual NPP identifies the most suitable range, with topography plus either 4 NPP or 4 BioClim producing similar results. The topography + annual NPP model identifies range in the Congo basin, currently occupied by the Eastern lowland gorilla, which argues that a common level of vegetative production may be necessary for both mountain and Eastern lowland gorilla. Because the 4 months of NPP in the topography + 4 month NPP model comprise 88.4% of the model, (the four months identified as most important being June, September, April and November), it is possible that mountain gorilla range is constrained by months that are either high or low in plant production. It is interesting to note that under both the topography and 4 NPP and the topography + 4 BioClim models, considerable areas adjacent to and outside the parks are modeled as suitable range under current time.

The question raised by this finding is, "If the gorillas could survive across this wider definition of their range than that which they currently occupy, is movement (relocation) of human populations and restoration of tilled lands to gorilla habitat justified to try and extend the size of the gorilla population?" Under current time, this seems to be the case.


2 Topo and 4 BioClim - current
High
Low
N
Kilometers
0 100 200 400

a.


2 Topo and 4 BioClim - current
High
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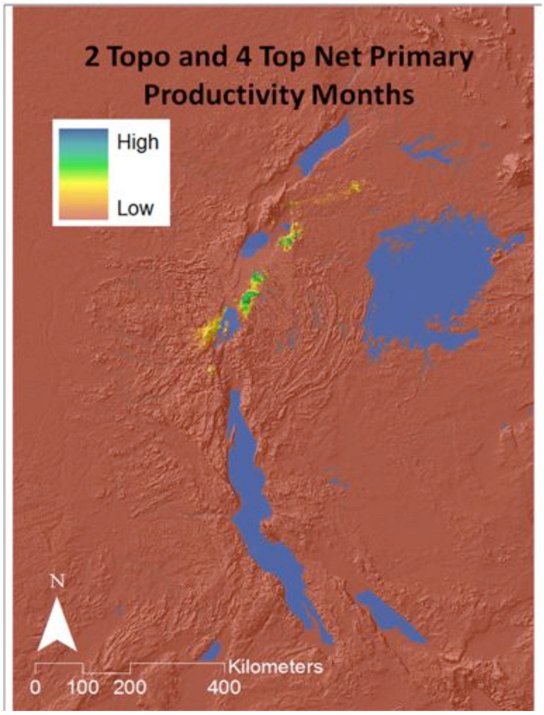
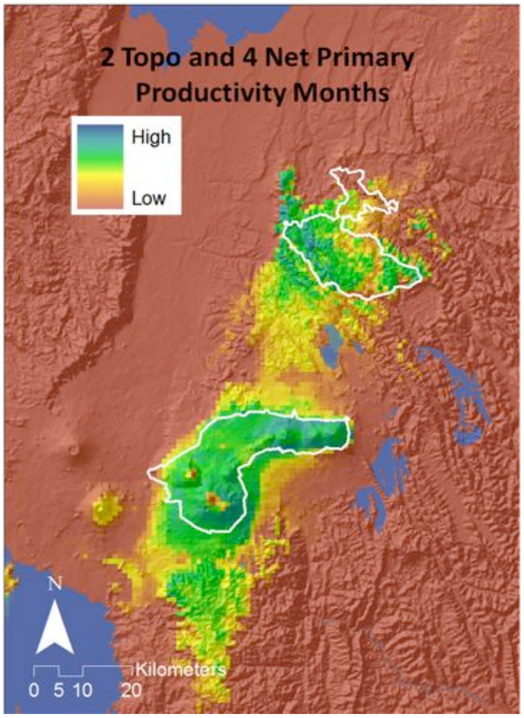
Kilometers
0 5 10 20

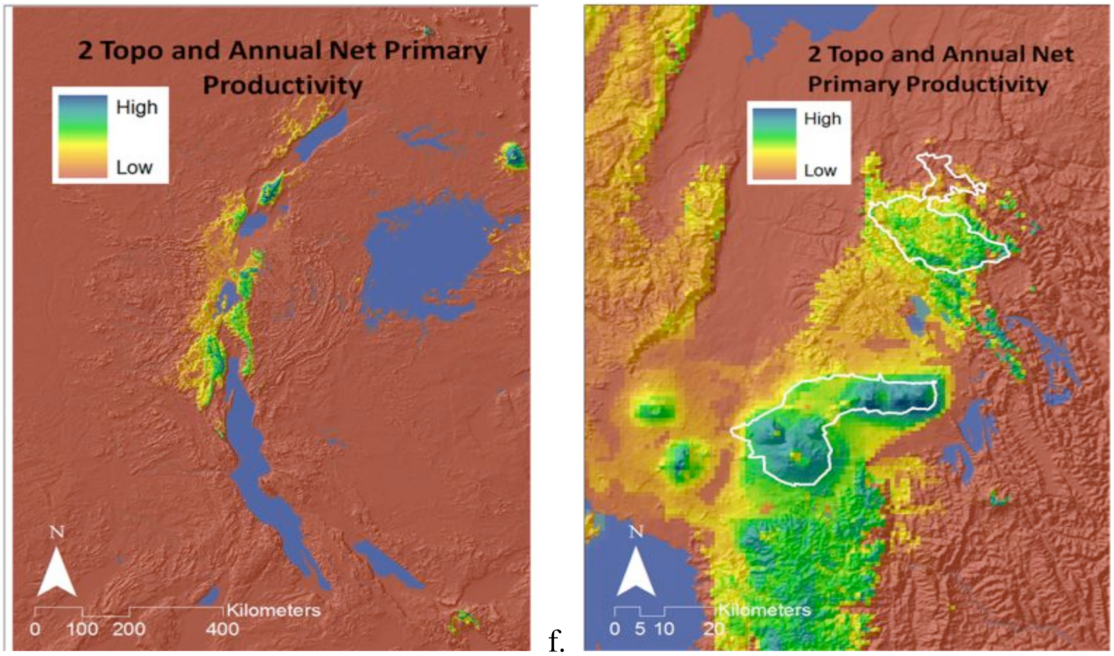
b.


2 Topo and 4 Top Net Primary Productivity Months
High
Low
N
Kilometers
0 100 200 400

c.


2 Topo and 4 Net Primary Productivity Months
High
Low
N
Kilometers
0 5 10 20

d.



e.

f.

Figure 9. Ecoregional and local maps of mountain gorilla range as predicted by 2 topographic variables and four BioClim variables (a, b); by 2 topographic and 4 NPP months (c, d); and by 2 topographic variables and an annual sum of NPP (e, f).

*Future range of mountain gorillas under 2 scenarios, 3 modeling groups using Maxent*

All the future climate scenarios we reviewed show warming, higher precipitation in the wet months, and some show slightly drier conditions in the dry months (Figure 10). The average warming found in all scenarios is 1.89 C◦ (SD 0.33) in 50 years, and 3.6 C◦ (SD 3.04) in 90 years for the two park regions containing mountain gorilla. Precipitation varies considerably more between projections (and is harder to quantify), but is estimated to increase on average 1.4 cm/year (SD 1.18).

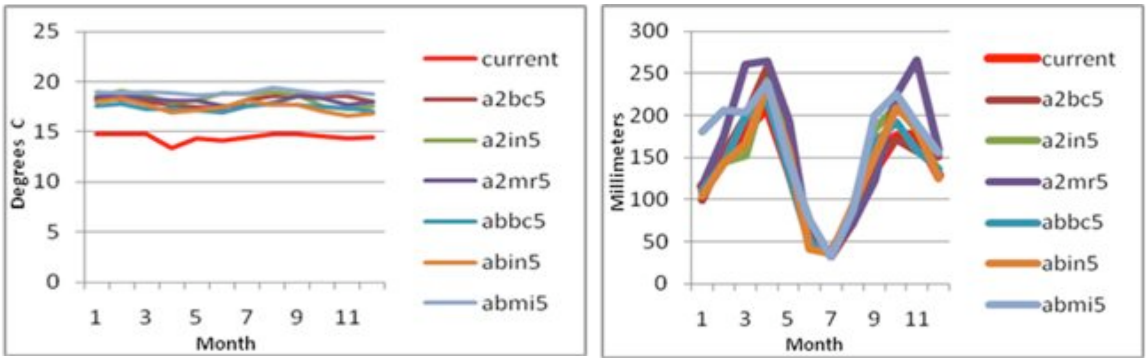
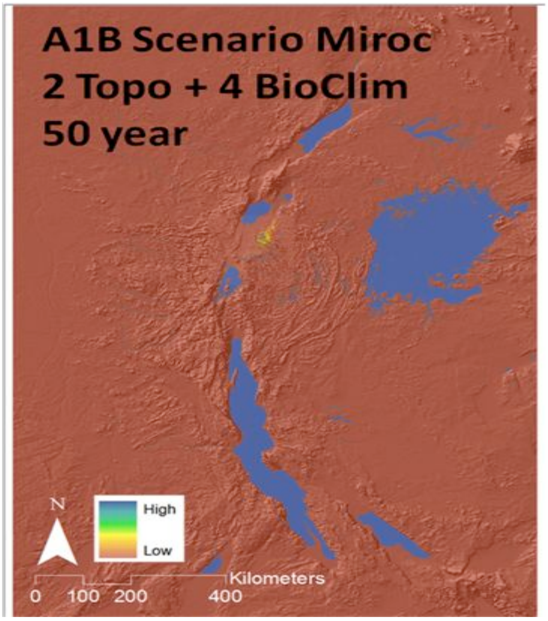
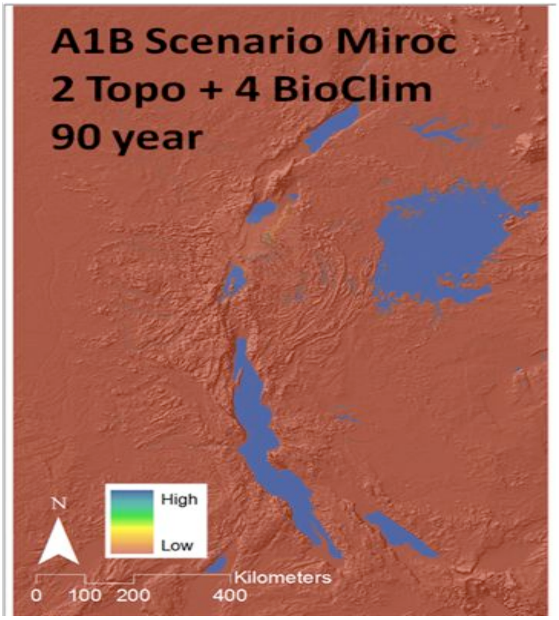


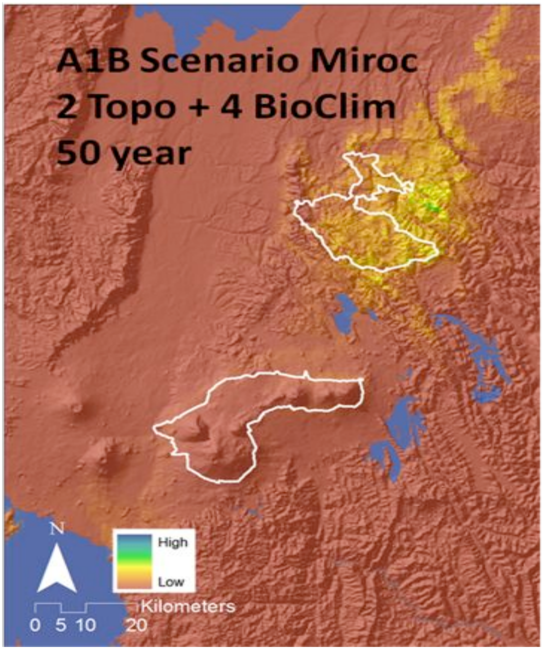
Figure 10. The future climate scenarios by month show an increase in temperature (C◦) and generally heavier precipitation (mm). Every future scenario examined is warming in every month. The future scenarios also generally point to increased precipitation.

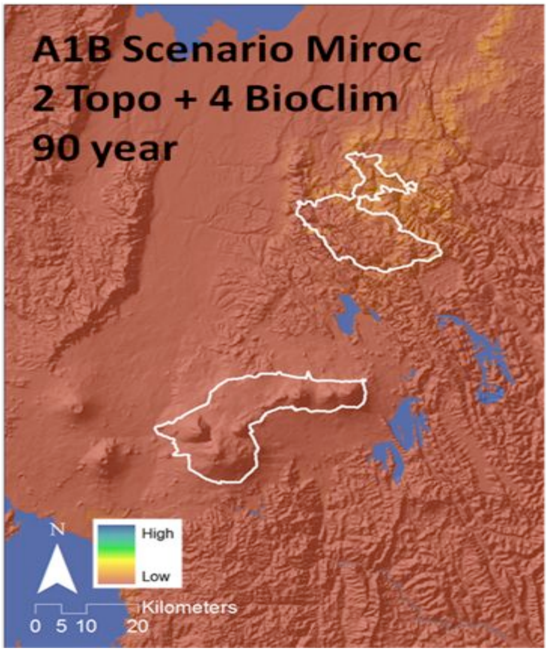
Species distribution models produced using the IN modeling group data (The Russian modeling group) were very similar to species distribution models using the BCCR group's (Norwegian) scenario models. Therefore in the rest of this report we present species distribution models based on the BCCR and the Miroc models, but not the IN.

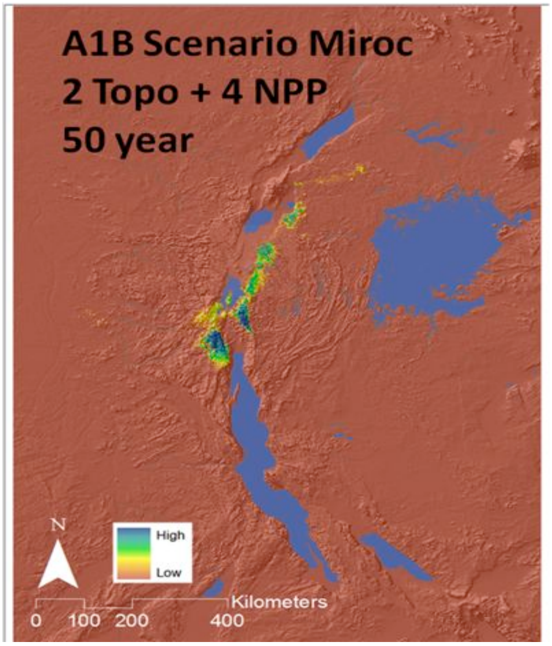
For the Miroc A1B, species distribution models produced using topography and the 4 BioClim predictors, predict that suitable habitat within both protected areas will decline severely by 2050, and then nearly completely disappear by 2100. This result is visible in Figure 11 for both the local and the ecoregional scales.  However, under the same scenario (A1B) and modeling group (Miroc), but using topography and 4 NPP, species distribution models show remaining habitat. The difference is that this habitat has shifted east, out of the Virunga Volcanoes by 2050, and by 2090 half the suitable areas within Bwindi are mostly gone (Figure 11).

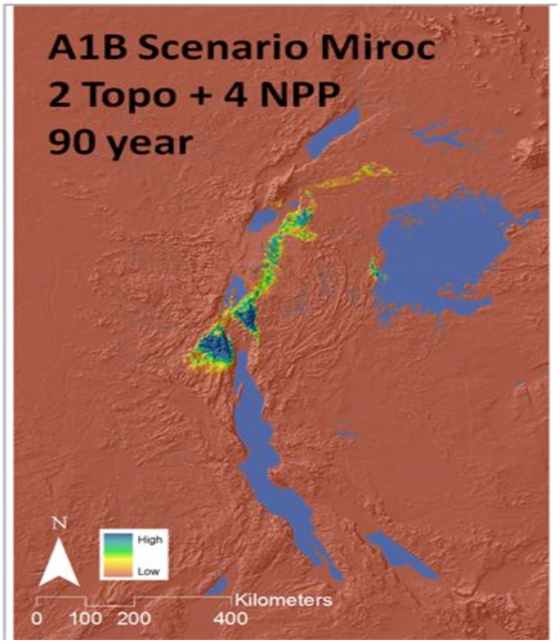





A1B Scenario Miroc
2 Topo + 4 BioClim
50 year
N
High
Low
Kilometers
0 5 10 20


A1B Scenario Miroc
2 Topo + 4 BioClim
90 year
N
High
Low
Kilometers
0 5 10 20


A1B Scenario Miroc
2 Topo + 4 NPP
50 year
N
High
Low
Kilometers
0 100 200 400


A1B Scenario Miroc
2 Topo + 4 NPP
90 year
N
High
Low
Kilometers
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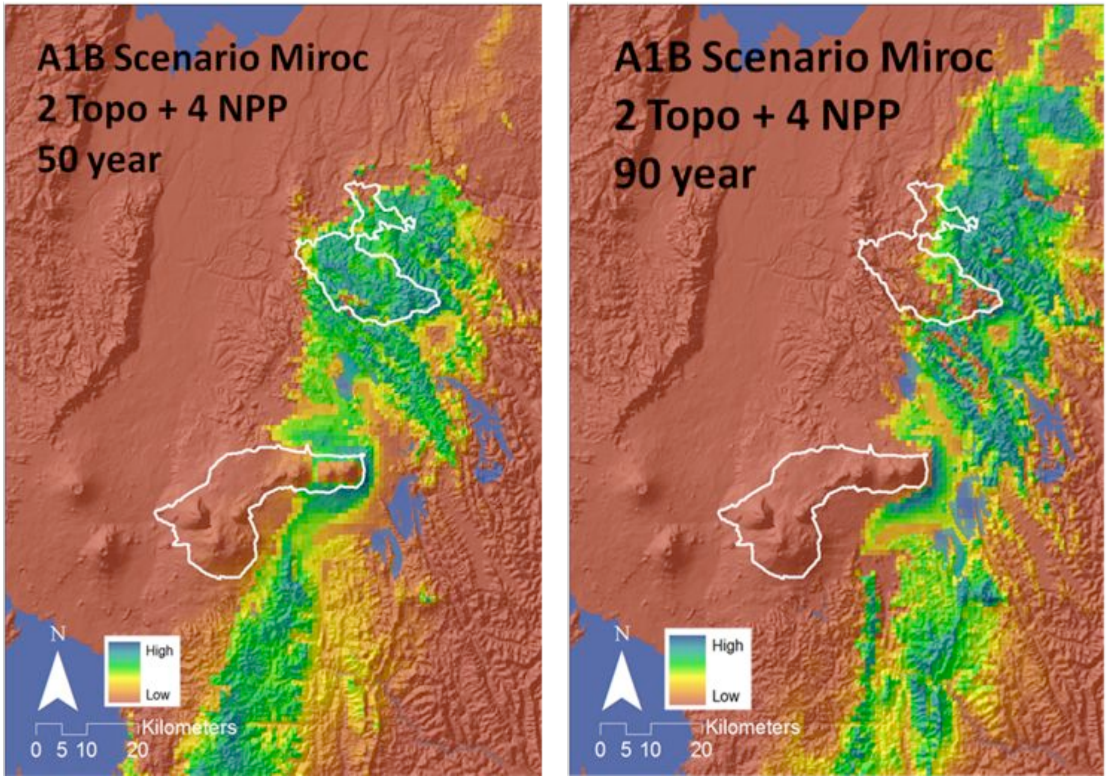
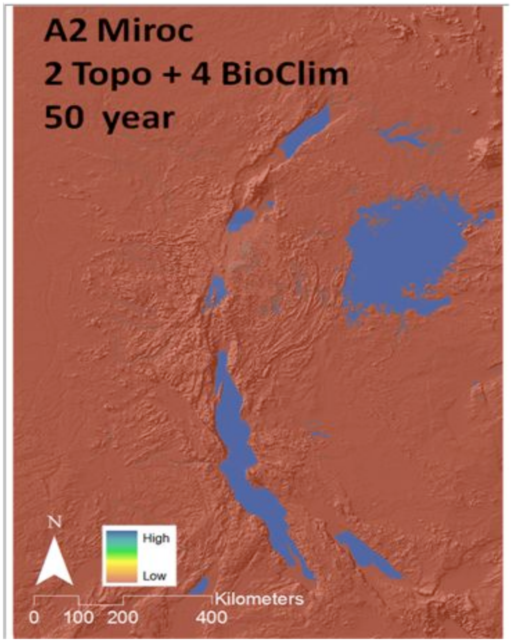
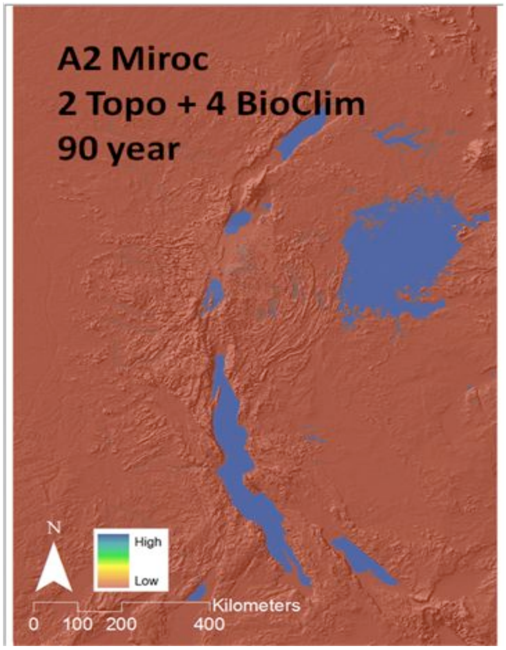


Figure 11. Species distribution models using the future climate scenario A1B by the Miroc group, showing divergent predictions of suitable range with plant productivity (+ topography) indicating remaining, but shifting range, while BioClimatic variables (+topography) project near entire loss of suitable range at both local and ecoregional levels.

