



Faculty of Science and Technology

**Modelling the effects of anthropogenic climate change on the
distribution patterns of *Cercocebus*, *Lophocebus* and *Papio* in
sub-Saharan Africa**

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Sciences

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Abstract

Global industrialisation and a reliance on fossil fuels as its cornerstone have led to unprecedented rates of carbon emission entering the earth's atmosphere throughout the last few decades, a trend that appears likely to increase exponentially in the future. As a result, the global climate has been changing at an alarming rate. The impacts of anthropogenic climate change on wildlife biodiversity is a long studied and well documented topic. There have been many innovative techniques developed as a way of further understanding and evaluating what is happening with regard to species' susceptibility to climate driven changes in habitat on a global scale, both in the present and in attempting to predict ongoing conditions into the future. The analysis presented is intended to be contributed as one small component of the large body of research currently being carried out in the region, with a view to identifying ways in which anthropogenic climate change may be allayed and the detrimental impacts attenuated. Here, the current distributions of three primate genera in sub-Saharan Africa, *Cercocebus*, *Lophocebus* and *Papio*, are examined and predictions of how these distributions may be altered in the face of anthropogenic climate change across multiple time periods and carbon emission pathways are modelled. It was demonstrated that not all animals are likely to be affected in the same way, and that while climate change has the potential to affect some extremely negatively, as is the case for *Cercocebus* and *Lophocebus* respectively, who will likely see contractions and fragmentations of suitable habitat range occur, *Papio* remains relatively unmoved and may possibly even experience range expansions.

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1. Introduction

1.1 Overarching Issues

In recent decades, many African primate populations have suffered from instability, fluctuation and decline (Oates, 1996; McGraw 1998; Chapman et al. 2000; Oates et al. 2000; Campbell et al. 2008), particularly those that rely on forest habitats. There are many factors attributed to these negative population trends, such as game hunting (N’Goran et al. 2012; Ripple et al. 2016), urban sprawl (DeFries et al. 2010; Swift 2012) and deforestation through agriculture. For example, the Millenium Ecosystem Assessment (MEA 2005) released a report stating that, globally, more land was converted to cropland between 1950-1980 than in the 150 years between 1700-1850, resulting in approximately 25% of the earths terrestrial land being used for cultivation. There are also overarching abiotic processes affecting wildlife populations that are frequently associated with global climate change (Dunbar 1998; Isabirye-Basuta and Lwanga 2008) and as such, it is estimated that approximately 10.5% of forest cover was lost between 1980 and 1995 across Africa, at a rate of 12.5 million hectares annually (Chapman and Peres 2001). Global climate change is long regarded to be one the primary pressures on biodiversity (Opdam and Wascher 2003; Root et al. 2003) and is believed to have been responsible for at least one species-level extinction, the golden toad *Bufo periglenes*, in Costa Rica (Pounds et al. 1999).

It is understood that non-human primates are currently undergoing distribution changes and are likely to be severely affected by all of these pressures in the future as time progresses. A recent study has determined that of the 504 primate species known to the Neotropics, sub-Saharan Africa and Asia, 60% of them are now currently threatened with extinction, while approximately 75% of them are populations in decline (Estrada et al. 2017). Sterl et al. (2008) have reported that there is likely to be an increase in the severity of serious droughts, raised land temperature and heat waves across the world, all of these processes pose a very credible threat to primate survival, as they directly affect the composition of the local environment and species biodiversity. In Africa, the Intergovernmental Panel on Climate Change (IPCC 2007) reported that throughout the previous century there has been an increase in rainfall in the richly biodiverse Albertine Rift region, while also estimating that global temperatures have increased by up to 1°C in the previous 150 years to date, claiming that the rate of increase has accelerated in the most recent decades.

1.2 Causes of Climate Change

It is important to identify the underlying causes of climate change when developing a strategy for understanding the effects it may have upon the native wildlife of a region. As climate change is believed to be accelerating under the influence of anthropogenic activity, it is of particular urgency that measures are taken to mitigate the impacts that modern human society is having upon the planet. Anthropogenic climate change is widely regarded to be related to an increase in atmospheric carbon dioxide as well as other greenhouse gases, such as methane, nitrous oxide and chlorofluorocarbons that are commonly emitted into the atmosphere as a by-product of the heavily industrialised modern world.

Approximately 75% of CO₂ emissions are believed to be a result of excessive use of fossil fuels in industry, while the remaining 25% are predominantly linked to processes associated with forest degradation, caused by changing land use such as deforestation and agricultural development. The IPCC (2001) have reported that during the period between 1750-2000, atmospheric CO₂ has increased by 31%, and 60% of this increase has occurred since 1959. The current levels of CO₂ have not been surpassed in the previous 420,000 years, and likely haven't in the past 20m years. Similarly, N₂O levels have increased by 17% in the same time span, to reach levels that have not been exceeded for at least 1000 years. Forests contribute greatly toward the environment as large-scale carbon sinks, removing carbon from the atmosphere, storing it and producing oxygen (Gumpenberger et al. 2010; Pan et al. 2011), they play a vital role in the success of all life throughout the world. The process of removing forest therefore contributes to the production of greenhouse gases twofold, firstly via the physical removal of forest, producing pollution as carbon is released into the atmosphere, and secondly, as the natural carbon sink is diminished. These figures have resulted in the creation of various climate modelling platforms, which have pointed to a potential increase in global surface temperature of up to 4.8°C and larger fluctuations in precipitation levels will occur in the period 1990-2100 (IPCC 2013).

Thus, changes in climate such as these are believed to be a major issue for the survival of species around the world, a particular concern is the potential for shifts and changes in vegetation type (Bond et al. 2003), which may result in less favourable conditions for wildlife over time (Davis and Shaw 2001; Belfiore et al. 2015). It is also expected that other stress factors may be indirectly increased through climate change. For example, previously unencountered diseases and non-native species are liable to undergo range

expansions into new regions, which may expose an existing species vulnerability to disease or parasites (Barrett et al. 2013; Chapman et al. 2009; Harvell et al. 2002). Additionally, the effects of pollution could be exacerbated by changes to soil temperature or chemistry, and changes to the rate of precipitation may also result in unforeseen movements of pollutants around the ecosystem, which could then adversely affect wildlife directly, or via the availability of vital resources (Noyes et al. 2009). There are many ways in which a species may respond the changes in climate. Depending on the organism in question, it may directly affect the phenology or physiology of the species, for example, the timing of seasonal events such as breeding, flowering or migration periods may change (Hüppop and Hüppop 2003; Menzel et al. 2006). This has serious implications for the balance of trophic interactions within an ecosystem, if the timing of such events is distorted