For the Miroc (Japanese) A2 scenario, species distribution models produced using topography and the 4 BioClim predictors, suitable range is completely gone at the local and ecoregional scales by 2050 (Figure 12). But, when using topography and 4 NPP, the species distribution models indicate initial decrease but then increasing habitat in the Virunga mountains, but Bwindi has become unsuitable by 2050 (Figure 12).


A2 Miroc
2 Topo + 4 BioClim
50 year
N
High
Low
Kilometers
0 100 200 400


A2 Miroc
2 Topo + 4 BioClim
90 year
N
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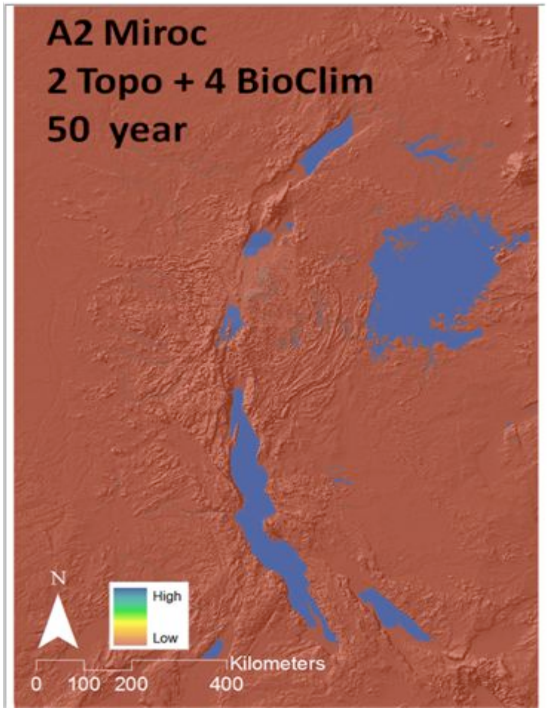
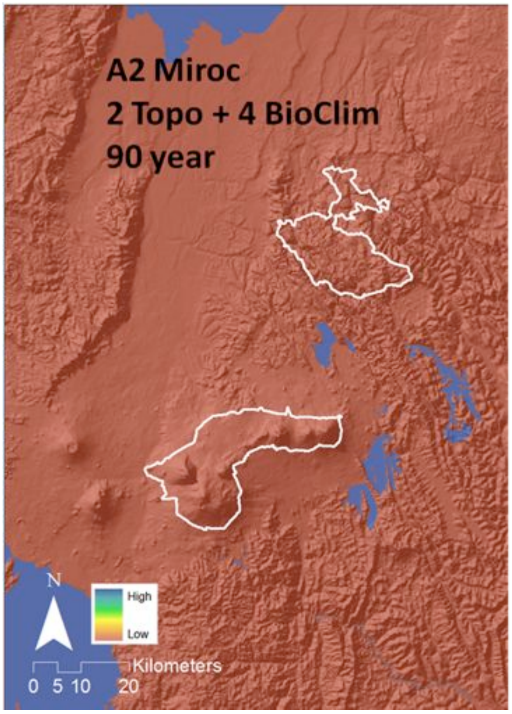
Kilometers
0 100 200 400


A2 Miroc
2 Topo + 4 BioClim
50 year
N
High
Low
Kilometers
0 100 200 400


A2 Miroc
2 Topo + 4 BioClim
90 year
N
High
Low
Kilometers
0 5 10 20

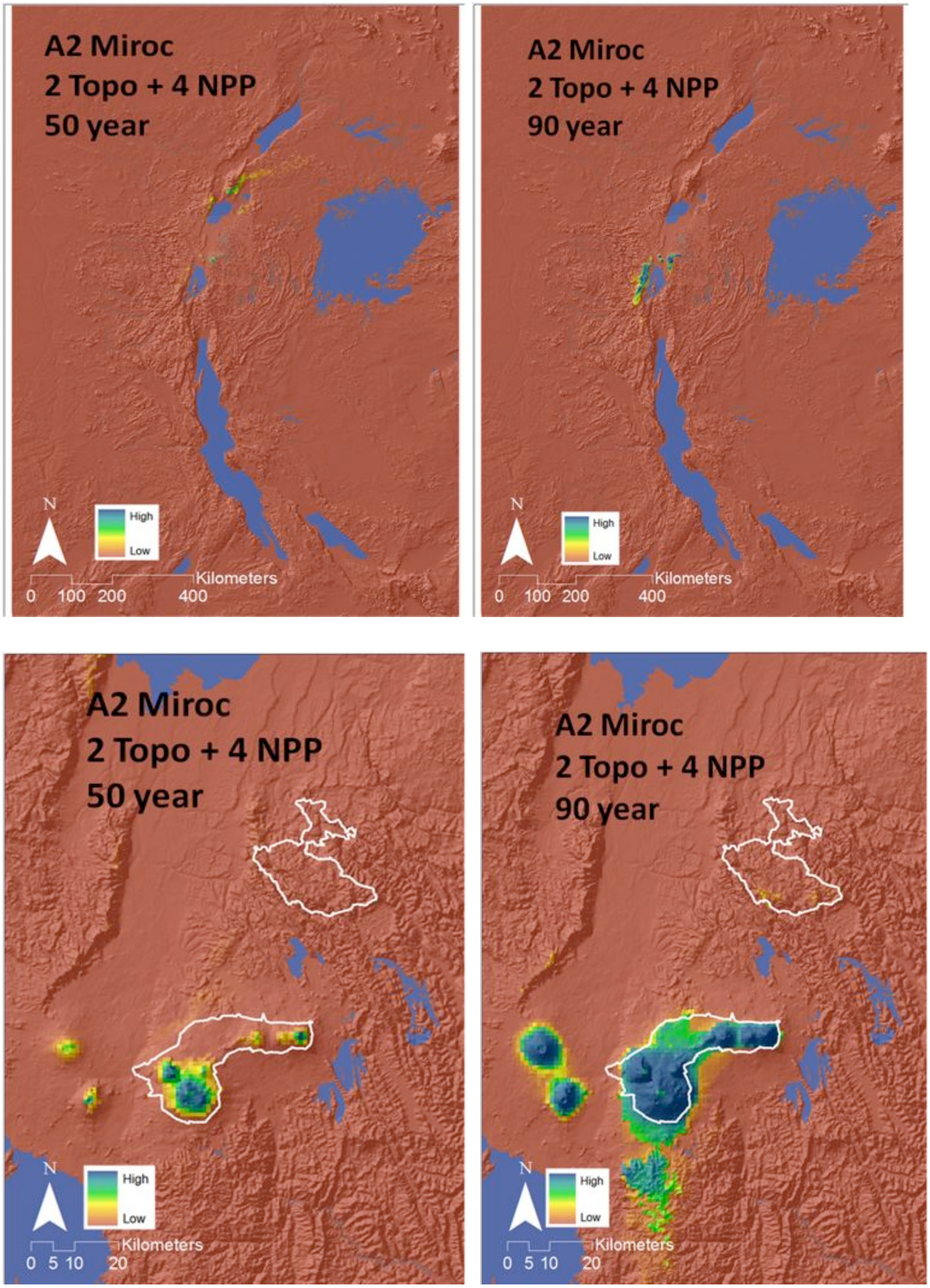
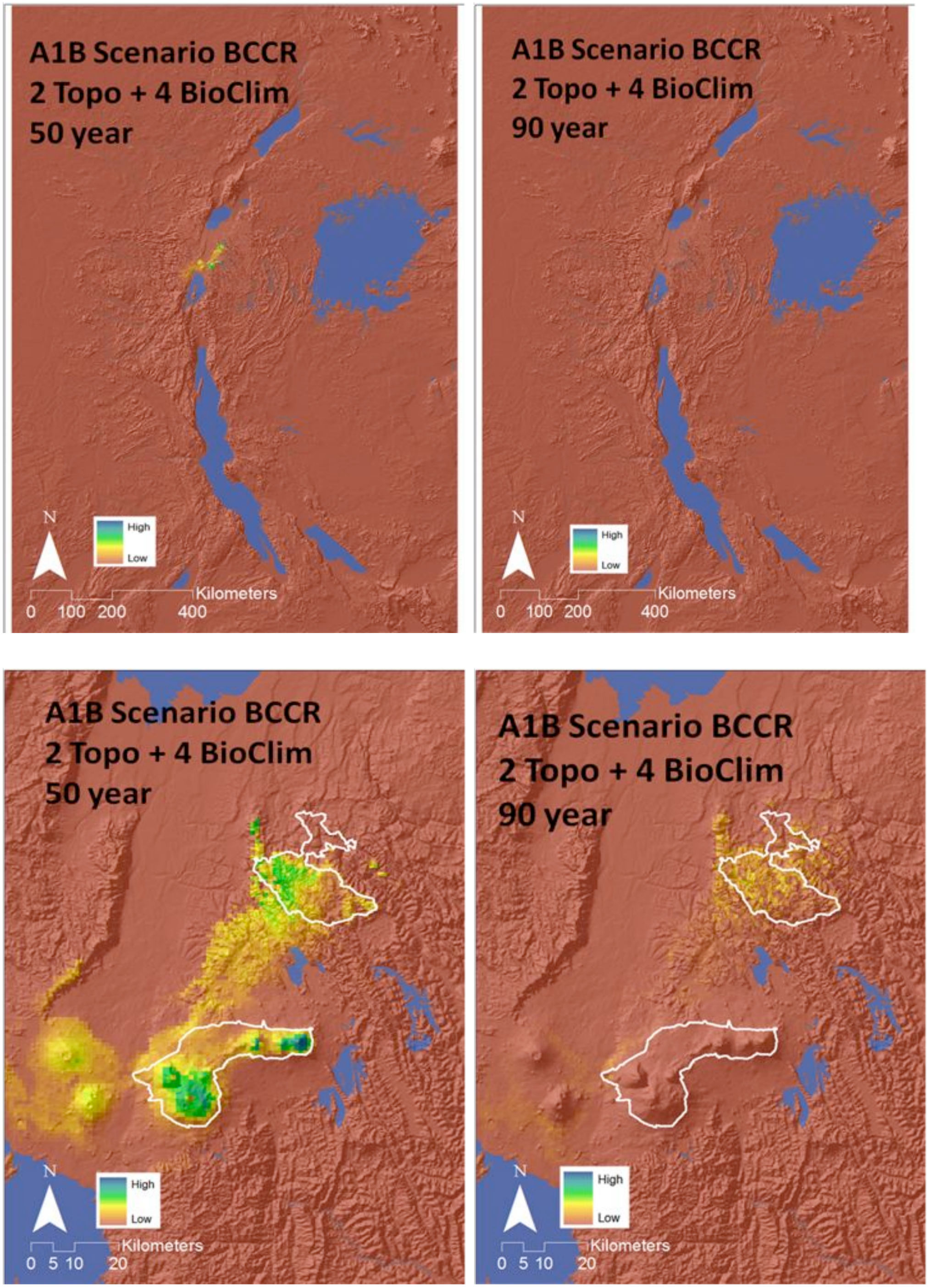


Figure 12. The SDMs using future scenario A2 by the Miroc modeling group

For the Norwegian BCCR outputs under the A1B scenario, using the topography + 4 BioClim predictor variables, suitable habitat declines in both protected areas by 2050, and then nearly completely disappears from the Virungas and is greatly degraded in Bwindi by 2100; this is visible at both the local modeling and the ecoregion modeling levels (Figure 13). The species distribution models using topography + 4 NPP  for the A1B scenario, indentify that both protected areas are still viable in 2100, and some areas around other rift lakes become suitable as well (Figure 13).



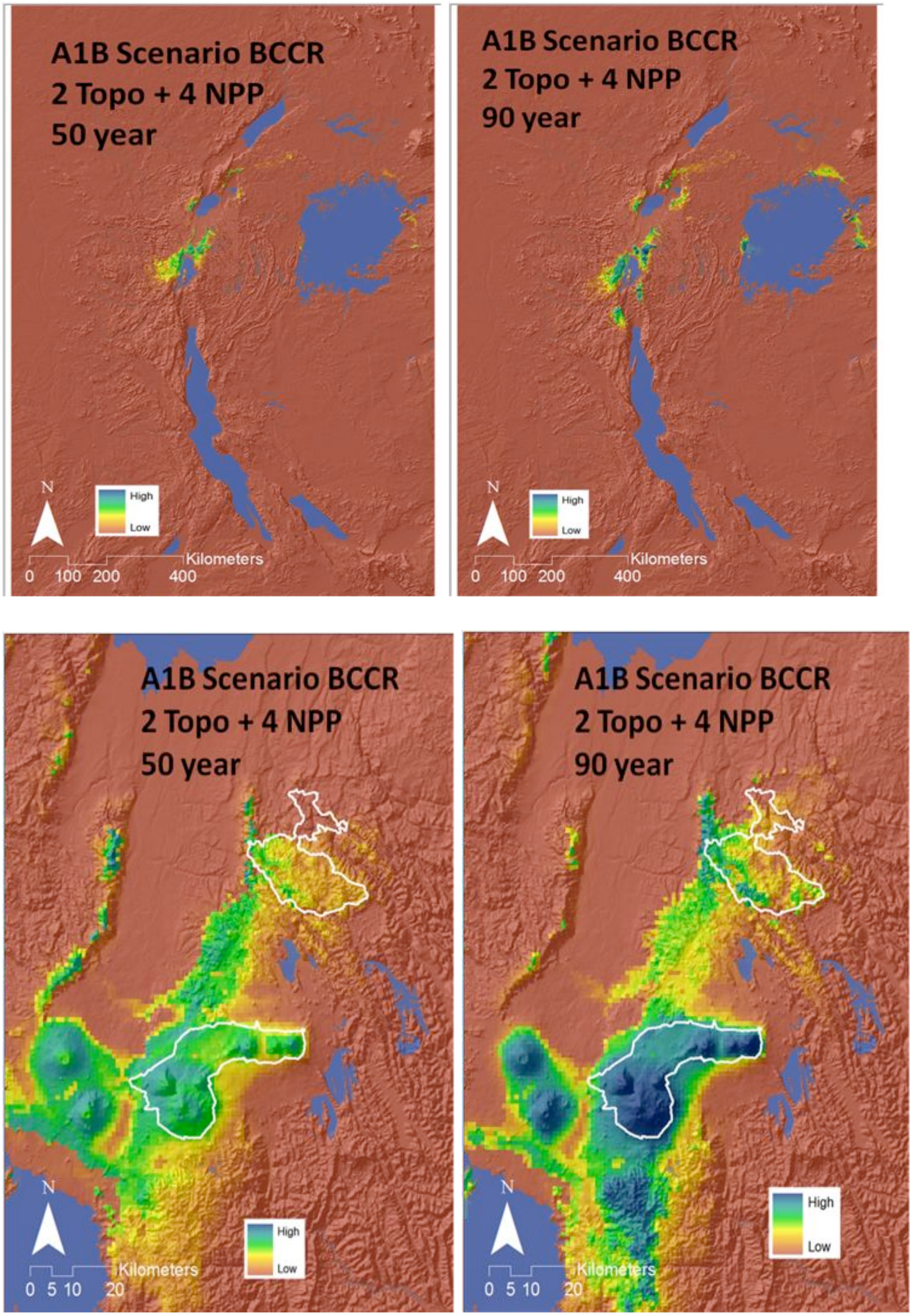
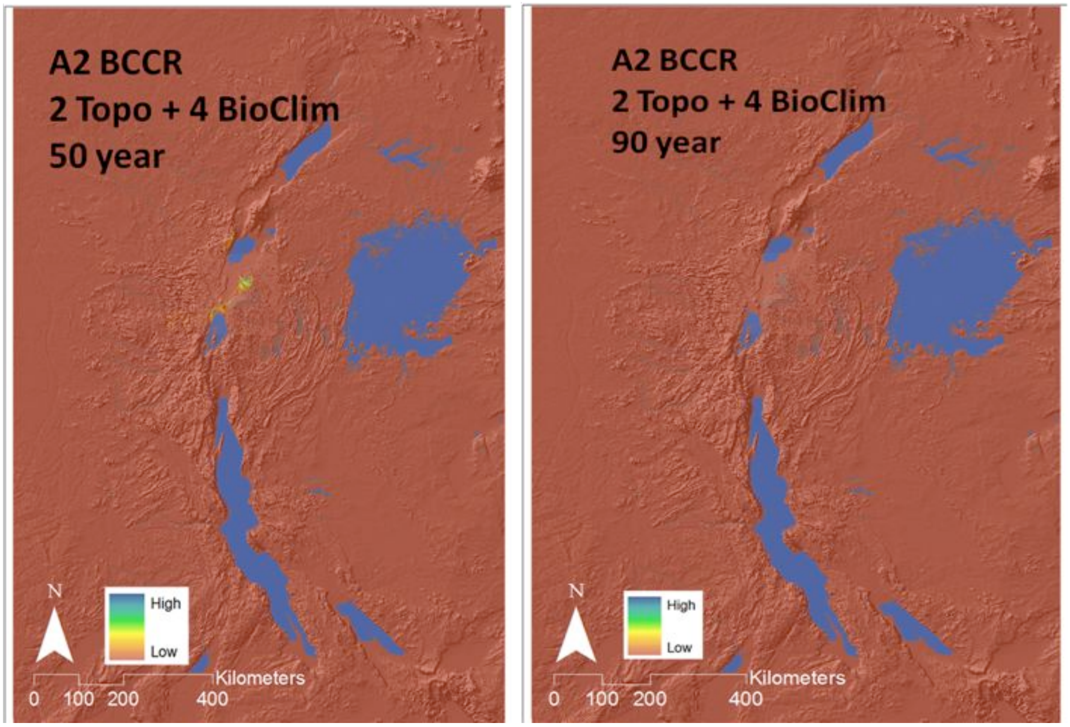
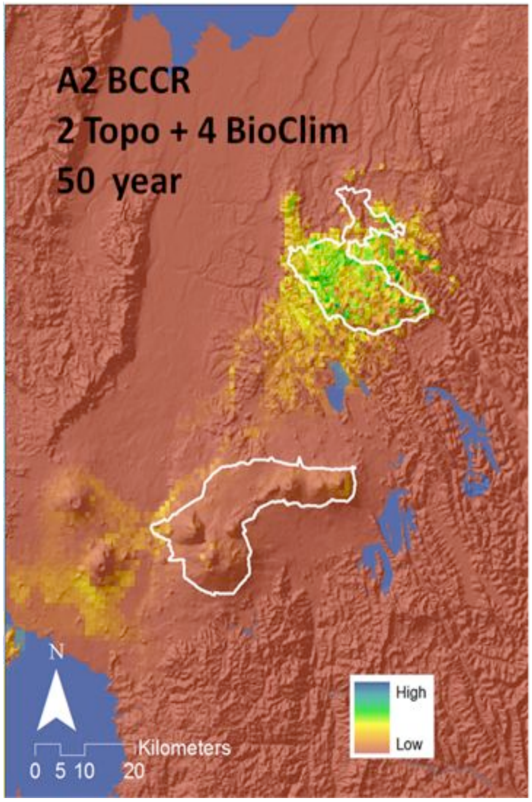
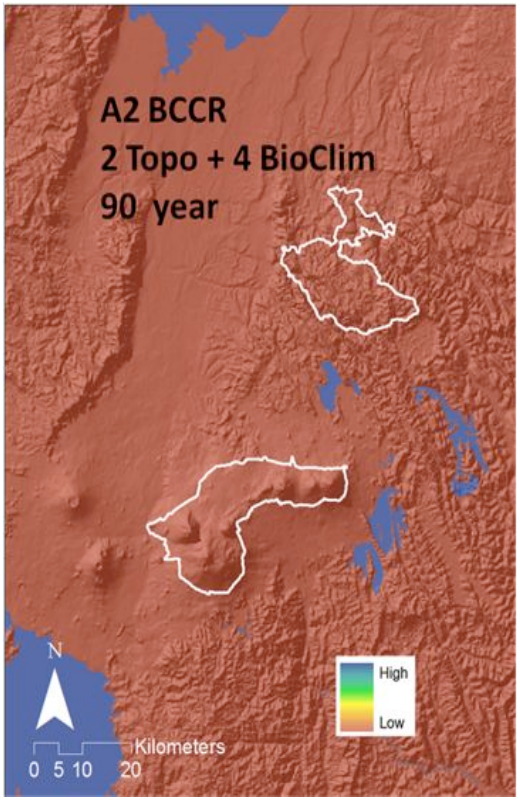


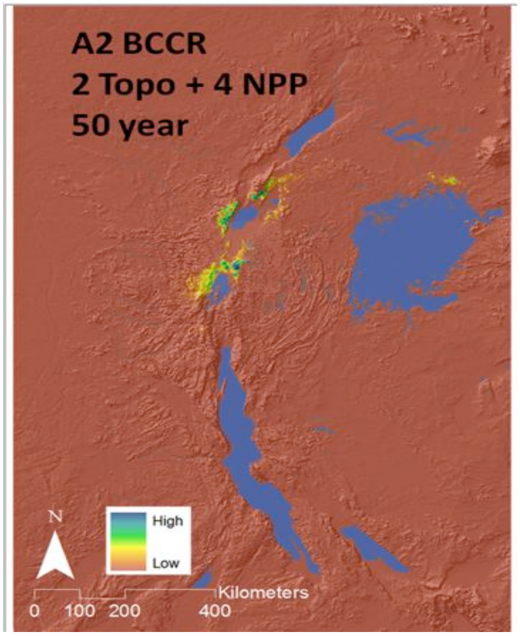
Figure 13. The SDMs using the future climate scenario A1B by the BCCR group

For the BCCR using the A2 scenario, under the topography + 4 BioClim predictor variables, the Virungas abruptly lose suitability by 2050. Bwindi remains suitable through 2050 and becomes unsuitable by 2100 (Figure 14). Using the topography + 4 NPP variables, both protected areas are still viable in 2100. Terrain to the south of the Virungas, where an ancient rainforest called the Gishwati, used to occur (having been reduced to about 6 km$^2$ at the time of this conference) is identified as potentially suitable range (Figure 14).




A2 BCCR
2 Topo + 4 BioClim
50 year
N
High
Low
Kilometers
0 5 10 20


A2 BCCR
2 Topo + 4 BioClim
90 year
N
High
Low
Kilometers
0 5 10 20


A2 BCCR
2 Topo + 4 NPP
50 year
N
High
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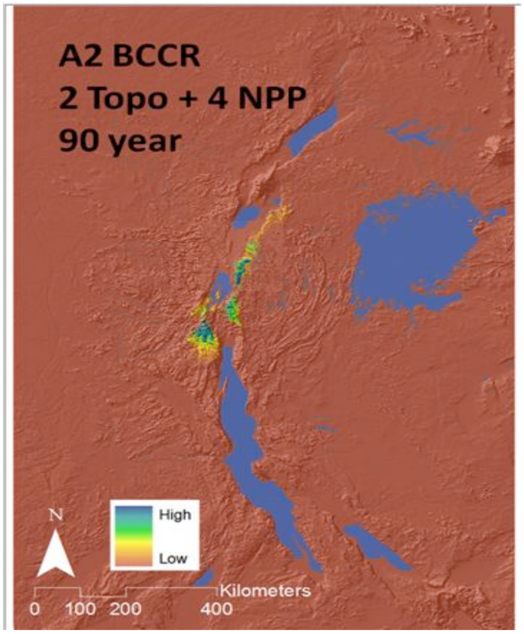
Kilometers
0 100 200 400


A2 BCCR
2 Topo + 4 NPP
90 year
N
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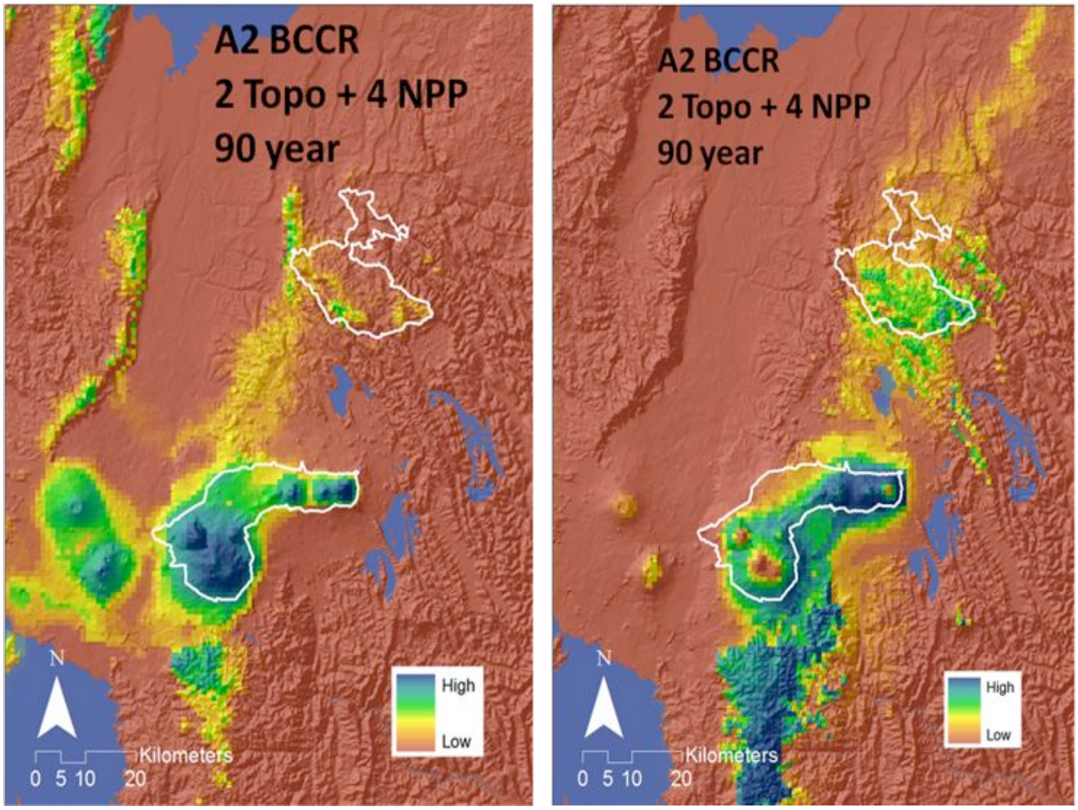

Figure 14. The SDMs using the future climate scenario A2 by the BCCR group

## V. Interpretation of Model Results for Mountain Gorilla Management

*Tradeoffs between park expansion with restoration and better enforcement*

One of the big questions facing gorilla conservation biologists is whether to try and expand the parks where the mountain gorilla is found. The interest in this option is not in small part due to the already diminished extent of some of the four parks. For example, the Parc National des Volcans in Rwanda had lost about half of its original extent to incursions by landless and displaced peoples by the middle 1970s. While mountain gorilla population numbers have since increased in the remaining park lands, it is recognized that suitable habitat which formed below the bamboo zone, in the *Neptomia* zone, has for the most part been eliminated. The workshop also led to some discussion about whether the remaining Virunga habitat sits unnaturally high for mountain gorilla, which, if so, further supports an argument for expanding the park boundaries.

Expansion of any of the four parks would entail the purchase of land from local people, the replanting of that land for forest restoration, and the hope that gorillas would then use these new habitats. SDMs driven by current and future climates can permit assessment of whether areas replanted to forest are viable for mountain gorilla now, and whether they would remain so into the future. The good news is that under current climate scenarios, suitable locations are to be found between the two parks, and also to the south of the Virungas.

Species distribution modeling informs this question by allowing consideration of what is likely to happen to lands that could potentially be included in an expansion under future climates. The investment in reforestation and human relocation would hardly seem worth the cost, if in 40 to 100 years the region would become unsuitable as gorilla range.

The gorilla experts who reviewed the SDM results in the workshop were generally skeptical that temperature was the driving factor for the present distribution of mountain gorilla. They pointed out that the proximity of a sister sub-species, the Eastern lowland gorilla, at a much lower elevation is evidence that mountain gorilla are likely more adaptable to changing temperatures than was indicated by the BioClim-based future SDMs, which almost uniformly have the mountain gorilla parks losing most if not all suitable range. The Net Primary Productivity SDMs were considered to be more realistic. Most of the NPP scenarios indicate that the areas adjacent to at least some of the parks will continue to be suitable into the future. This type of model output could be used as part of the justification for expansion of the parks and restoration of the *Neptomia* forests. In the Virungas, this restoration would need to be sensitive to use of the species that currently occur in the *Neptomia* zone, which is the dominant tree species found in the zone below the bamboo belt of those mountains.

Funding for national park expansion might be possible under the need for carbon sequestration. Particularly in Rwanda, where current park organization and protection is very high, the infrastructure may be in place to be able to handle the logistics and challenges of the buy-out of local peoples. With the funding coming from international carbon sequestration programs, the very clear opportunity for tracking the progress of the restoration (because the acquired lands would be predominantly in agriculture before restoration takes place), and the base of personnel to handle the change, it is conceivable that some areas adjacent to the Parc National des Volcans could be restored to forest habitats that would also be suitable for mountain gorillas. One part of the discussion necessary to implement this idea can be informed through the use of the SDMs presented in this report.

### *Gorilla use of currently protected areas*

Mountain gorilla conservation managers have been interested in knowing why some areas of the two regions are not currently used by mountain gorillas. Modeling such as that performed here could assist in understanding this phenomenon.

Nearly all the species distribution models project that gorillas can use the majority of current areas in the Virungas and Bwindi as habitat. In Bwindi, there are few family groups in the northern peninsula of the park, even though habitat appears to be suitable to gorilla biologists when they explore the area visually. There is a road passing through the constricted part of the park, and it is possible that the traffic and noise from the road have been sufficient to keep family groups from moving north to occupy this habitat. Dennis Babaasa, a graduate student working in Bwindi, relayed that recently one family group that was habituated to people had crossed over into the north sector. However, according to the SDMs all parts of all four parks are suitable, with the exception of this northern sector. One possible reason that no range is predicted in northern Bwindi is because we had no observation records to use from this area for training the models.

Perhaps now that a family group is in the region, it will permit this area to be indicated as suitable. Other locations currently missing family groups should, according to the current SDMs, be suitable. Hence their absence may be attributable to any of the wide range of reasons other than suitability, for example, poaching, ranching or other human disturbances.

Under some future scenarios, the parks lose all or nearly all of the suitable range for mountain gorillas. The likelihood is that the future will bring an even stronger influence of warming climate than the mean warming reported here, because $CO_2$ concentrations have already exceeded some of the lower scenarios. Stronger warming would bring intensifying of effects, such as droughts, heat waves, etc. However, as mentioned above, if NPP is a better predictor than temperature, then the parks continue to offer at least some suitable range under most scenarios.

*NPP- plants and vegetation, drought and research needs*

The NPP-based models indicate more habitat will be available in the future than do the climate models. While we felt the NPP model outputs were the most realistic of the various predictor variables examined, there is also opportunity to improve them. Discussions at the workshop on this topic led to a review of the plant foods that are most commonly used by mountain gorillas. While they eat over 200 species of plants, a subset of about 20 make up the majority of their diet. Despite the apparently great flexibility of gorillas to adapt their diet, behavioral observers felt that the gorillas actually rarely will try new species of plants to eat. This means that they may be more tightly tied to the location of their primary food plants than would be expected merely from examining the list of their food plants, at least until they try, and eat, new suitable plant species. It also means that if new invasive species move into the parks, and comprise the majority of the NPP, this could compromise the food security of mountain gorillas.

Therefore, modeling the distribution of the most important food species becomes an important objective in refining SDM estimates of mountain gorilla range, because if they are tightly tied to their preferred foods, the movement of those food species may be a good predictor of the new range of suitable mountain gorilla habitat. We found there were not enough records of the important food species to be able to model their distribution. In some cases there appeared to be enough individual records, but when these were reduced to presence by 1 $km^2$ cells, there were not enough.

Another intriguing possibility has to do with the gorillas' source of water. Currently, the plants they eat are so succulent that mountain gorilla do not appear to have to drink often from open water sources. However, should this water heavy plant species dry out under future warming this may force the gorillas to start to drink surface waters. Dr. Martha Robbins indicated she has observed gorillas drinking from streams in Bwindi on some occasions over the past two years during which there has been a drought. During this period, plants had somewhat dried out. The consequences of a permanent shift to fixed water sources could be that mountain gorillas might become less mobile, because they would be tied to these water sources. Would a less mobile gorilla be able to acquire the necessary plant bio-mass for the daily feeding of up to 50 kgs? This is an open area of conjecture.

We encourage a new research initiative based on these findings. The new initiative would be to survey vegetation plots across the western parts of the Albertine Rift ecoregion, and the eastern parts of the Congo basin. The objective would be to record the presence and location of the important food species, and important structural tree species for subsequent use in species distribution modeling. Since there is also interest in carbon accounting, we propose that these plots be surveyed both in and out of the area parks, and that the general amount of standing carbon be measured at the same time. This type of integrated survey will permit the potential funding to come from the carbon accounting funding sources, but would also provide a regional baseline inventory of plant biodiversity as well as provide a basis for the implementation of SDMs for mountain gorilla (and possibly Eastern lowland gorilla) plant foods.

*Managed Relocation*

A commonly considered management option under climate change scenarios is managed relocation, also called assisted migration. This mostly theoretical (to date) idea is to move a population of a species to a new location thought to be suitable under future climates. The ecoregional scale modeling of mountain gorilla range shown in this report is meant to help inform this question. Mountain gorillas are good candidates for this idea in some ways, because they are limited to just two locations with a total of 680 individuals. Even without climate change, the threat of disease is sufficient to have prompted a large veterinary effort focused at preventing contamination of the gorillas by the visiting tourists. A third viable population in another location would go a long way towards providing better long term security. However, we recognize that there are many considerations, not the least of which is the considerable monetary incentive to keep the entirety of the mountain gorilla populations where they currently are, and the extreme risk incurred by placing precious mountain gorillas in an entirely new, un-vetted location subject to new food, disease potential, competition with other species, etc. The purpose of this section is not to answer whether managed relocation should be done, as could only be decided by home countries. The purpose of this section is to ask, “Are there locations which would be suitable for mountain gorilla relocation within the Albertine Rift?”

To inform this question we looked at the ecoregional scale for other suitable range in the SDM outputs. Under the current time frame a mountainous region due east of Queen Elizabeth National Park in Uganda shows up as suitable under both the topographic and the NPP models, as does a stretch of the rift to the west of Lake Kivu. Mt Elgon, on the border of Uganda and Kenya also shows up as suitable under the topographic and BioClim models. However the three models don’t have any other places in which even two of them are agreement.

The options for managed relocation seem to be slim, with few of the models indicating suitable habitat in other locations. However, using NPP rather than climate variables suggests more potential locations that could become mountain gorilla habitat, particularly to the west and south of Lake Kivu. This is an area that needs further development.

## Acknowledgments

Data to conduct this study were provided by the following people and groups. We thank everybody who helped to make this study possible: Dr. Augustin Basabose (IGCP); David Williams (AWF); Dr. Martha Robbins (Max Planck Institute); Dr. Andy Plumptre (WCS); Maryke Gray; Dr. Robert Hijmans (U. California, Davis); Rangers and field workers from all the parks; the organizing team from EcoAdapt; and funding from the John D. and Catherine T. MacArthur Foundation. In addition, we thank Gerard Caddick, founder of Terra Incognita EcoTours.

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## Appendix I

List of edible plants for mountain gorilla in Bwindi Impenetrable Forest. This list is not intended to be comprehensive, but is a list that was developed and shared with us in conjunction with data also shared to us by Dr. Martha Robbins, Department of Primatology, Max Plank Institute, Leipzig, Germany.

**Most commonly eaten herb species to consider:**
The most commonly eaten herb species in the eastern part of the park (Ruhija):
Basella alba
Mimulopsis arborenscens (might be called Brillantaisia arborenscens in some places)
Ipomea sp
Mimulopsis solmsii (this is probably also one of the most common herbs; its everywhere)
Mormodica sp( probably best to combine m. calantha and m. foetida)
Peucedanom linderi
Urera hypselodendron
Urtica massaica

**The most commonly eaten herb species in the western part of the park (Buhoma):**
Basella alba (also very commonly eaten in the Virungas and Kahuzi-Biega)
Clitandra cymulosa
Laportea alatipes
Mormodica spp.
Palisota mannii
Rubus sp.
Urera hypselodendron
Urtica massaica

**Fruiting trees that are probably most important for the gorillas:**
Bridelia micrantha (only in Buhoma; there is almost none in Ruhija sida)
Chrysophyllum sp.
Myrianthsu hostii
Maesa lanceolata
Psychotria mahonnii
Ficus (problem differentiating between species, so maybe you could combine them; they are also important fruits for chimpanzees)
Syzigium guineense
Cassine aethiopica

# 7.0 Developing a Climate Change Adaptation Framework for Mountain Gorilla Conservation

## I. Overview

Climate change adaptation is an “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2007). In other words, adaptation activities are those performed to reduce the negative effects of climatic changes, or to take advantage of any new opportunities brought about by climate changes. It has emerged in recent years as a necessary response to and preparation for the unavoidable impacts of past, current, and projected greenhouse gas emissions. Creating a robust future in the face of climate change is the primary goal of climate change adaptation.

Conservation, natural resource, and development agencies around the world have only recently begun to grapple deeply with what it means to reduce the vulnerability of their work to climate change. The field of adaptation is growing rapidly, but in an ad hoc fashion. In general, efforts focus either on **decreasing a system’s vulnerability** to climate change and its effects, or **increasing its overall resilience** (Lawler 2009; Levin and Lubchenco 2008; Pew Center 2009).

One approach to making adaptation a reality is to work to increase the ability of a system to withstand (resistance), recover from (resilience), or accommodate (response) climatic changes and its effects (Millar et al. 2007). There is not one correct or best approach, and what works well in the short term may not over the longer term.

**Resistance** efforts focus on limiting change or increasing the ability of an ecosystem or species to remain relatively unaffected. Examples include increased prevention methods and accelerated efforts to fight fires, or aggressive removal of invasive species. Such ideas fall into the category of early defensive actions, but over time, as changes accumulate, they may begin to fail and become untenable. It is important to note that some of these kinds of actions are targeted at the short term and should thus be focused on the highest value resources. Others, such as reforestation, have long term effects and value.

**Resilience** efforts focus on increasing the ability of a system to recover from change, that is, return to its prior state over time. This might include supporting food web diversity or genetic diversity within populations. Obviously, this will not be completely effective if climatic and environmental changes are extreme and the prior state of the system is not an option.

**Response** actions are those that enable a system or components of a system to change to accommodate climatic and accompanying environmental changes. Responses are enabling activities that support species range shifts, ecosystem shifts either spatially or in terms of species composition, and directed evolution (e.g., agricultural breeding). Monitoring changes in species’ ranges and other behavioral, phenotypic, or physiological changes will lead to understanding of the direction and character of ecosystem and species responses. Response actions can then be taken to advance, accelerate, or promote those natural changes. Examples include mimicking or assisting in species migrations from one habitat to another. Additionally, one could introduce high value plant species in a variety of areas likely to serve as refuges. A third example is planting high value plants in anticipated corridors or buffer areas, to assist their movement or transition to new locations.

Given the emerging nature of the field of climate change adaptation and the importance of developing place, species, and organization-specific strategies, stakeholder engagement is critical to developing adaptation plans and processes. The White Paper process has sought to build participation by all parties involved in mountain gorilla science and conservation, as well as in conservation, climate science, and development in the regions surrounding the areas where mountain gorillas persist.

## II. 'Climate Camp' Workshops

*Initial stakeholder meeting*

We held a small stakeholder meeting in the Fall of 2009 to obtain initial input into project design, to introduce the project goals and general time table to key stakeholders, including members of the Transboundary Core Secretariat and park directors from each country, as well as some of the scientists currently involved in studying climate change and climatology in the region. The goal of this meeting was to get ideas about how to proceed, what the key mountain gorilla vulnerabilities might be, to obtain feedback on our approach, and to obtain buy-in from relevant officials. This meeting helped us to identify additional stakeholders and to form our specific approach for developing a vulnerability analysis. This was followed by two larger stakeholder workshops, phased to allow time for stakeholders to be identified and be engaged, for background to be compiled, for modeling to take place and interpretation of findings to date.

*Stakeholder 'Climate Camp' workshops*

The goal and primary purpose of the two subsequent stakeholder or 'Climate Camp' workshops was to initiate and progress the five main steps in the process actions described in Chapter 1. To reiterate the five main steps are:

1) **Clearly identify the mission, vision, or goals** of the group doing the assessment and of the assessment itself.
2) **Assess the vulnerability** of the mission, vision, and goals to climate change.
3) **Identify and design management, planning, or regulatory actions** that address the vulnerabilities identified in step 2.
4) **Design and enact monitoring programs** that assess changes in those climate and environmental parameters most important to the system in question and determine if adaptation measures are delivering the desired management or policy outcomes.
5) **Create an iterative process** by which activities can be reevaluated and redesigned, if necessary.

Building on background documents and modeling efforts, these two workshops pushed forward the assessment of mountain gorilla vulnerability to climate change (Step 1). Brainstorming and prioritizing adaptation and research ideas by discussion groups led to significant progress towards designing management, research, monitoring, and policy options to address those vulnerabilities (Steps 2 and 3). Chapter 8 puts the workshop results and suggested adaptation options into a broader framework for evaluation and implementation. It will be up to all stakeholders working on mountain gorilla conservation to advance Steps 4 and 5, building on the work documented in this White Paper.

The second and far larger stakeholder workshop was held February 15-17, 2010, in Gisenyi, Rwanda. The workshop was attended by 39 participants, including 6 representatives from the natural resource agencies of Rwanda, Uganda and the Democratic Republic of Congo, 21 representatives from non-governmental organizations or foundations, and 9 from research institutions or universities. Twenty-three of the participants were African nationals.

After modeling results were presented and discussed with workshop participants, the group separated into three working groups: (1) gorilla ecology, health and conservation; (2) park management; (3) regional socioeconomic considerations. The groups met over the course of a day to discuss specific topics in light of modeling outcomes, and to brainstorm adaptation, research, monitoring and policy ideas. Each group then reported back in plenary and discussed general ideas for how to prioritize or rank the ideas. In final meetings of the working groups, the groups ranked, scored, or narrowed their suggestions for adaptation, research and monitoring activities, as well as policy changes. Participants in each group are listed in Appendix 1. A comprehensive list of suggestions, scores, and urgency assessed, designated by the group that generated each, was then presented in a table.

The third and final stakeholder workshop in this White Paper process was held on September 20th in Kabale, Uganda. The workshop was attended by 32 participants, including 4 representatives from the park authorities of Rwanda, Uganda and DRC, 11 representatives from local government, 9 representatives from non-governmental organizations or foundations, and 8 from research institutions or universities. Twenty-eight of the participants were African nationals.

During the final workshop the group met over the course of one day to review and prioritize the comprehensive list of adaptation suggestions from the second workshop. The table of adaptation priorities developed was modified to reflect the changes made during the final workshop, and this table is discussed in Chapter 8 and attached in full in Appendix II.

## III. Evaluating Adaptation Strategies

The stakeholder engagement process is remarkably effective at generating creative ideas and drawing on deep institutional, scientific, and on-the-ground knowledge to assess the ideas. Ultimately, funding, personnel, conflicting priorities, logistics, or uncertainty force organizations to choose among adaptation ideas given limited resources. Many approaches to ranking adaptation options exist, but most fall into one of the categories explained in the box, below, which includes: *importance*, *urgency*, *feasibility*, *cost*, *economic efficiency*, *consistency*, *equity*, *climate change impacts*, and *performance under uncertainty* (see Box 1 taken from Hansen and Hoffman 2010).

One criterion to highlight from the above list is *no regrets and co-benefits*. This focuses on whether the benefits of a course of action outweigh the costs; or, conversely, it asks whether costly or irreversible harm might result if the action or the assumptions underlying it turned out to be flawed.

Some additional criteria highlighted by several other authors are *flexibility* and *speed of implementation*. *Flexibility* considers the question: given the uncertainty in climatology and climate change predictions, coupled with the uncertainty of the future responses of all sectors affected, how readily can plans be altered or adjusted as more information comes into play? *Speed of implementation* considers the "low hanging fruit" dictum, which implores one to consider simple, obvious, and clearly beneficial options that can be quickly applied (see also Asia Development Bank, 2005; Bizikova et al., 2008; de Bruin et al., 2009; Lawler, 2009; Titus, 1990).

During the second stakeholder workshop, participants were asked to generate their own criteria for evaluating suggestions rather than using pre-existing criteria, and then to attempt to score or rate the suggestions accordingly.

The socioeconomic group narrowed topics down to 8 categories they considered to be most important. Within each category, they scored ideas as being of immediate concern, or of "medium or long term" concern. The gorilla ecology, conservation and health group ranked each of the suggestions as 1 or 2 based on overall importance or urgency, and then within each ranking with 0 to 3 stars to indicate incremental importance within each ranking. The park management group used two scoring criteria: time frame (immediate concern, of concern over the medium term, or, of concern over the long term) and impact (high, moderate, or low based on the extent to which climate change, per se, would exacerbate this problem or pressure).

All of the suggestions have been combined into one table (Appendix III) to illustrate the large array of ideas generated by this process. Each idea was assigned a designation under "Activities/Pressures" to indicate the type of existing pressure to which the group was responding. Different groups often came up with the same concerns, and sometimes the same adaptation, research, or monitoring suggestions; groups also put forth some unique ideas deriving from their differing perspectives.

Each suggestion has a designated "sensitivity." This is an assessment of how likely the pressure is to become greater under climate change, per se. For example, "gorilla illness" is an "Activity/pressure" designation. The sensitivity is "high" which indicates that those present felt that climate change is highly likely to increase gorilla illness. By contrast, the sensitivity for "wood extraction" was "medium," indicating that participants felt that climate change was only moderately likely to directly increase wood extraction. In a third example, the sensitivity of "carrying capacity of gorillas" was "unknown," as there is very little information on this potentially important component of gorilla biology. Because the gorilla ecology group felt that knowing the area's current and potential future carrying capacity for gorillas is critical to protecting them through climatic changes, a number of proposed research options related to this were given that group's highest possible ranking.

To fully evaluate every adaptation, research/monitoring, or policy suggestion, more thorough studies and discussion would be needed. These might involve determining technical feasibility and costing some of the options, reviewing the policy implications, or determining the amount of training required to carry them out.

Nevertheless, many extremely important pressures were highlighted by the discussion groups and important suggestions were put forth. The final workshop looked at all the ideas generated by the second workshop and prioritized the adaptation strategies. The group split into the same working groups and in addition to prioritization, the groups looked at the time frame and allocated responsibility. We highlight here issues within each group from both workshops that were particularly brought to the fore, or exacerbated by the consideration of climate change. Most of the issues discussed by the groups had previously been raised in discussions of conservation or development in the region. Some issues were uniquely raised by the discussion of climate change, or stand out as needing especial attention.

### *Gorilla Ecology, Conservation and Health Group:*

The gorilla ecology, health and conservation group raised many important issues about which not enough is known to determine the possible effects of climate change. In particular, the role of seasonality of rainfall peaks and nadirs, or other triggers, in plant flowering and fruiting phenologies is poorly understood but potentially critical for regional ecology. If important food plants change flowering times, pollinators may not be available for pollination and fruiting might not occur. As a result of these and other information gaps, the group highlighted proposals to study the distributions of key pollinators and food plants, fruiting and flowering phenologies and to monitor changes over time, as being important to initiate where not present, intensify where present, and follow up on regularly.

The question of water availability for mountain gorillas was also raised. It has long been noted that gorillas rarely drink open water, but rather obtain much of their water from water-rich plants such as forest celery. In drier periods, gorillas move to higher ground where plants have higher water content. However, recent observations report gorillas drinking open water more frequently at times. Studies of gorilla water use and seasonal changes were highly recommended, along with training of park staff in observing, monitoring and measuring water use, availability and seasonality.

Given that climate change could influence forest size, distribution and composition both directly through effects on tree survival and reproduction and indirectly by altering land and resource use by nearby human populations, the question of the carrying capacity of the parks for mountain gorillas was also highlighted as an important consideration. Little is known about carrying capacity and what it depends on. The group strongly recommended continuing research and monitoring of population size, dynamics reproduction and growth rates, especially in conjunction with gaining an improved understanding of habitat quality and use by gorillas.

It should be noted that the issues of primary concern highlighted by this working group were not adaptation suggestions per se, but rather the lack of background information needed to recommend specific actions. Explicit consideration of possible climate change effects on mountain gorilla resources led to a specific and urgent research and monitoring agenda. To relate these examples to the resistance-resilience-response rubric, it is possible that resistance or resilience actions could become necessary for mountain gorilla survival should conditions change rapidly. For example, park managers could provide water or food for gorillas under extreme circumstances. The long term goal is that the gorillas adapt to the changes, either behaviorally, physiologically, or eventually, genetically, so generating appropriate response actions is desired. The discussion group realized that there was a dearth of key background information about gorilla resource use and that this gap must be filled in order to develop appropriate response actions.

The discussion in the gorilla ecology, conservation and health group raised a number of possibilities as well as unknowns regarding climate change impacts, heightening awareness of potential new risks to gorilla health, as well as increased sources of infection and transmission. As in the previous category, many of the newly considered threats did not lead to adaptation recommendations because so much of the information was unknown. Thus, the group strongly recommended ongoing monitoring of gorilla health, along with increased knowledge sharing with groups monitoring and studying emerging and intensifying risk to human health, such as insect borne, respiratory pathogens, and water borne diseases and parasites. Similarly, they strongly recommended increased communication with groups monitoring and studying human-livestock-wildlife disease transmission in the region. The active engagement of the Mountain Gorilla Veterinary Project and other groups involved in gorilla health maintenance, illness prevention, and intervention activities will be critical. While the MGVP has always kept up to date on disease and pathogen threats, the possibility for rapid changes in transmission, infection, and immune response to new and existing threats with climate change heightens the need for aggressive and proactive knowledge-sharing. The group also highly recommended comprehensive modeling of diseases over the entire mountain gorilla habitat.

Recommended measures included creation of a pan-African primate pathogen network, development of early warning and response systems based on existing models of human, wildlife and gorilla diseases, development of contingency plans for major disease outbreaks based on advanced scenario-building exercises, and improvement of access to in-country diagnostic facilities.

The knowledge-sharing activities recommended by the group, while not adaptation measures per se, clearly fall into the category of resilience-building. The adaptation measures of highest priority fall into this category as well. While some exposure prevention may be possible, it is more realistic to focus on being aware of emerging diseases and pathogens in the region, and being prepared to support the gorilla population by a variety of means, through periods of illness and rapid transmission, with the hope that they will return to health afterwards.

*Park Management Group:*

Most of the issues of managing park boundaries, such as human-wildlife conflicts, illegal extractive use of forest products, and managing tourism, are reviewed regularly by the various in-country park agencies, and by the Transboundary Core Secretariat and IGCP. Virtually all of the problems currently encountered and addressed by rangers, park managers and park officials were seen as likely to be exacerbated by changes brought about by climate change. Thus the overriding adaptation recommendations were to continue performing the prevention, monitoring, and preemptive activities currently ongoing to protect the parks – but with renewed vigor and sense of urgency.

**The strong impression of the group was that the biggest climate-related risks to the parks were from changes in the livelihoods of human communities surrounding the parks**. As resources become scarcer for humans, the likelihood that park boundaries will be ignored increases. The direct benefits of the parks for people, including limited increased funding to regional infrastructure from national ministries and some local tourism dollars, are somewhat remote. Thus, the penalties for breaking the rules or losing those benefits will be far outweighed by the potential for immediate resolution of human needs using park resources. In particular, the extraction of water and possibly other resources such as fuel wood, timber, and other plant and animal resources, was deemed likely to increase. Much of this activity is currently tolerated at low levels, and there was little information on actual levels of extraction, timing, or numbers of people entering the forests. The group highly recommended beginning to monitor encounters with people removing resources from the forest, keeping track of when, how many, and how much is being taken, as well as from where.

At the extreme, if human communities become desperate for resources or landless due to poverty or other crises, there is a strong risk of human encroachment on the parks, ranging from individual families forming small settlements within the boundaries to large scale deforestation. This sort of behavior did happen during the conflicts in eastern DRC, and happened very rapidly, with little hope of stopping it given the desperation of the human populations involved. Some of the forest was completely denuded and there is no chance for reclamation. Other portions were more sporadically damaged and there are ongoing efforts to restore the forest to a level where it can at least be used as a corridor (Basabose et al., 2010). Several adaptation suggestions address this concern including participation, initiation and involvement by gorilla and parks organizations in efforts to develop alternative incomes, integrated population, health and environmental programs, and collaboration with local governments and communities. In addition, there was discussion of park authorities performing advanced review of areas where there was already a high threat of encroachment. Pre-emptive efforts, such as developing a system of joint forest management or creating multiple use or buffer zones, might be more important in some locations than others. *One specific case already proposed was to upgrade the status of the Sarambwe Reserve in the DRC, which is contiguous with the Bwindi Impenetrable Forest National Park in Uganda and used by mountain gorillas, to increase its protection.*

One additional issue was deemed of high importance: the possibility of fire, stemming from the potential for hotter and drier conditions over the short term. Although fire prevention and extinction are already part of park management, they are somewhat ad hoc. The group strongly recommended developing more elaborate and advanced fire response plans for all parts of the parks. In addition, the existence of Moderate Resolution Imaging Spectroradiometer (MODIS) data from the United States National Aeronautics and Space Administration (NASA) satellites, and its ability to show fires in real time, was brought to the attention of managers. This kind of data, in combination with local meteorological predictions for especially fire-prone conditions, could be an extremely powerful tool to anticipate and quell fires rapidly. An adaptation recommendation was that capacity be built within the park authorities to monitor and interpret MODIS fire data and to develop good working relationships with local meteorological stations, so that there is an early warning system for fire outbreaks.

*Socio-Economic Issues Group:*

The issues that the socioeconomic group deemed of high importance, relative to gorilla conservation, were largely the same issues that are of high importance to poverty alleviation and development concerns without considering climate change. There were many suggestions, falling under several pressure categories. We highlight here the issues that are expected to be exacerbated by climate change, in particular.

Projected regional climatic changes include continuous warming with a very slow increase in precipitation for 20 or more years. If this comes to pass, a period of severe drying could cause failures in a number of systems surrounding the parks. Specifically, water availability to human communities will become scarcer, and will likely cause agricultural and livestock failures, and declines in human health. People living near the parks already travel inside the parks to obtain water; this is estimated to be occurring at a relatively small scale at present, and even though it is not legal, the practice is largely overlooked by authorities. However, if these activities increase, the threat to the gorillas would increase as well. The IGCP and the park authorities are already involved in assisting nearby communities to develop rainwater catchment devices and devices for water storage. Adaptation suggestions from this discussion group included increases in development of rainwater catchment systems, development of shade and water-storage systems, and the implementation of educational programs on water-use reduction, safe storage, and the importance of an intact forest ecosystem for long term water availability.

Current agricultural practices could well fail if there is a severe drought, which could result in desperate populations encroaching on the forests for food. The group highly recommended researching practices that could result in higher crop yields with less water and lower risk of crop failure. These include development of buffer zones around the parks to reduce the risk of crop raiding by wildlife, and to grow or allow the harvest of cash crops within these zones. Although development of buffer zones around the Virunga Massif and Bwindi is difficult due to the extremely high population density around the parks, a buffer zone exists in the Nkuringo area south of Bwindi Impenetrable National Park in which strategies are being trialed for reducing the risk of crop raiding by wildlife. Additionally for several years now preliminary discussions have been held at the level of the Government of Rwanda regarding a possible "extension" of Volcanoes National Park. The group recommended supporting programs of local Universities and research institutes in implementation of integrated pest management programs, introduction of drought resistant crops as well as engineered or hybrid crops that permit higher yields over less space, education about soil erosion avoidance techniques, and further development of micro-financing programs to assist people in making these transitions. There was significant debate around whether engineered crops and micro-financing would be effective in practice. Some group members felt that engineered crops could disempower small-scale farmers and increase agricultural risk by lowering crop diversity.

At a regional level, the group highly recommended improving access to family planning programs and planning for more concentrated settlements further from the forests as means of reducing human pressure on gorilla habitat. The group also recommended increased support of wildlife health initiatives in the region, as well as implementation of wildlife and human health management, response, and early warning systems. This addresses the potential increase in human disease outbreaks should climate change lead to water and food scarcity, sanitation problems, and increases in previously rare pathogens and parasites. In addition to being a problem for humans, this would increase the risk of illness and disease spread to gorillas.

Finally, this group highly recommended continued support of efforts to provide economic valuation of the forest and its resources, especially if these efforts integrate the potential effects of climate change into the relative valuation. The group felt this could be used as an educational tool to help convince local communities that they would be better off retaining the parks and forest intact than allowing or contributing to their degradation, even more so as climate change progresses.

### *Assisted migration: a controversial proposal*

A proposal to design and plan for the possible assisted migration of mountain gorillas to another locality altogether was introduced and discussed in the gorilla ecology, conservation and health group. This subject is highly controversial and there was not agreement among the discussants about a recommendation to look into this possibility. We do not support or oppose this idea, but merely report here some of the arguments surrounding it.

The desire to establish a new, remote population of an endangered species generally arises from a sense of extreme risk. Refugial populations of the species, by definition, are small, live in a restricted location, and are extremely vulnerable. If a catastrophic event were to occur, for instance a lethal disease outbreak, catastrophic fire, comprehensive slaughter or deforestation event, it is possible that the species would go extinct. Establishing one or more new colonies of the species in a distant location minimizes the risk that a single catastrophe would affect all remaining members of the species, and the surviving population(s) could be used to re-establish populations in the former location, if appropriate, or simply represent the survival of the species.

The arguments in favor of pursuing this option in the case of mountain gorillas followed this reasoning. Although there are currently two populations of mountain gorillas, they are only separated by a valley, approximately 25 km in width. If a disease, fire, or other catastrophe were to affect one population, there is a chance that it would affect the other. Because gorillas are vulnerable to many human diseases, it is highly possible that if a fatal disease outbreak was to hit the region, it would be transmitted to gorillas and all 680 (best current estimate) would succumb. This concern drives the desire to consider assisted migration.

Arguments in opposition to this idea are also compelling, however. First, there is no obvious location available at which to start a new population. There is no mountain peak known to have had mountain gorillas in the past, but from which they are currently extirpated. All possible locations have pre-existing ecological communities and the introduction of mountain gorillas would undoubtedly have very dramatic effects on these communities. To threaten the resident species of another location, already very likely to be under conservation pressure, would require a value-laden judgment that puts mountain gorillas above all other species in that locality.

Second, there is no reason to believe that mountain gorillas could withstand being transported and then expected to survive in an entirely new location. It is not known how gorillas learn what and how to eat for example. There was much discussion about how they might learn to shift their diets if current food items were to start disappearing and be replaced with other potential food items in their current habitat. It is even less predictable how gorillas might learn what and how to feed in an environment that contained none of their familiar food items. Along the same lines, the very susceptibility of mountain gorillas to human disease vectors that has led some to promote assisted migration could prove to be disastrous in a translocation scheme. The human and wildlife diseases they might be exposed to in the new locality could take hold and prove lethal to the incipient population.

A third consideration was the political reality of developing such a scheme. Currently, the mountain gorilla conservation efforts and tourism are the major contributors to Ugandan and Rwandan governmental budgets for environmental conservation. Any of the locations proposed for relocation would be outside of Rwanda and likely outside of Uganda. The political strife that could ensue associated with the threat of loss of revenue, not to mention the cost of the project itself, could put strain on a currently stable transboundary management system.

### IV. Research-Based Policy Change

Some proposals included direct changes in policy or changes to research or monitoring whose outcomes could lead to changes in policy. The mountain gorilla conservation community is in the unique position of being part of the Transboundary Core Secretariat (TCS), a trilateral governmental body made up of representatives of the three countries where mountain gorillas reside. In this regard, implementation of proposals to research and monitor facets of gorilla conservation and park management that could lead to policy changes could be relatively straightforward. The Secretariat and the individual park agencies within each country employ park rangers and managers who are already trained in survey and monitoring methods, and who are fully committed to providing information that might be needed to improve policy. For this reason, park-related proposals should be undertaken right away in an effort to collect and compile information necessary for incorporating climate change into park policy and management.

Four park-related proposals were given high priority by the park management group, and one a lower priority depending on what happens in the near future. The first recommendation is to review all park management, planning, and policy taking climate change into consideration and making appropriate adjustments accordingly. The second is to institute a two year review cycle of park policy to allow for accommodation of new climate-related information and models, and feedback from measures undertaken. The third, mentioned above, is to upgrade the status of the Sarambwe Reserve to National Park status to provide higher protection for gorillas using that land, and to increase the coverage of land protected for mountain gorilla survival. The lower priority consideration was to review the gorilla trade prohibitions and actions in an attempt to dramatically slow or stop the trade efforts that still persist in some regions; this was proposed in response to the unpredictable reaction of poachers to climate change pressures. The final, and very high priority proposal, was for the TCS to be involved in the review of existing national policy and legislation related to tourism and the environment, in order to consider climate change in the ongoing policy.

Some adaptation-driven policy changes will relate more to development and country-wide aid issues. There is potential for conflict or apparent conflict of interest between environmental concerns and the needs of the human populations. For this reason, engaging in the research and planning necessary to demonstrate the value of environmental resources in concrete terms (e.g., watershed protection, cloud forest retention) will be a pro-active strategy towards influencing policy changes. The links between forest and wildlife retention and human survival in the region must be made explicit, and policy developed to aid climate change adaptation for human populations will have to include conservation planning.

*Several policy-related proposals were highly recommended by the socioeconomic group.* The first two are directed at planning at the regional level and they encourage the explicit inclusion of climate change in multi-sectoral planning, and managing the landscape as one unit so that the parks, agricultural lands, multiuse lands, human settlements, and infrastructure are all considered under the same rubric. The latter two relate to national governments. First is the strong reminder that no successful planning can occur without working national governments, and recommendations to work toward this end. Second, and final, is the urgent recommendation that each country work faster and harder to develop and institute a clear legal land tenure system. This last recommendation is something that has been under consideration in each country for some time, and which park authorities are aware of as an impediment to park security. The risks are clearly exacerbated under the threats brought on by climate change.

## V. Risks and Benefits of Adaptation Measures

Chapter 7 does not attempt to provide a comprehensive list of adaptation, research and monitoring proposals for mountain gorillas. Rather, it is a brief discussion of ideas developed during the stakeholder workshops, highlighting those generated in response to anticipated problems that would be greatly exacerbated, or uniquely caused by climate change. All of the ideas generated at the workshops are presented in Appendix III. <u>The next step for all stakeholders is to continue to refine a prioritization system that suits the capacity of existing organizations, and above all to implement those actions that are clearly in the top priority group</u>.

It is highly recommended that each action be considered for its risks as well as benefits. Specifically, no policy or practice change will occur in a vacuum. Changes in one realm will have an effect in others, and these effects may not be in line with the long term goals for the region. Conversely, there may be straightforward but expensive measures that could have immeasurably good consequences down the line. This sort of action would warrant the investment. The key will be to develop an iterative process wherein representatives and specialists from several sectors discuss ideas among themselves, and then bring them back to a larger planning body for consideration in conjunction with the overall plan. For example, ideas for water catchment devices, water conservation measures and education and water safety may take different forms when discussed by park authorities, human settlement specialists, and hydrologists. However, each group must be consulted and the risks and benefits of each idea be discussed in the context of each group's expertise.

## VI. Adaptation Measures Undertaken

This White Paper is a vulnerability assessment and a first step towards an adaptation plan. This is its first iteration and it is expected that there will be many more. The brainstorming and discussions so far serve as a foundation for an adaptation plan but are not a plan per se. Turning these results into an actionable plan will involve review of this document and ideas from stakeholders, with consideration of what is feasible logistically and financially. As measures begin to take form and research results come in, the ideas concerning priorities, what will work best and what is feasible will continue to change. It is likely that the Secretariat, IGCP and other stakeholders will want to establish a system to agree, implement and monitor adaptation action.

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# 8.0 Moving Forward on an Adaptation Framework for Mountain Gorilla Conservation

## I. Overview

Dozens of concerns and ideas were generated throughout the life of this project, particularly at the second and third stakeholder workshops, which will doubtless spur additional ideas and concerns. In particular, the conclusion that climate change's greatest threats to mountain gorillas come from its interactions with existing stressors, most notably pressures from human communities near the parks, highlighted the importance of strong communication, support, and coordination among those focused on gorillas and those focused on human well-being. Project partners engaged in mountain gorilla conservation and management will use this framework and these ideas to refine and implement strategies for the coming months and years.

The final portion of the stakeholder workshops focused on how to carry the ideas, priorities, and needs expressed in the workshops forward to implementation, with the ultimate goal of reducing the vulnerability of mountain gorillas to climate change. In this Chapter we present the main recommendations arising from the workshops for moving forward with adapting mountain gorilla conservation to climate change. We present specific ideas and thoughts regarding further climate and species distribution modeling and other related research. Finally, we present our conclusions, including next steps to be taken by the partners towards achieving an adaptation framework for mountain gorilla conservation.

## II. Stakeholder Recommendations

Table 1 presents a summary of the more detailed list of priority adaptation actions identified in the stakeholder workshops, and attached in full as Appendix III. Below Table 1 we summarize the recommendations into four main areas of action in order to inform efforts to determine the capacity, priorities, and precise next steps to adapt to climate change in the realm of mountain gorilla conservation.

When considering the various adaptation actions, and research and monitoring actions suggested during the White Paper process, the stakeholders agreed that it was important to assess carefully whether or not each suggestion is actually already underway, or is readily added onto an existing action (e.g. ongoing research) or whether it is more a question of intensifying and accelerating ongoing conservation actions. These questions were considered within the discussion groups, and we highlight below some of the ideas that are new or different from business-as-usual, or that address existing problems likely to be exacerbated by climate change. The stakeholder group concluded that these actions should be strongly considered and pursued immediately as a first step in development a long-term adaptation framework that will support the conservation of mountain gorillas and strengthen local community livelihoods in face of the urgent need to reduce vulnerability to climate change.

## Table 1: Priority Mountain Gorilla Adaptation Strategies Identified by Stakeholders

| **Working Group** | **Problem/Activity** | **Adaptation strategy – priority actions** |
|---|---|---|
| **Park Management** | **Crop raiding** | • Encourage compatible land use practices<br>• Construction of physical barriers<br>• Creation of crop protection groups (e.g., HUGO) |
| | **Human encroachment** | • Collaboration between park authorities, government and community<br>• Support/initiate efforts in integrated population, health and environment programs (focus on population control)<br>• Support/initiate programs for alternative sources of income |
| | **Poaching: bushmeat** | • Strengthen law enforcement<br>• Reduce demand/providing alternatives |
| | **Wood extraction** | • Encouraging agro forestry practices (production of alternatives for timber, fuel wood, handicrafts, stick, charcoal)<br>• Encourage energy saving stoves (and biogas, pressure pots, solar cooking devices)<br>• Strengthen law enforcement and monitoring |
| **Gorilla Ecology, Conservation and Health** | **Fire management** | • Develop contingency planning for extreme fire hazard (widespread crown fire outbreak)<br>• Build capacity for fire management (training, equipment)<br>• Improve real-time monitoring for fire in gorilla habitat |
| | **Gorilla illness** | • Contingency plans for major disease outbreaks through scenario building to anticipate threats and actions required<br>• Extend park employee health program to all 3 countries<br>• Improve early warning on human and animal health<br>• Knowledge sharing on primate disease |
| | **Carrying capacity/ Gorilla social structure** | • Better understanding of habitat quality and utilization<br>• Better understanding of population dynamics<br>• Geo-engineering i.e. habitat manipulation to increase food availability for gorillas (alongside research as a trial activity)<br>• Better data on gorilla nutrition; monitor for food stress<br>• Phenology of gorilla food |
| | **Gorilla use of water** | • Sustainable water harvesting/extraction from protected areas<br>• Monitoring of water quantity and quality |
| **Socio-Economic** | **Agriculture** | • Research stations/ institutes (incorporating GCC issues in agriculture; Integrated Pest Management; drought resistant crops; strengthen local govt. relationship re conservation)<br>• Buffer crop to reduce crop raiding<br>• Integrated, coordinated meteorological stations network<br>• Microfinance support to agriculture and off farm activities<br>• Re- introduce agricultural cooperatives<br>• Irrigation systems, watershed management, erosion control |
| | **Human encroachment: Land tenure uncertainty** | • Delimiting protected areas<br>• REDD+ project potential<br>• Specific management plan for buffer zones, National Parks |
| | **Human encroachment: population growth** | • Alternative economic incentives<br>• Development of Master Plan around protected areas<br>• Family planning strategies<br>• Water supply for communities |
| | **Human health as concerns forest/gorillas** | • Monitor immune system/ increase in epi-zoonotic diseases<br>• Disaster response management plan |
| | **Livestock adaptation** | • Integrating agriculture and livestock<br>• Hybrids: focus on fewer, more productive livestock<br>• Livestock or veterinary health services |
| | **Land less people (indigenous people)** | • Regional Batwa development plan<br>• Awareness and sensitization campaign to all stakeholders<br>• Income generating activities |

The four main areas of action prioritized by the stakeholders are:

1. *Create a regional committee or working group on climate change adaptation*

A first important step to carrying ideas forward will be to establish a team of decision makers that will set priorities, execute decisions, consider ideas, commit funds or commit to finding funding, and generally serve as an official or unofficial advisory directorate for climate change adaptation efforts to preserve mountain gorillas. This group could include representatives from the major NGOs working with mountain gorillas or related communities, as well as a team from the Transboundary Core Secretariat. It is worth considering inviting representatives from relevant ministries, such as those responsible for forests or tourism, in each country. This would ensure ongoing education of those officials and buy-in to new practices and ideas.

### *2. Accelerate and extend priority conservation actions*

Clearly there are important aspects of the long-established mountain gorilla conservation program that should be accelerated, intensified and extended into new areas in the light of the White Paper reflections on vulnerability and adaptation priorities, and many of these are identified in Table 1. These may be climate change adaptation ideas that should not wait, and which also are “no regret” actions, such as those that support sustainable livelihoods of human populations living close to mountain gorilla habitat and the ability of these human populations to adapt to climate change without increasing pressure on forest resources (see the group of socio-economic priorities identified in Table 1). Various suggestions were made including exploring pro-adaptation agricultural crops and practices, and improved water management and soil erosion control. Agro forestry practices which provide alternatives for timber, fuel wood and charcoal should be encouraged as should the use of energy saving stoves and alternatives (biogas, pressure pots, and solar cooking devices). Stakeholders recommended strengthening measures to mitigate the impacts of crop raiding by encouraging compatible land use practices, construction of physical barriers, and the creation of crop protection groups; improving enforcement; supporting integration of population, health and environment programs; and countering incentives for bushmeat harvesting. Furthermore an important complementary activity is for all stakeholders to encourage education, planning, and political engagement to improve resource management practices in the face of potentially more extreme conditions.

The park management discussion group strongly recommended reviewing all park practices immediately to see where climate change adaptation activities could be incorporated easily into existing practices. Further, the group recommended revisiting the park practices annually to update the practices and add new ones. Beyond that, because of the prediction of higher temperatures, and a drying period, with more extreme dry seasons, they recommended engaging in fire prediction training using GIS and weather station tools, development of contingency plans, building capacity for fire monitoring and management, as well as developing more sophisticated regional communication tools to ensure that fire response was pro-active rather than reactive. It was also recommended to investigate the potential of REDD+ projects in the region and to put in place specific management plans for buffer zones and protected areas.

### *3. Fill key data gaps for decision-making*

Multiple issues were identified as potentially critical to mountain gorilla management decision-making in the face of climate change, but about which so little was known that decisions could not be made in the present. As described in some detail in Chapter 7, many adaptation action ideas cannot be prioritized, or even fully formulated until more information is available. Many proposals for monitoring and research were put forth, most in the realms of park management and gorilla ecology. Decisions to go forward with these ideas, where feasible, should be made quickly so that information is available to inform decisions as time goes on.

A review of the White Paper chapters indicates that priorities should include research into carbon values of mountain gorilla forests; research into the value of possible extension of gorilla habitat; research and monitoring of gorilla water consumption and willingness to try new types of food, and research concerning specific plant phenology (see section III below).

Some of the research, surveys, and monitoring ideas, as well as some of the adaptation practices, are possible to implement as part of the ongoing work of research scientists, NGOs such as IGCP, park ranger activities, and the work of the Transboundary Core Secretariat. Implementing these ideas and establishing a rapid system for returning field survey results to a group that will make decisions on climate change adaptation actions, seems to be a highly important next step. See Section III below for more detail on research gaps.

### *4. Consider new large multi-sectoral investments in adaptation*

Many of the most important suggestions made through this White Paper process require investments, both financial and political, from many sectors. This is particularly the case with respect to possible extension of gorilla habitat and securing of habitat connectivity through increasing the protection status of new areas. This process of exploring mountain gorilla vulnerability has shown the critical importance of sound and complementary adaptation planning across all sectors including economic, health and conservation sectors. Effective adaptation of mountain gorilla conservation efforts requires complementary actions in other sectors.

In fact, an interesting overall result emerged from the stakeholder workshops and consideration of the vulnerability assessment. Mountain gorillas do not appear to be highly vulnerable, themselves, to climate change, if left alone. They are known to be highly intelligent, and to make behavioral changes to accommodate environmental variation and shifts. However, their extreme vulnerability comes from two conditions. First, their population size is extremely reduced, as is their protected habitat, which makes them highly susceptible to stochastic events such as a catastrophic fire or disease epidemic. Second, their continued well-being is entirely dependent on their continued protection and protection of their habitat and resources. This second condition is, in turn, entirely dependent on the will of local people. Given that local people are extremely poor, and highly dependent on subsistence-level farming, as well as use of local natural resources, their own survival is strongly in jeopardy from climate change. This vulnerability in turns puts the mountain gorilla habitat at high risk to climate change, albeit indirectly. **It seems clear that most larger-scale adaptation measures for mountain gorillas will depend on strong measures being taken to help local populations adapt**. Establishing ‘mountain gorilla carbon’ access to carbon markets offers one route through to significant potential funding sources and should be explored urgently.

## III. Specific modeling and research recommendations

Although nearly all models concur on temperature trends for the region (broadly considered), significant uncertainty remains about precipitation trends overall and on all trends on the smaller spatial and temporal scales important to gorilla conservation. The goal of the modeling is to build a range of scenarios and to develop robust adaptation strategies that work well across the range. The best adaptation planning allows for adjustment as more is revealed.

While the species distribution models generated for this project were thought-provoking, it was clear from discussion within the group that there were key elements of species distribution and ecology that were not being captured by the models. We discuss here the limitations of the modeling efforts so far, and ideas for improving these in future iterations.

The efforts by Drs. Anton Seimon and Guy Picton-Phillips of the Wildlife Conservation Society on regional climatology (Chapter 2 of the White Paper) and by Drs. James Thorne of the University of California, Davis, and ChangWan Seo of the University of Seoul on species distribution modeling under various climate change scenarios (Chapter 6 of the White Paper) underscored the uncertainty inherent in climate change adaptation. Both teams performed scientific inquiries and modeling at the highest levels of sophistication and technical expertise using all available data sources known to them at the time, but were left with as many questions as answers. As all are aware, model outputs are only as reliable as the data put into them.

### *Climatology*

Although climatic trends were identified by the large scale modeling and by observations at several weather stations in the area, Dr. Seimon was unable to state with certainty the timing or intensity of changes in local climate over the next century (see Chapter 2). It was clear that weather station data, for example, need to be looked at over several decades and in multiple ways to observe real shifts in temperature, precipitation or seasonal averages. The longest-running weather station data available in this project was 16 years old; most data series were 10 years or shorter. Closer investigation of long-term weather station data would allow climatologists to track not just long-term trends but changes in potentially important patterns such as spikes or valleys in precipitation and help refine these White Paper recommendations. Further, the limited availability of long term local weather data combined with the topographic irregularity of the mountain gorilla habitat make finer-scale climatic projections for this region extremely difficult.

### *Species distribution*

Species distribution modeling was performed using advanced GIS modeling methods, and the best available climate change projections for the region (see Chapter 6). The models projected the availability of gorilla habitat at various times in the future. Several modeling approaches were taken, using the current distribution of mountain gorillas as a baseline and to define suitable mountain gorilla habitat. There were extreme disparities among results from different models, ranging from no remaining gorilla habitat in 90 years, to extremely small patches southwest of the current range only, to extremely small patches northeast of the current range only, to moderately sized patches overlapping with the current distribution. The main reason for the extreme results seems to be the limits of the data available for the model runs.

The complete or near-complete disappearance of “suitable” mountain gorilla habitat in model results was not supported by the expert opinion of several ecologists and gorilla biologists present, even knowing the climate change projections for the region. Using the current distribution of mountain gorillas to indicate the bioclimatic tolerance of gorillas or of vegetation where they live is not representative of the underlying truth. As far as we know, gorillas only occupy a small fraction of their former range; the range reduction is very recent, in evolutionary terms, and a result of human activities rather than habitat selection or tolerance by gorillas. Thus, the bioclimatic or vegetative "limitations" that the models derived from current distribution data were likely overly restrictive to predict hypothetical gorilla distributions.

These imprecise results were discussed at length during the stakeholder workshops. The breakout group that focused on gorilla biology and health, in particular, explored the possible reasons for the extreme modeling results and the utility of models in this situation. Research and monitoring suggestions were explored and prioritized in this group to address the data gaps, where possible.

In addition, a possible approach to addressing the lack of historic distribution data for mountain gorillas was discussed. As a first step, maps are available of the extent of forests surrounding the current mountain gorilla protected areas that go back half a century. Second, palynologists, including Dr. David Taylor of Trinity College of Dublin, have made some strides in inferring past forest-type distributions from pollen records. Third, scientists who have studied mountain gorilla diets and habitat use for decades, have an understanding of mountain gorilla behavior, space use, diet flexibility, bioclimatic tolerances, and other relevant information. An imprecise but knowledge-rich approach to estimating mountain gorilla historic ranges would be to gather the known information, such as that described above, and the experts to a single or multiple day workshop to discuss and explore what is known. From these data- and knowledge-based discussions, an improved collective opinion, which would however still be a guess, could be formulated describing the historic range of mountain gorillas.

With all of this new information in hand, including new monitoring and survey data, and an expert inference of historic gorilla range, a second round of species distribution modeling could be undertaken. Reducing the uncertainty of climatic projections will depend on the availability of more long-term datasets, and thus will not be possible for some years.

*Other research gaps*

Because the small population size of mountain gorillas makes disease outbreaks a potentially serious threat to the species, stakeholders recommended the development of a Pan-African primate health network that would be managed and updated by wildlife veterinarians, conservation practitioners, and other qualified professionals, in real time. This should be geographically linked (possibly with a spatial mapping tool) and be vetted and monitored regularly. This was seen as a critical way to transmit and receive information regarding potential health risks in advance of catastrophic events. Given that diseases may be carried by many species, it was also proposed to link the network with groups monitoring human, wildlife and livestock health more broadly.

To the same end, it was proposed further disease modeling be undertaken to generate scenarios to help anticipate threats and plan actions required, for the possibility of disease spread, intensity, susceptibility and other factors under a variety of climatic and sociopolitical futures. This kind of effort would assist in the development of early warning, response, and contingency plans. Efforts to anticipate gorilla survival needs with climate change within the context of the forest resources focused mainly on food and water. However, as mentioned, specific points of stress could easily be overlooked or unanticipated since much information is unknown or poorly understood at this time. Specifically, it was recommended that monitoring and research programs determine flowering/fruiting/pollination phenology of plants of importance to gorillas, water use and extraction, and to continue efforts to determine carrying capacity (including assessing habitat quality, habitat utilization and gorilla population dynamics) of the parks for gorillas and tourism. It was also suggested that geo-engineering of the habitat (i.e. habitat manipulation to increase food availability for gorillas) be a priority topic of research.

## IV. Conclusions and Next Steps

This White Paper has provided a detailed review of the key elements in understanding mountain gorilla vulnerability to climate change. In addition, it has described the process by which project partners and stakeholders engaged to consider expert reviews of these issues and propose ideas for adaptation to climate change specifically to reduce mountain gorilla vulnerability. Many ideas were put forth, including those actions indicated in Table 1.

Because of the nature of climate change adaptation, and of climate change, this White Paper and the mountain gorilla adaptation framework will always be a work in progress. Priority conservation research and actions have been identified, but need to be revisited as vulnerability assessment develops. Like conservation biology itself, conservation in the face of climate change is open-ended and needs to be constantly under consideration. We hope that this White Paper serves as a solid introduction to adaptation planning for mountain gorilla conservation upon which future efforts will be based. The immediate next steps for organizations partnering to conserve mountain gorillas are to:

1. Develop a regional multi-stakeholder Climate Change committee or working group to take forward a second phase of climate change adaptation planning building on this White Paper, and provide oversight and coordination for responding actions and research.

2. Investigate the Forest Carbon potential in the Virunga-Bwindi region and actively take forward exploration of REDD+ project sites.

3. Carry out immediate urgent practical actions, as identified in this chapter, to adapt to the impact of climate change.

4. Undertake priority adaptation research and monitoring projects including:
    a. Monitoring of phenology and other forest resources and inclusion with vegetation surveys to provide good baseline data for any further modeling;
    b. Establishing a network of micro-meteorological stations in mountain gorilla habitat to gain a sound understanding of climate change impact at micro-habitat level of the mountain gorillas. This would require funding to purchase equipment for monitoring climate variables, specifically automatic weather stations and a terabyte storage drive, and personnel to plan, manage and process the data;
    c. Additional priority topics for research (as outlined in Chapters 7 and 8).

5. Work within National Adaptation Planning processes within each partner government to ensure mountain gorilla adaptation planning is integrated appropriately.

## Appendix I: Definitions

**Anthropogenic** - Resulting from or produced by human beings.
**Bioclimatic** – Describing the interaction between climate and living organisms.
**Bushmeat -** Meat hunted in the wild.
**Climate futures/future climate scenarios**-A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatologically relationships, that has been constructed for explicit use in investigating the potential consequences of *anthropogenic climate change*, often serving as input to impact models. *Climate projections* often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A "climate change scenario" is the difference between a climate scenario and the current climate. IPPC 2007
**Climate/climatology-**Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. In various chapters in this report different averaging periods, such as a period of 20 years, are also used. Climatology is the study of climate.
**Cline**- A gradient of morphological or physiological change in a group of related organisms usually along a line of environmental or geographic transition.
**Endemism/endemicity** – The property of being restricted or peculiar to a locality or region.
**Evapotranspiration-** The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.
**Frugivory/frugivore**- The act of feeding on fruit/ one who feeds on fruit.
**General circulation model/global circulation model -** A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. Coupled Atmosphere-Ocean General Circulation Models (AOGCMs), often called general or global circulation models, provide a representation of the climate system that is near the most comprehensive end of the spectrum currently available.
**Global ensemble/ ensemble forecasting**- An ensemble is a group of parallel model simulations, or simulations run with slightly different initial conditions, used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Global ensembles attempt to generate predictions using ensemble approaches at a global level.
**Grid cell/grid**- In Geographic Information Systems, a grid cell or grid is a two-dimensional object representing one element within a regular tessellation of a surface.
**Herbivory/herbivore**- The act of feeding on plants/ one who feeds on plants.
**Net primary production/productivity**- In ecology, this is the amount of energy which primary producers can pass on to the next trophic level. This represents the amount of carbon dioxide taken in by a plant minus the carbon dioxide it emits during respiration.
**Phenology (phenologies)**- Periodic biological phenomena that are correlated with climatic conditions.
**Pluviogram -** The graphic presentation of precipitation data.

**Predictor variables/response variables-** Predictor variables are values or variables that can be used to predict the value of another variable (as in statistical regression). Response variables (or dependent variables) are the observed variables in an experiment whose changes are determined by the presence or degree of one or more predictor variables

**Receiver operator curve** In signal detection theory, a receiver operating characteristic (ROC), or simply ROC curve, is a graphical plot of the sensitivity, or true positive rate, vs. false positive rate (1 − specificity or 1 - true negative rate), for a binary classifier system as its discrimination threshold is varied. ROC analysis is related in a direct and natural way to cost/benefit analysis of diagnostic decision making. The closer the curve gets to a value of one, the better the model being tested is performing.

**Refugia/climate refugia**- An area of relatively unaltered climate that is inhabited by plants and animals during a period of continental climatic change (as a glaciation) and which remains as a center of relict forms from which a new dispersion and speciation may take place after climatic readjustment.

**Species range dynamics**- These are characteristics of species' ranges determined by mapping the historic, current and expected future areas that a species can occupy, and measuring the level of disruption that a species may face, as a result of having to move.

**Statistical downscaling/downscaled climate models**- Downscaling is a method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses. Two main methods are distinguished: dynamical downscaling and empirical/statistical downscaling. The empirical/statistical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. In all cases, the quality of the downscaled product depends on the quality of the driving model.

**Topographic roughness**- A measure of the degree of elevation change in any given grid cell.

## Appendix II: List of Attendees at First Climate Camp Workshop

| No | Name | Organization | Position | Country |
|---|---|---|---|---|
| 1 | Eugene Rutagarama | IGCP | Director | Rwanda |
| 2 | Jean Pierre Jobogo | Virunga Nat. Park, DRC | Chief Park Warden | DRC |
| 3 | Miriam van Heist | ITFC/WCS | Deputy Director, ITFC | Netherlands/Uganda |
| 4 | Francois Bizimungu | RDB | Research Monitoring Manager | Rwanda |
| 5 | Isabella Masinde | AWF | Climate Change Advisor | Kenya |
| 6 | Augustin Ngumbi Amuri | ICCN/DRC | Asst of Administrateur Delegue General | DRC |
| 7 | Tom Sengalama | GVTCS | Executive Secretary | Uganda/Rwanda |
| 8 | Benoit Kisuki Mathe | ICCN/DRC | Administrateur Directeur Technique | DRC |
| 9 | Augustin K. Basabose | IGCP | Species Conservation Coordinaor | DRC |
| 10 | Jan Ramer | MGVP | Regional Vet Mngr | USA/Rwanda |
| 11 | Anton Seimon | WCS | Climate Change Adaptation | USA |
| 12 | Paul Scholte | GEF-UNDP-REMA | Technical Advisor | Netherlands/Rwanda |
| 13 | Francoise Kayigamba | NELSAP | Environment Officer | Rwanda |
| 14 | Jennie Hoffman | EcoAdapt | Senior Scientist | USA |
| 15 | R. Jean Gapusi | ISAR | Head of Forest Research Station | Rwanda |
| 16 | Guiseppe Daconto | CARE/EEEGL | Regional Prog Coordinator | Italy/Rwanda |
| 17 | Douglas Sheil | ITFC/WCS | Director ITFC | Ireland/Uganda |
| 18 | Prosper Uwingeli | RDB/VNP | Chief Park Warden | RWANDA |
| 19 | Jean Felix Kinani | MGVP | Field Veterinarian | Rwanda |
| 20 | Tasha Belfiore | EcoAdapt | Scientist | USA |
| 21 | Therese Musabe | GVTCS | Planning and Policy Dep Excecutive Secretary | Rwanda |
| 22 | Eugene Rurangwa | IGCP | TBNRN/Advocacy Coord. | Rwanda |
| 23 | Telesphore Ngoga | RDB | Community Conservation Manager | Rwanda |

| | |
|---|---|
| AWF | African Wildlife Foundation |
| CARE | CARE Rwanda /Uganda |
| EEEGL | Enterprise, Environment, and Equity in the Virunga Landscape of the Great Lakes |
| GEF | Global Environmental Facility |
| GVTCS | Greater Virunga Transboundary Core Secretariat |
| ICCN | Institut Congolais pour la Conservation de la Nature |
| IGCP | International Gorilla Conservation Programme |
| ISAR | Institute des Sciences Agronomiques du Rwanda |
| ITFC | Intstitute of Tropical Forestry and Conservation |
| MGVP | Mountain Gorilla Veterinary Project |
| NELSAP | Nile Equatorial Lakes Subsidiary Action Program |
| RDB | Rwanda Development Board |
| REMA | Rwandan Environmental Management Agency |
| UNDP | United Nations Development Programme |
| VNP | Volcanoes National Park |
| WCS | Wildlife Conservation Society |

# Appendix III: Stakeholders' Priority Adaptation Options for Mountain Gorilla Conservation

***Note*: This Excel spreadsheet is too large for inclusion into the White Paper; therefore, please view in its entirety at: http://www.awf.org/priority_adaptation_options.**

## Appendix IV: Regional Projects Addressing Climate Change

This Appendix gives short summaries or links for all known projects in the greater Albertine Rift region that relate to climate change. This list is likely to be incomplete, but is provided to help connect interested parties to as many resources as possible. The list below is by organization/program. The list in the subsequent table is of ongoing and proposed research projects.

**NELSAP**: the Nile Equatorial Lakes Subsidiary Action Program includes the six countries in the southern portion of the Nile Basin—Burundi, Democratic Republic of Congo, Kenya, Rwanda, Tanzania and Uganda—as well as the downstream riparians Egypt and Sudan. The objectives of NELSAP are to contribute to the eradication of poverty, promote economic growth, and reverse environmental degradation. Several of its initiatives involve considerations of climate change adaptation prospects, and modeling of climate change effects. http://nelsap.nilebasin.org/

**National University of Rwanda** and **Trinity College of Dublin:** Dr. David Taylor, taylord@tcd.ie, from the Department of Geography, Trinity College, Dublin, and affiliated with the National University of Rwanda, and his PhD student, Gayle McGlynn, are conducting ongoing research on sediments collected from crater sites on Muhabura and Mgahinga. The work seeks to reconstruct vegetation and fire histories of the eastern Virungas over the last c 8000 years based on sedimentary evidence. They expect to conduct additional collections in the future from crater lakes on Bisoke and Karisimbi volcanoes (i.e, within the Volcanoes NP). This work will to target the last c. 1000 years of changes in forest history in this work. The work of Ms. McGlynn is partially funded by the National Geographic Society.

**Birdlife International**: Birdlife has recently completed an assessment of over 800 bird species across Africa, focusing on Important Bird Areas, to model and assess their status under climate change predictions. The report from this project is nearly available. In brief, the Great Virunga Landscape is one of the identified high priority planning units based on species richness and endemicity. The Albertine Rift, currently outside IBAs, were shown to be important as they will retain habitat suitable for 14 endemics at risk. An output of the project is a web-based clearinghouse of data and conclusions, called Africa Climate Exchange (ACE), which welcomes deposits of information from related projects. Birdlife recently received a follow-on grant to develop and test an adaptation plan for important bird areas, focusing first on the Albertine Rift to develop the approach.

http://www.birdlife.org/index.html
http://www.africa-climate-exchange.org

**International Union for the Conservation of Nature (IUCN):** The IUCN has current initiatives related to climate change that are of interest in the Albertine Rift area. The IUCN has developed a set of climate change guidelines for IUCN Red List assessments. As follow on to a 2005 regional assessment by the IUCN of over 1600 species from the region, the IUCN will apply the assessment tool in the Albertine Rift. Specifically, it will select target species from the region that are important for human use, and for which there is some biological information, and test the new climate change assessment guidelines on these species. They have run surveys to access expert knowledge on human use of Albertine Rift species and have recently conducted a species workshop in the region which focused on coming up with traits associated with climate change vulnerability within broad taxonomic groups, for example, reptiles, fishes, mammals, and began gathering data on these for Albertine Rift species. It will also target reptiles in the region in conjunction with the Global Reptile Assessment program, as well as plants.

**International Gorilla Conservation Programme (IGCP)**: In addition to the current collaborative project to develop a vulnerability assessment and adaptation plan for mountain gorillas, Dr. Augustin Basabose is embarked on an ongoing study to understand and monitor the effects of climate change in Virunga National Park in the Democratic Republic of Congo. It focuses on gorilla foods and other plant life in the Mikeno sector of the Park, which approximately 200 gorillas call home. The study will be expanded to gorilla ranges in Rwanda and Uganda in the coming years. http://www.igcp.org/

**WHRI**: The Woods Hole Research Center (http:www.whrc.org)- Drs Nadine Laporte and Glenn Bush are examining the drivers and determinants of land cover change using spatially explicit econometric models. To do this, they are populating a meta-data set of economic and social data for the Albertine Rift with remotely-sensed spatial data to assess the current status of land use and land cover and to model future scenarios under different policy and management options. This modeling platform can also be adapted to model future scenarios under different environmental constraints such as climate change. Information about other WHRC activities in the Albertine Rift may be found at: http://www.whrc.org/mapping/pawar/

**TEAM**: The Tropical Ecosystem Assessment and Monitoring network is a systematic, operational, approach to biodiversity and climatic monitoring set up at various locations around the world. The data at each site is intended to be made available in real time. The Wildlife Conservation Society (**WCS**) and The Institute of Tropical Forest Conservation (**ITFC**) are currently establishing the first site in the Albertine Rift, including new sites set up at Ruhija in Bwindi, Uganda, with others to follow in Nyungwe National Park in Rwanda, Kibale National Park in Uganda, and the Ituri Forest in Congo DRC.
http://www.teamnetwork.org/en/

**Wildlife Conservation Society, Albertine Rift Program**: WCS is embarked on the second phase of a MacArthur-funded climate change and protected area project (2009-12). This will include implementation of long-term monitoring programs for climate, vegetation and sensitive taxa (amphibians and chameleons). http://www.albertinerift.org/WCSActivities/tabid/2514/Default.aspx

**ITFC**: In addition to collaborative work with WCS on the TEAM station, ITFC has received funding to develop projects that focus on emerging threats to forest biodiversity, including explicitly Adaptation and Climate change, for example altitudinal zonation; how will it change with climate change? Where can endemic plants and animals find refuge?, and Mitigation and Climate Change, for example REDD opportunities: forest carbon dynamics, assess carbon in afro-alpine peat (Mgahinga, Rwenzori, Virungas), improving landscape connectivity, and providing corridors for species to move to better climates. They are in the process of developing projects with students to pursue these topics. http://www.itfc.org/

**START**: START is the global change **S**ys**T**em for **A**nalysis, **R**esearch and **T**raining, a non-governmental research organization. START assists developing countries in building the expertise and knowledge needed to explore the drivers of and solutions to global and regional environmental change with the goal of reducing vulnerability through informed decision-making. http://www.start.org

**United Nations Environmental Program (UNEP)/Great Apes Survival Partnership (GRASP)** GRASP has focused, in recent years, on four main areas including "Great Apes and Climate Change." Specifically, members of the program are looking into incentives to conserve great ape habitats, none currently in AFrica, including carbon projects, and other forms of payment for ecosystem services. In Africa, GRASP is involved in a pilot REDD project with WCS based in Takamanda, Nigeria. GRASP is also supporting UN-REDD in DR Congo; Wahida Shah is the main contact person for this project.

These are only pilot projects, and GRASP hopes to have more pilots in the future. However, GRASP does not currently have climate change projects in mountain gorilla or Eastern lowland gorilla habitat. GRASP has and continues to support other conservation programs and efforts for mountain gorillas.

Ongoing projects in the region also include efforts to raise funds in DRC to support multiple elements of a conservation program that includes park conflict management, and development of alternative fuel sources, both relevant to climate change adaptation strategies for mountain gorillas such as those recommended in this project. http://www.unep.org/grasp/

**National Adaptation Programmes of Action (NAPA)** The NAPAs are intended to be concrete plans of action focusing on urgent and immediate needs, that is, needs for which further delay could increase vulnerability or lead to increased costs at a later stage. The Adaptation Fund was established to provide funding for these actions in developing country Parties to the Kyoto Protocol that are particularly vulnerable to the adverse effects of climate change. Guidelines for NAPAs include projects that use existing information, requiring no new research. In addition, projects must be driven within each country, be flexible, and be based on conditions within each country.

Each of the three countries involved in mountain gorilla conservation have submitted multiple NAPA projects and a country-wide action program. Mountain gorilla, or other biodiversity conservation does not appear to be included in any of the projects, to date, but is an obvious sector to consider for future submissions.

**http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php**

**http://unfccc.int/national_reports/napa/items/2719.php**

**Rwanda National Advisory Committee Report on Economics of Climate Change**: This study was funded by the UK Department for International Development (DFID), and focused on the economic impacts of climate change in Rwanda. The study was undertaken by the Stockholm Environment institute, and led by Mr Prosper Musafiri and Dr Rose Mukankomeje (DG Minecofin and DG REMA respectively). Multiple aspects of the topic were evaluated and the overall final report is found at http://rwanda.cceconomics.org/rwdo/Final_Report.pdf. Documents from other components of the project are found on the project web page http://rwanda.cceconomics.org/, including sectoral reports. Notably, a sectoral report was completed on Climate Change and Mountain Gorillas in Rwanda.

**ELDIS** is an on-line resource that has the goal of to sharing the best in development, policy, practice and research. Eldis is one of a family of knowledge services from the Institute of Development Studies, Sussex. As part of the database, ELDIS supports the Linking Climate Adaptation (LCA) Network. This is a community of over 900 practitioners, stakeholders, researchers and policy-makers exchanging information on climate adaptation research and practice around the globe via the Networks email list. Postings are available to network members on the database/web site.
http://community.eldis.org/LCA/

**World Climate Application and Service Programme (WCASP):** The WCASP hosts the Regional Climate Outlook Forums which are active in several parts of the world, including some in Africa. These fora routinely provide real-time regional climate outlook products, and may prove useful to projects working in the region for obtaining climate modeling outputs to inform project plans.
http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

## Summary of Regional Climate Change Research Ongoing and Proposed

| Title of the project | Objective | Expected outcomes /Results | Contact Person, affiliation; web address | Project funded by |
|---|---|---|---|---|
| **The Implications of Global Climate Change for Mountain Gorilla Conservation in the Albertine Rift** | To reduce the vulnerability of mountain gorillas to the negative effects of climate change<br>By understanding its effects on gorillas, their habitat and all necessary resources.<br>By using this new understanding to inform new conservation guidelines and management plans. | Comprehensive vulnerability assessment for mountain gorillas<br>Jointly develop an IGCP climate change response plan<br>Capacity building at all levels | Eugene Rutagarama (IGCP), Isabella Masinde (AWF) and Natalia Belfiore (EcoAdapt);<br>http://www.igcp.org/<br>http://www.awf.org/<br>http://ecoadapt.org | MacArthur Foundation |
| **Climate change impact on the distribution and availability of mountain gorilla food** | Investigate the impact of variability of climatic factors on spatial-temporal distribution of mountain gorilla foods and therefore the ranging pattern of mountain gorillas as shown by the Ranger Based Monitoring (RBM) Program. To elucidate the impact of climate change, results of both long term monitoring and rapid assessment programs will be compared to those of studies conducted in the same region two or three decades before. | • Baseline information on plant distribution status in mountain gorilla habitat is available for future climate change impact assessment<br>• Contribution to the Park rangers knowledge to update the check list of plant species consumed by mountain gorilla<br>• Park rangers are familiar to botanical rapid assessment and plant identification<br>• Permanent Transects and plots for long term monitoring on spatiotemporal variation of gorilla food availability in Virunga- Bwindi landscape are established<br>• Micro station of weather records established in mountain gorilla habitats<br>• Park rangers able to manipulate weather equipments and to interpret climate data<br>• Climate change impact on mountain gorilla food availability and ranging patterns assessed and management decisions/actions taken accordingly. | Augustin K. Basabose Species Conservation Coordinator, International Gorilla Conservation Program;<br>http://www.igcp.org/ | IGCP and its coalition members (AWF, WWF and FFI) |
| **Effect of climate change and land use on nutrient** | In order to understand the potentiel impact of land use and the climate change employed in the basin area of lake Kivu on the fish production, the | Data recorded in this study, will provide a quantification of the respective effects of natural and antrhopogenic inputs to the lake, a better understanding of the different transfer routes and | Mr Jean Jacques Bagalwa Mashimango, Laboratory of Malacology & Limnology, Centre de | IFS (International Foundation for Science), Sweden: 2004-2005 |

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| **budget affected fish production in Lake Kivu, Democratic Republic of Congo, Central Africa** | project objectives are:<br>• To identify the main sources of nutrients (Phosphorus and Nitogen), to determine where and how such nutrient is negatively impacting fish production.<br>• To understand how and in what quantity these nutrient are transported to the lake and to attempt to understand their impact on the lake ecosystem.<br>• To suggest ways in which alternative livelihood, strategies can be introduced which changes in current input, which may be detrimental to fish production. | fate of matter, including potentially harmful anthropogenic substances. Levels of nutrients (P and N) examined inlight of ecological processe taking place in the open environment are expected to provide a new insight into the functioning and the health of the lake Kivu ecosystem.<br>Data sets will provide a sound landmark and an improved predictive capacity on which future assessments can be based.<br>Chemical deposition is an important factor of a global interdisciplinary approach to develop a predictive understanding to the main determinants of the functioning of the ecosystem in a region where there is an increased biomass burning and volcanous eruption.<br>However, if we are to understand the nutrient budget of the ecosystem and their relation to fish production, information on the source of deposition, sediment regeneration and rivers inputs are crucial. | Recherche en Sciences Naturelles, Lwiro, DRC | |
| **Impact of climate change on the biogeochemistry of Lake Kivu, Western basin (Kalehe), Democratic Republic of Congo, Albertine Rift** | The overall objective of the research is to determine how climate change affects nutrient dynamics and phytoplankton composition within the lake.<br>Specific objectives are:<br>• To assess water quality, (physico-chemical parameters such as temperature, nutrients (phosphorus and nitrogen) and water level) and to analyze previous collected data.<br>• To analyze Wet and Dry deposition of Phosphorus and Nitrogen<br>• To analyze long term meteorological data collected in stations around Lake Kivu.<br>• To collect, analyze phytoplankton and determine the phytoplankton biomass<br>• To determine the zooplankton | The Lake Kivu region is a hot spot for both aquatic and terrestrial biodiversity, and the lake is an important source of food to surrounding populations. Maintaining this diversity, and managing fisheries, requires an understanding of the biogeochemical cycles that both influence and are influenced by biota. For example, excess phosphorus loading may lead to extreme nitrogen limitation, which favours cyanobacteria (blue-green algae), which have low usefulness as a food source for fish, and may even by toxic, leading to fish deaths. Climate change and biomass burning results in the re-location of nutrients may negatively affect terrestrial biomes by reducing biomass and diversity, and may also negatively affect aquatic systems by promoting the growth of undesirable algae and the development of anoxic conditions. The research proposed will allow bettering understanding the potential consequences of climate change to biodiversity in Lake Kivu. | Mr Jean Jacques Bagalwa Mashimango, Laboratory of Malacology & Limnology, Centre de Recherche en Sciences Naturelles, Lwiro, DRC | MacArthur Foundation through the University of Dar es lam, Tanzania, 2008 |

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| | species | | | |
| **The Influence of atmospheric deposition on biogeochemical cycles in Lake Kivu** | The overall objective of the project to contribute to the understanding of seasonal variations in the atmospheric nutrient deposition to Lake Kivu and its potential influence on biogeochemical cycles in Lake Kivu.<br>Specific objectives are:<br>• To determine primarily through measurements, the atmospheric removal rates by dry and wet deposition of nutrients (Pand M)<br>• To determine the temporal variability of atmospheric nutrient deposition<br>• To establish a collaborative research network in Central and East Africa scientists and understanding of human influences on aquatic ecosystems<br>• To strengthen international collaboration with the Great lakes water institute (University of WISCONSIN – MILWANKEE), the Department of Fisheries of Malawi (Malkey Bay) and the Department of Geology (University of Nairobi) in the management analysis and interpretation of data | We believe that this project would provide better understanding of the relationships between human activities and biogeochemical cycles in the Lake Kivu region. Levels of nutrient (P and N) and carbon inputs compared with data in others region are expected to provide new insights into the relative influence of physical setting, climate and anthropogenic impacts on the nutrient and carbon cycles of Lake Kivu. Data sets will provide a sound baseline and an improved predictive capacity on which future assessments can be based. This research will address the importance of atmospheric nutrient loading in the Lake Kivu region, help in abatement and or mitigation of pollution and give guidance to lake managers. | Mr Jean Jacques Bagalwa Mashimango, Laboratory of Malacology & Limnology, Centre de Recherche en Sciences Naturelles, Lwiro, DRC | START/PACOM<br>2005-2006<br>Pan African START |
| **Climate Variability in the Albertine Rift Region** | The objective of this study is to characterize climate variability in four Albertine Rift Region locations (Bukavu, Lwiro, Goma and Kibuye) using rainfall and temperature data, and linking this variability to land use change. | Understanding the spatial and temporal variations in climate within a zone, and their relationships with other factors, is important in the management of the natural resources, land-use planning, watershed management and territorial ordering. In this study, temperature and rainfall are used to characterize climate variability in four locations (Bukavu, Lwiro, Goma and Kibuye). The study | Dr Katcho C. Karume<br>Department of Geophysics, Centre de Recherche en Sciences Naturelles de Lwiro, DRC<br>Department of Seismology, Observatoire Volcanologique de Goma, | **?** |

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| | | tested the hypothesis that land use change is the main factor influencing climate variability in the Albertine Rift Region. Temperature and rainfall data obtained from meteorological stations were first summarized for different periods from 1966 to 2007. | DRC; http://www.wovo.org/0203.html | |
| **Prediction of Biomass change in Mbarara district-Uganda using climatic parameters from 1984 to 2003** | The objective of this study was to assess the impact of land-use change on climate, especially on temperature using the status of the biomass. | In this study, a method is presented for mapping and analyzing the land use change linked to climatic parameters (minimum and maximum temperature). The study tested the hypothesis that land use changes in Mbarara District have had an impact on the minimum and maximum temperature and suggested a model to predict or reconstruct biomass distribution using minimum and maximum temperature data.<br>Land use patterns for 1984, 1990, 1995, 2000 and 2003 were interpreted from a set of satellite images, using unsupervised classification procedures in a buffer zone of 5 km around the meteorological station. Temporal variations of seven predominant land use types: tropical high forest, open water, farm lands, woodlands (scrubs and fallow), grasslands, wetlands and built-up areas in a buffer were correlated to the annual maximum and minimum temperature | Dr Katcho C. Karume Department of Geophysics Centre de Recherche en Sciences Naturelles de Lwiro, DRC, Department of Seismology, Observatoire Volcanologique de Goma, DRC, http://www.wovo.org/0203.html | START<br>Pan African START |
| **Building Resilience to climate variability through improving coping strategies: The role of social capital in promoting resilience** | The research question being addressed here is: Is social capital important for resilience to climate related-shocks and trends a) through its contribution to livelihood diversity and b) as a mechanism for coping and adapting? This study will analyze the potential effects of climate change on coping strategies and livelihood options of small scale farmers, and their implications on influencing resilience to climate variability in the context of post conflicts. | This study is aimed at documenting generic outcomes of social capital and producing research findings that can be used to promote effective approaches and processes for strengthening social capital, in resilience to climate variability impacts and other shocks in post conflict area. | Jules Barhalengehwa Basimine, Lubumbashi University, DRC | PhD Research Proposal, funded by the Canadian International Development Agency |

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| **Biomass and Hydropower potential and demand in the Uganda Albertine Rift Region** | The overall objective of this study is to establish the availability, potential and demand for energy (hydropower and biomass) in the Uganda Albertine Rift region taking into account the environmental effects. The specific objectives of the study are to:<br>• Assess the energy potential of biomass and hydropower for the Albertine Rift Region of Uganda.<br>• Establish the dynamics of biomass as well as the dynamics of energy demand for the region.<br>• Identify the most important environmental issues associated with harnessing the energy resources.<br>• Assess the energy consumption and demand of the households according to income levels, as well as the proportion of this income, which the households are willing to spend for their energy needs. | This study assessed the hydropower potential in the Albertine Rift Region and suggested electricity as an alternative to reduce the pressure on biomass. Hydrological and topographical conditions of the region were analyzed in GIS environment, in order to identify potential hydropower sites. River flow measurements were used to estimate capacity of each site in power generation.<br>This study also assessed the current trend of biomass consumption in Uganda Albertine Rift Region, and explored possible solutions for sustainable development of these resources in the future. | Dr Katcho C. Karume, Department of Geophysics-Seismology, Observatoire Volcanologique de Goma, DRC<br>http://www.wovo.org/0203.html | Doctoral Dissertation |
| **Land use and climate change effects on livelihoods and sediment and carbon loading in the lake Tanganyika region** | The objectives of this study were to characterize and quantify historical land use and livelihood changes in the Tanganyika region; characterize the Tanganyika Basin soils and vegetation in terms of carbon stocks; and to estimate spatio-temporal fluxes of sediment, P, N and C into Lake Tanganyika owing to land use and potential climate changes. | **The main results of this study include:**<br>**1.** Agriculture is the main sources of income in the region followed by small businesses, and livestock.<br>**2.** Farmers perceive that<br>**a.** Agricultural activities have been affected by the fluctuating seasonal calendar.<br>**b.** Fishery activities have decreased because of fish biodiversity and abundance decline<br>**c.** Forest cover has declined and replaced by grassland and cultivated land<br>**3.** Most of Mulongwe micro-catchment carbon stock was initially (1974) under the forest cover (80%)<br>**4.** Half of the carbon stock of Mulongwe micro-catchment has been released in the atmosphere from 1974 to 2000.<br>**5.** Mulongwe average sediment yield is relatively | Dr. Majaliwa Mwanjalolo, Watershed management specialist, Department of Physics and Technology, ISP/Bukavu-D.R.C, Rwanda | START<br>Pan African START |

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|  |  | high.<br>**Recommendations**<br>1. Soil erosion studies need to be conducted in the study area<br>2. The Revised Universal Soil Equation need to be calibrated for Eastern D.R. Congo<br>3. Comprehensive catchment studies need to be conducted to identify hotspot areas to target for management in Uvira and Ruzizi areas<br>4. Best soil and water management practices need to be identified in the region<br>Final report:<br>http://start.org/download/gec07/majaliwa-final.pdf |  |  |
| **ARCOS Program on climate change** Environmental Threats (Climate Change) | Climate change is one of the factors affecting the afromontane regions and the Albertine Rift in particular. Climate change can affect social, cultural, economic life as well as water resources, agriculture, forestry, fisheries, human settlements, ecological systems and even human health.<br>Changes in the snowfall pattern have been observed in mountain and highland systems, notably the Rwenzori of DRC.<br>ARCOS plans to work with various institutions to establish and facilitate a regional mechanism for assessing the impacts of climate change in the Albertine Rift, strengthening local NGOs/CBOs and government institutions and promoting awareness and policy change in order to promote adaptability to climate change impact in the region. |  | Dr. Charles Kahindo<br>ARCOS, Regional Coordinator<br>http://arcosnetwork.org/ | MacArthur Foundation |
| **Capturing the Benefits of Ecosystem services to guide decision-making** | The main purpose of the project is to conduct detailed analysis on ecosystem services in the Greater Virunga Landscapes (including the Rwenzori mountains) of the Albertine Rift Region | The project will benefit from ARCOS regional information system in term of information sharing and synergy with other initiatives. ARCOS will be involved in project coordination, data collection, organizing workshops and establishing linkages | Dr. Charles Kahindo,<br>ARCOS, Regional Coordinator<br>http://arcosnetwork.org/ | MacArthur Foundation<br>April 2009 – March 2012 |

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| **in Greater Virunga's Landscape of the Albertine Rift Region<br>ARCOS and University of Cambridge joint project** | and to facilitate a better understanding and potential for informed decisions by stakeholders in the region. The project aims to achieve the following specific objectives:<br>a. To quantify and value ecosystem services derived from the Greater Virunga landscape, including the Rwenzori Mountains<br>b. To assess how amounts and values of services will change under future climate change and development scenarios<br>c. To inform and engage decision-makers and other stakeholders on values of ecosystem services to create incentives for conservation | with relevant processes in Uganda.<br>Technical support is expected from University of Cambridge and Natural Capital Project-based in the USA.<br>The project will use a general procedure model for mapping biodiversity and ecosystem services that has been developed by the Natural Capital Project in the USA, and adapted for the East African region by the Valuing the Arc programme (www.valuingthearc.org).<br>. | | |
| **Elaboration of a watershed management plan for Busogo, Shingiro and Rutoyi catchments** | There has been alot of problems in the areas surrounding ISAE mostly soil erosion and floods which killed people and destroyed alot of property including the main road from Kigali to Gisenyi. The floods also affected ISAE. This prompted the Rector to formulate a team to manage the watershed around the institute in order to find a management plan for the watershed. This started with a diagnostic survey of the area and the major problems were identified by the community which included soil erosion, poor agricultural yields and floods as the major problems.<br>The overall objective is to find solutions to the problems faced by the people in the watershed-specific objectives:<br>1. To control soil erosion in the watershed<br>2. To control / prevent floods in the watershed | 1. Map of the watershed (completed)<br>2. Map of land capability classification showing where to grow what<br>3. soil erosion management plan and gullies minimized<br>4. A flood map showing the different flood zones<br>5. A soil fertility management plan for the watershed<br>6. A land consolidation plan for the watershed with a uniform crop intensification plan<br>7. A map showing actions to be taken for each area | Violet Kanyiginya,<br>ISAE BUSOGO-Rwanda<br>The project is being done by a team of lecturers in ISAE from different disciplines. The Rector is actively involved and is spear heading the team. Shyrambere J. Claude and V. Kanyiginya are coordinating the project. V. Kanyaginya is also responsible for objective number 1, 3 and 4 plus report writing.<br>http://www.isae.ac.rw/ | |

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| | 3. To establish a land capability classification for the area<br>4. To improve soil fertility in the catchments<br>5. To improve animal husbandry in the catchments<br>6. To establish a land consolidation plan for the watershed with a uniform crop intensification plan | | | |
| **ITFC initiative on climate change**<br>The following themes are selected for new investigations using a three years proposal funded by MacArthur (2009-2011):<br>**Adaptation and Climate change**<br>**Mitigation and Climate Change**<br>**Additional biophysical threats** | To develop or improve capacity to identify, assess and anticipate changes in the Greater Virunga Landscape and beyond. Specific efforts will be made to develop effective local and international partnerships and alliances to be able to evaluate, anticipate and prepare for 'new' challenges including climate change, population trends and the changing demands on natural resources.<br>Examples from each category:<br>*Adaptation and Climate change*: altitudinal zonation; how will it change with climate change? Where can endemic plants and animals find refuge?<br>*Mitigation and Climate Change*:REDD opportunities: forest carbon dynamics, assess carbon in afro-alpine peat (Mgahinga, Rwenzori, Virungas), improving landscape connectivity, and providing corridors for species to move to better climates<br>*Additional biophysical threats*: $CO_2$ and how ecosystems respond, loss of large herbivores, invasive species | | Douglas Sheil, Institute for Tropical Forest Conservation, Director; http://www.itfc.org/ | MacArthur Foundation |

## Appendix V:  Accompanying Figures to Chapter 2

Fig 1 Albertine Rift map

## Fig 2 monthly rainfall

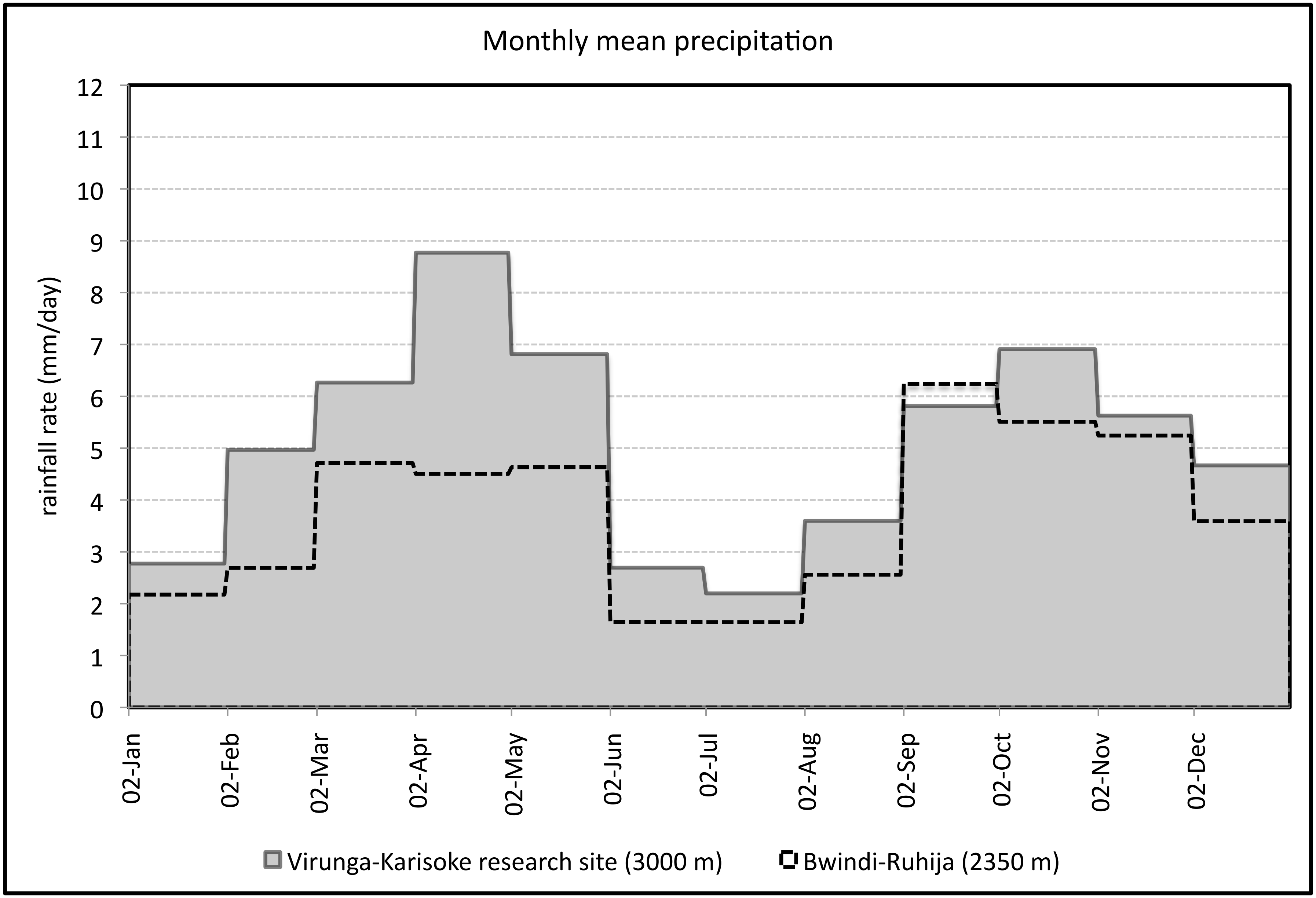
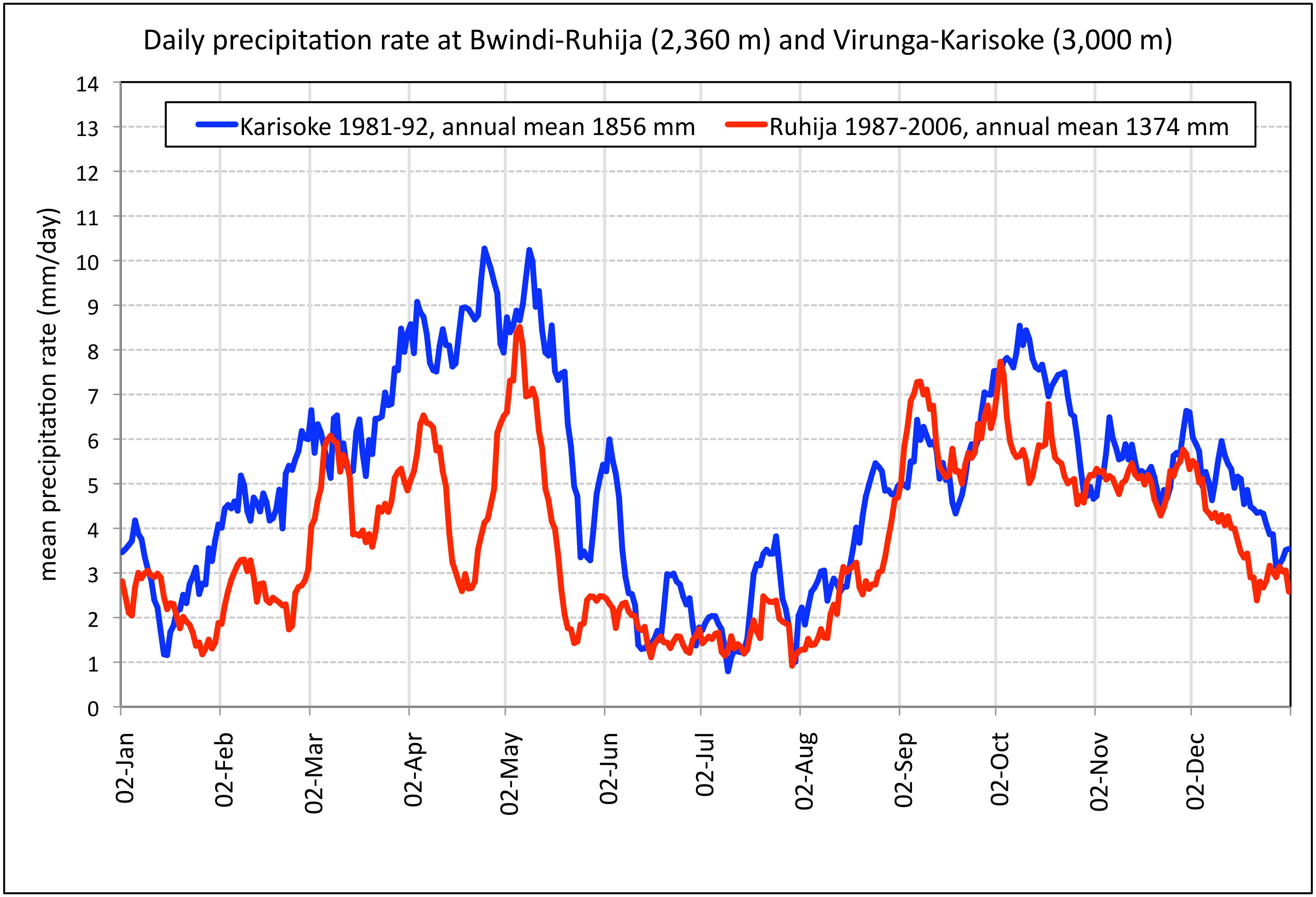


Fig 3 high-resolution rainfall


Daily precipitation rate at Bwindi-Ruhija (2,360 m) and Virunga-Karisoke (3,000 m)

# Fig 4Lwiro temperatures

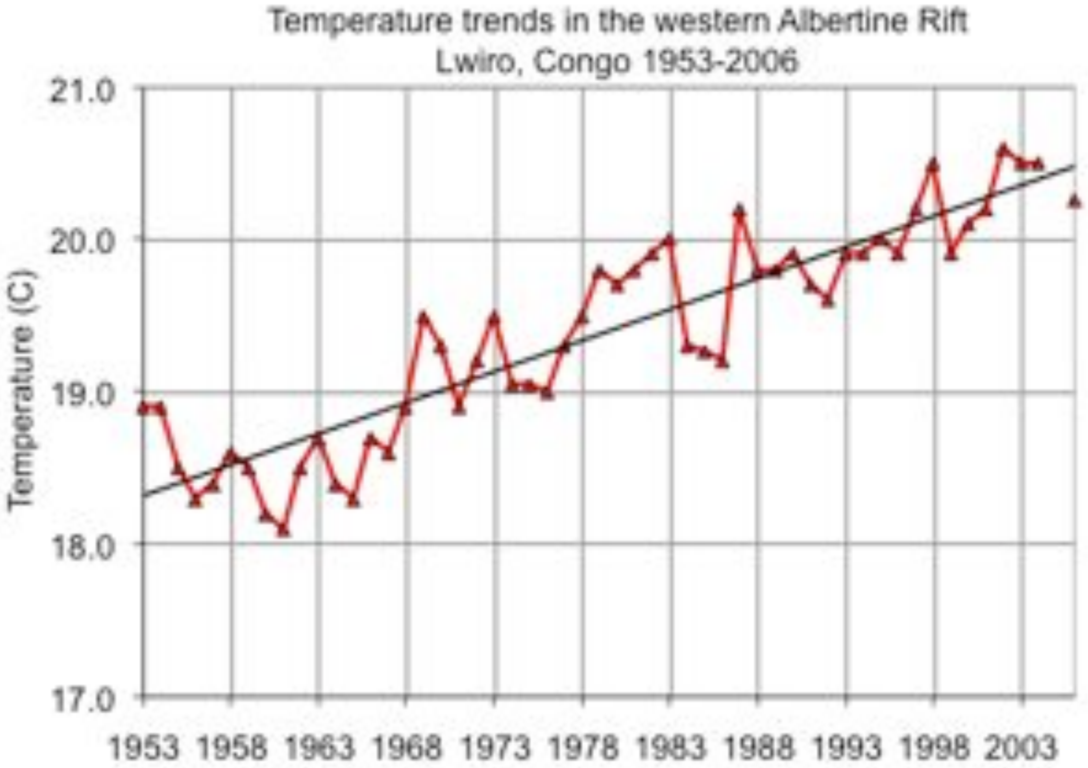
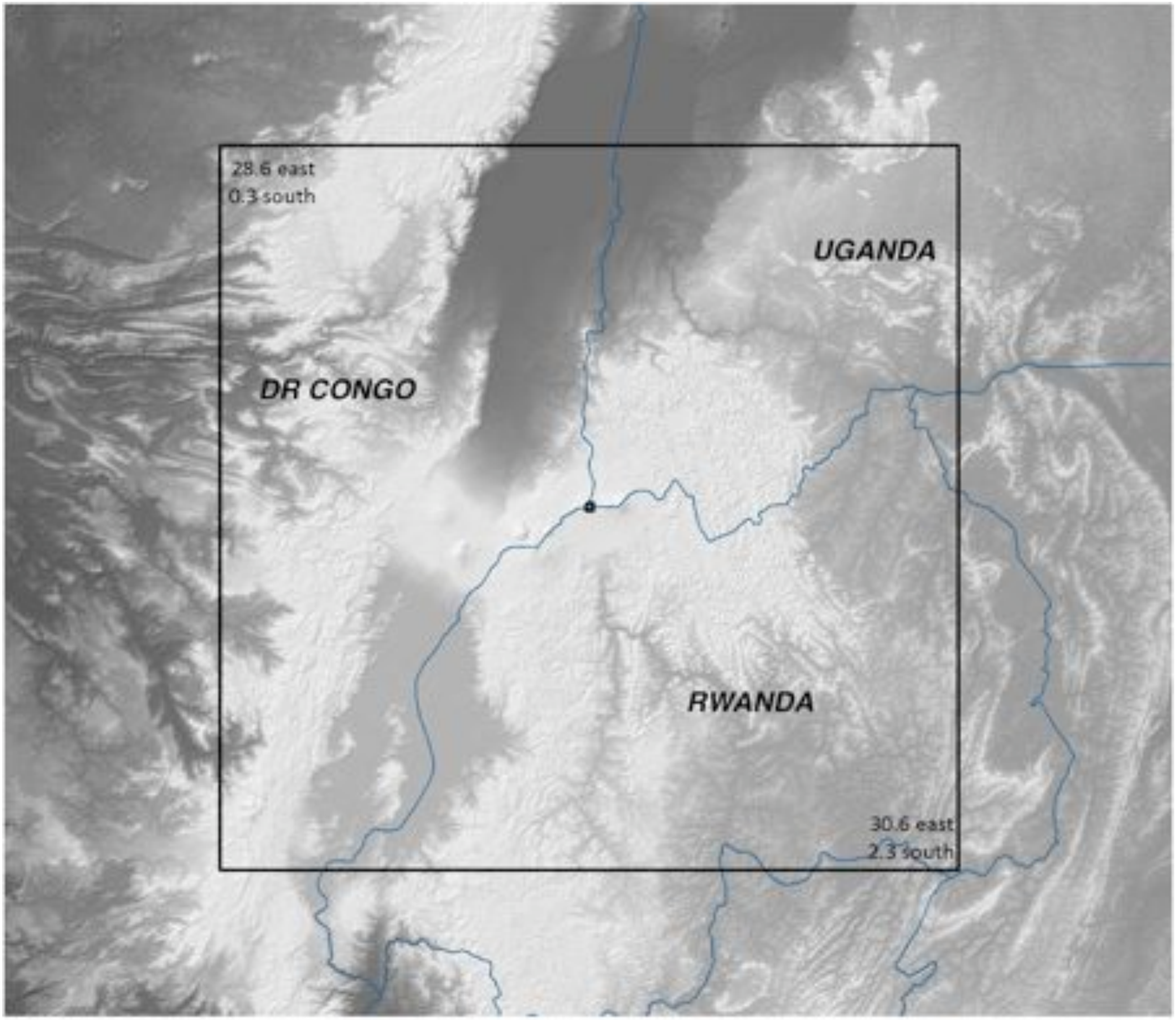
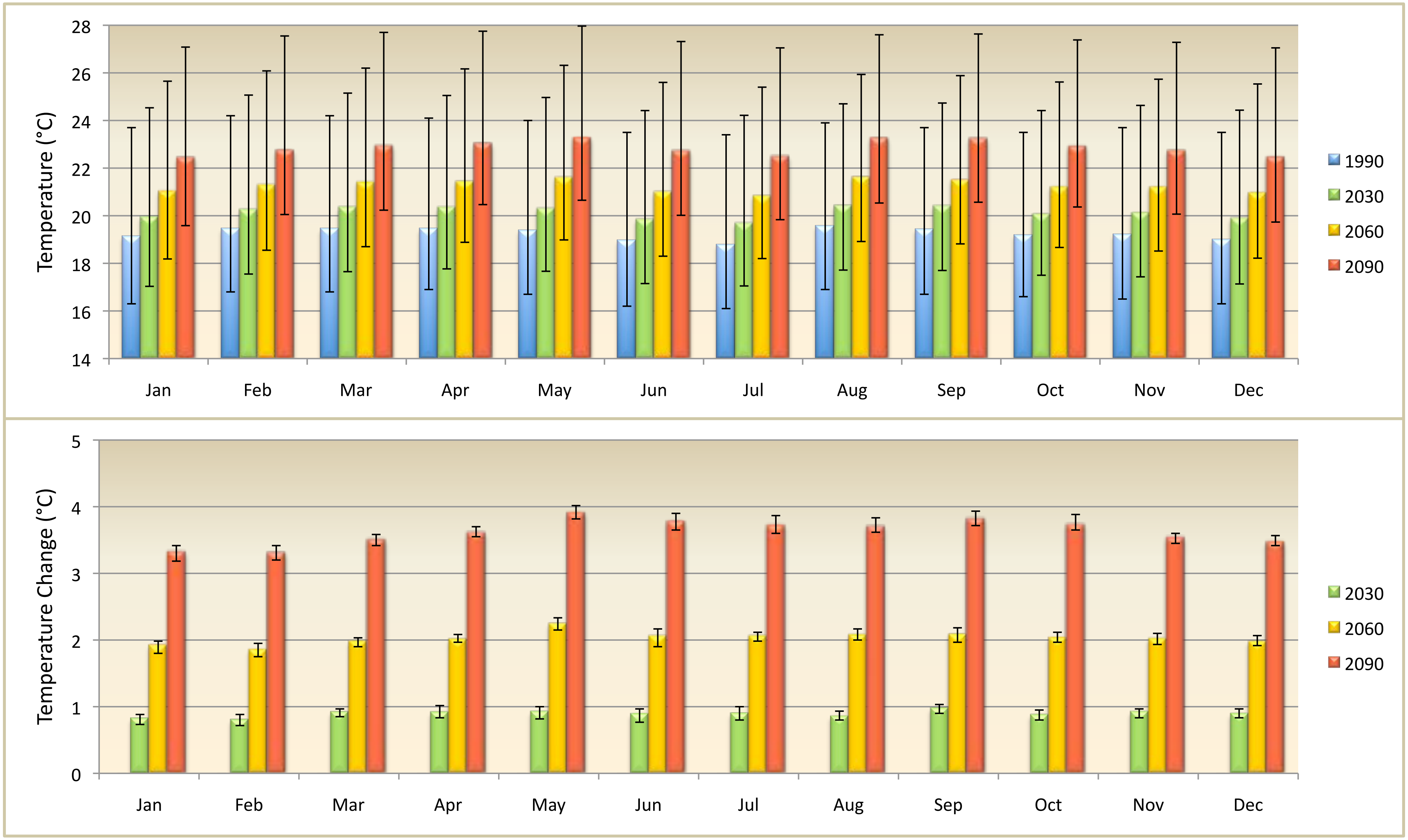


Fig 5 focused model domain



# Fig 6 temperature



# Fig 7 precipitation

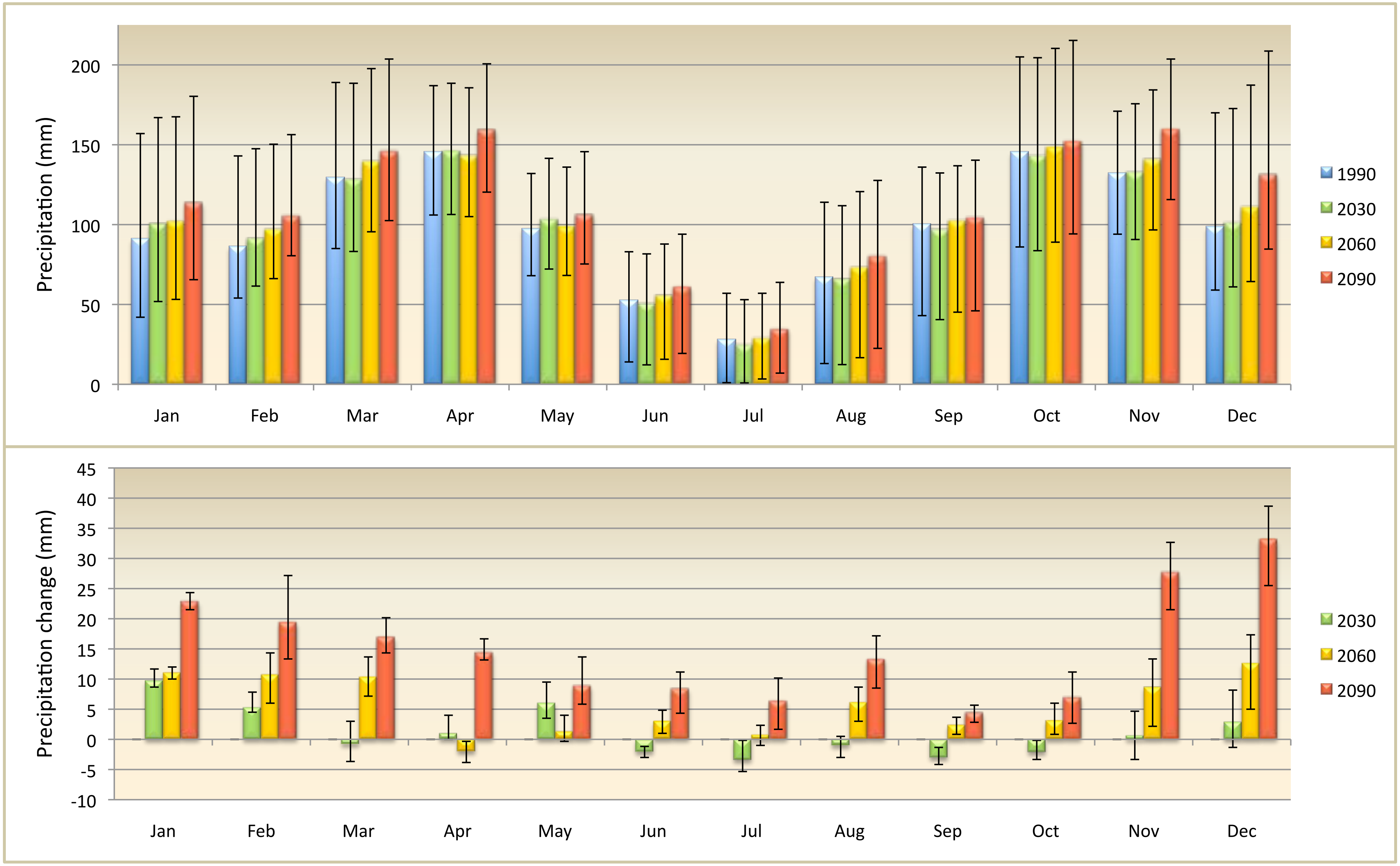


Fig 8 hydrological fluxes

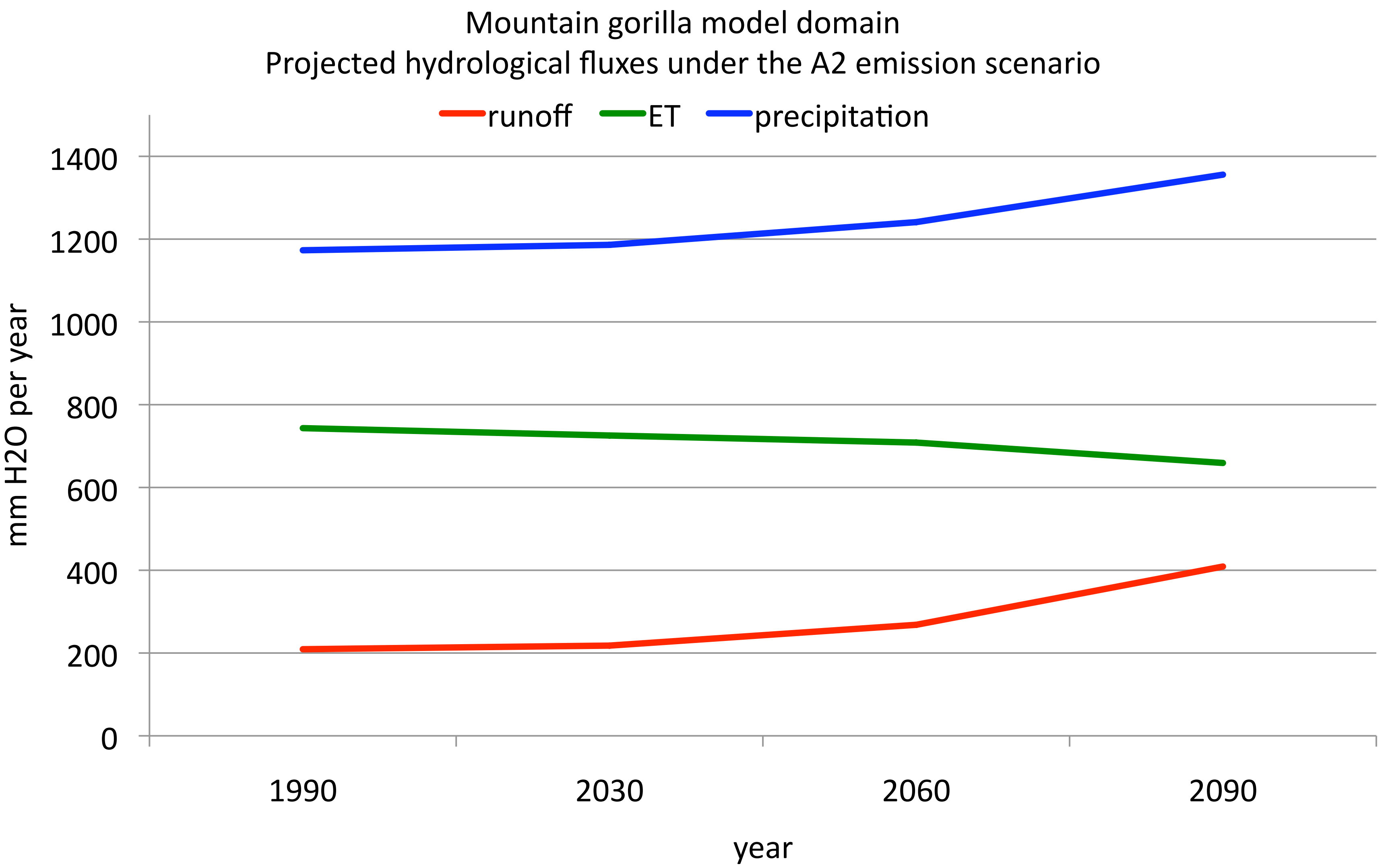


Figure 9 carbon loss from fire

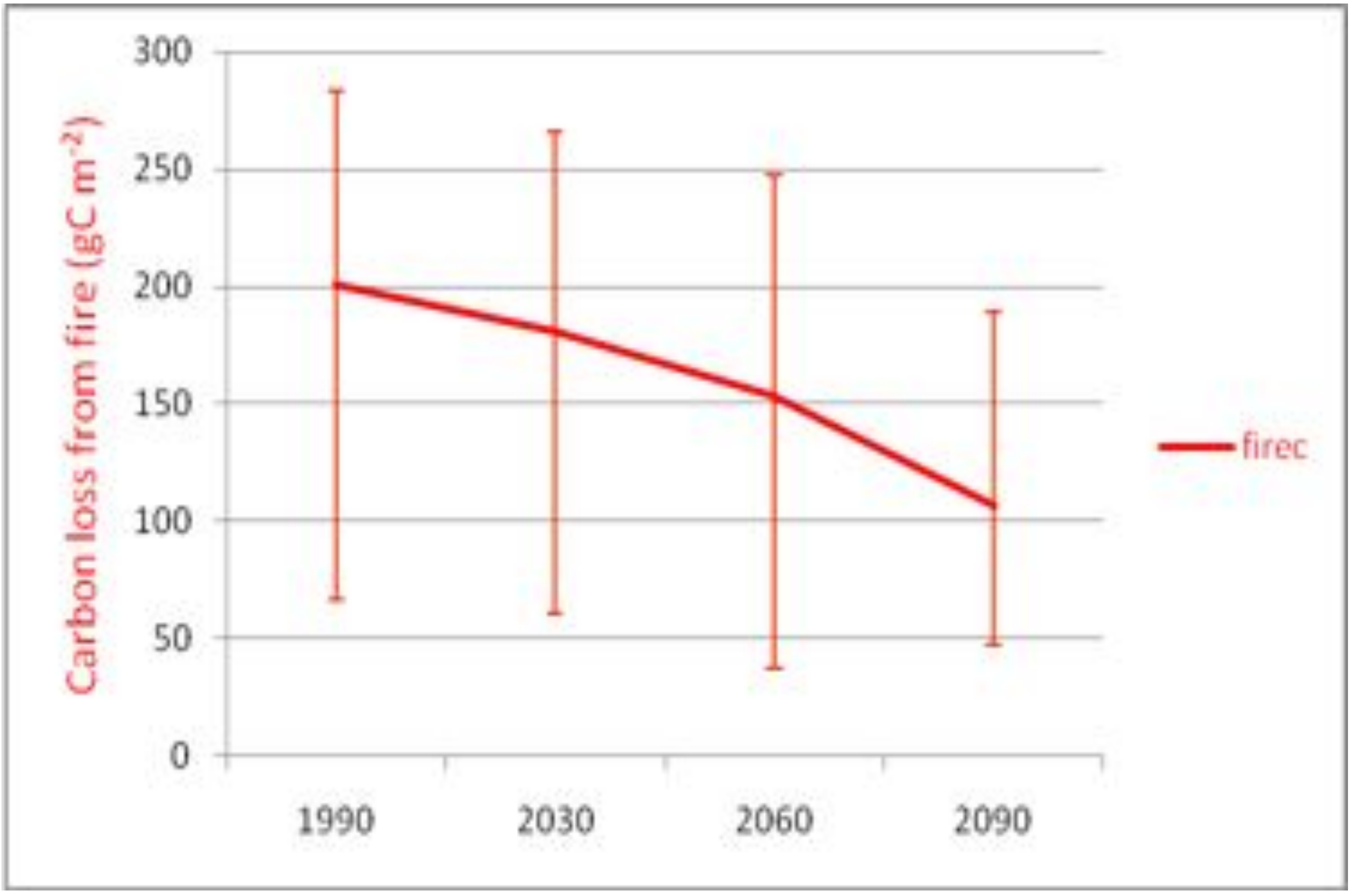


Figure 10 Virunga fires in July 2009

Fig 11 plant functional type

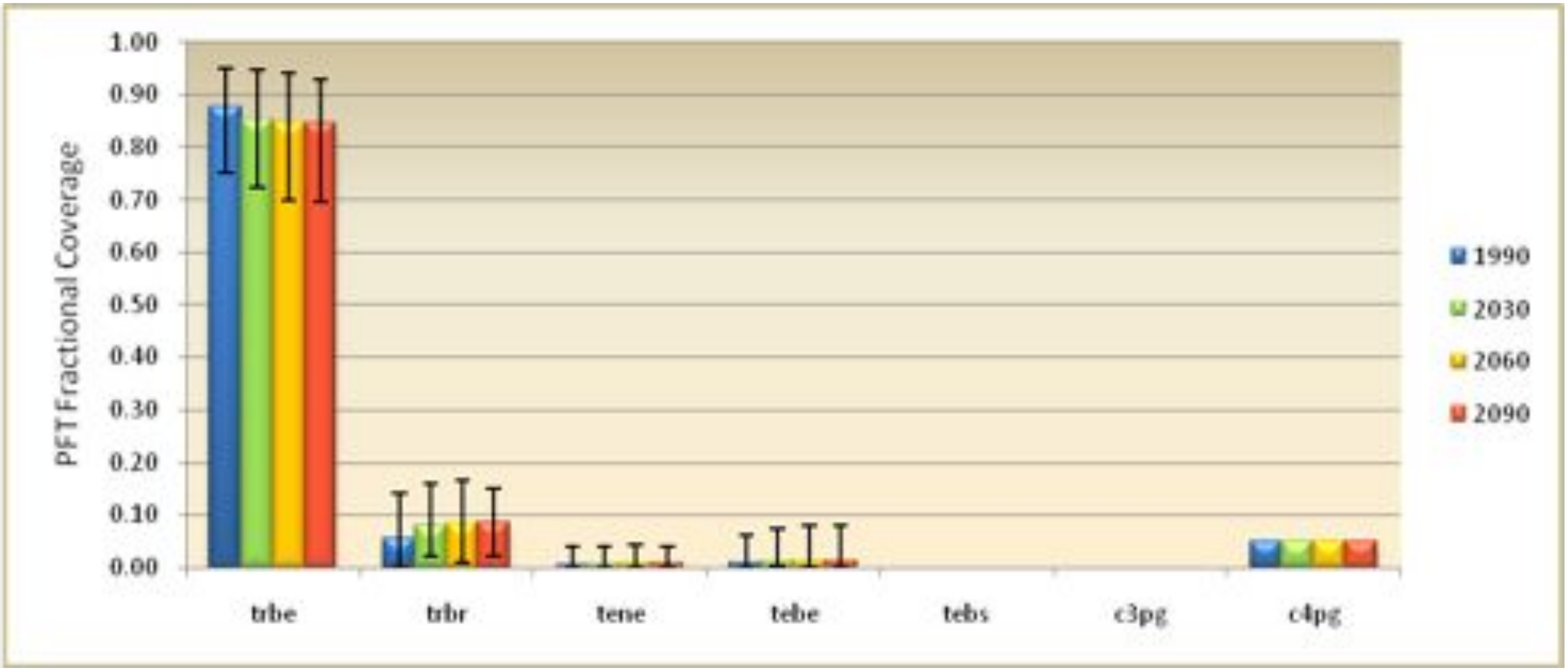
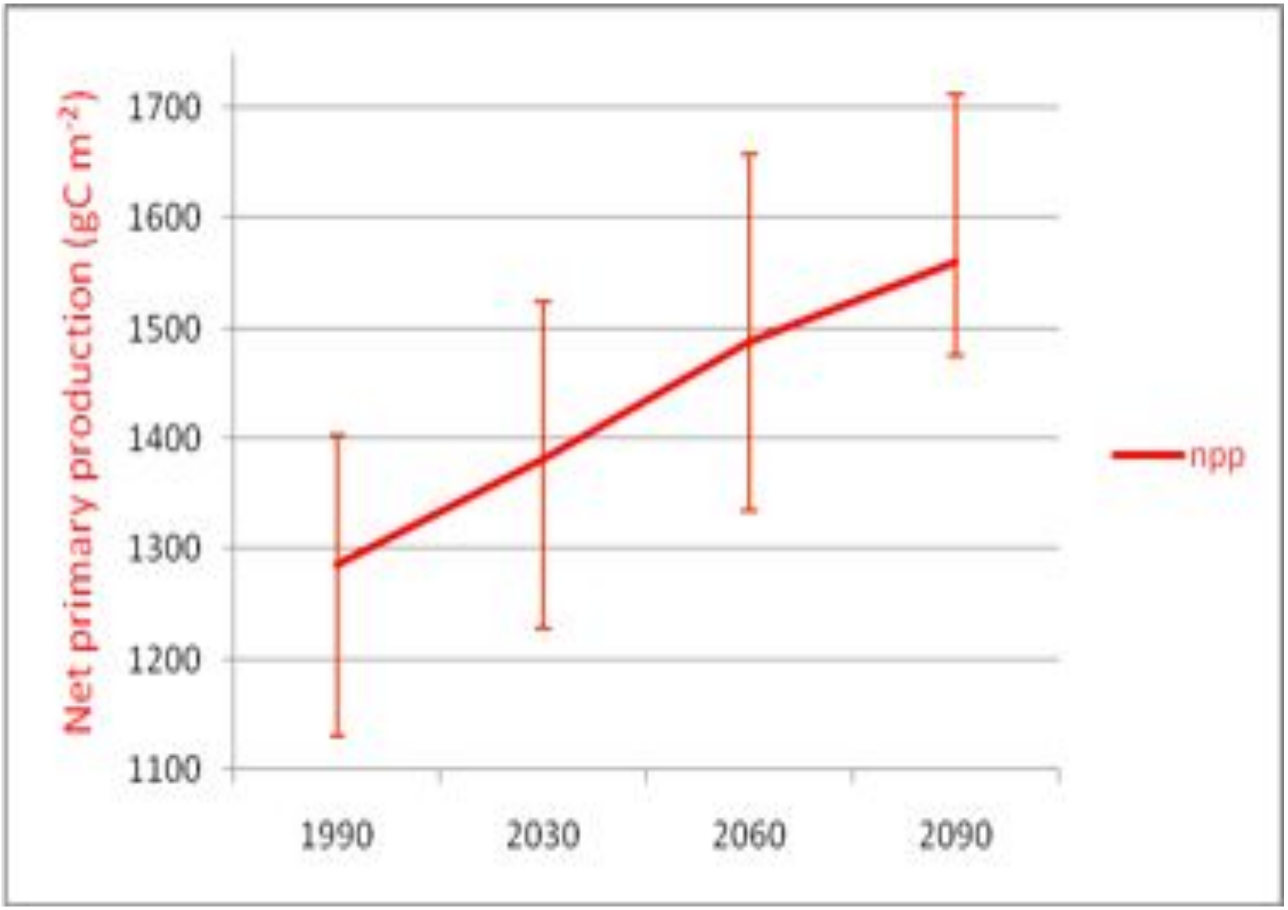


Fig 12 NPP


Net primary production (gC m-2)
1700
1600
1500
1400
1300
1200
1100
1990
2030
2060
2090
npp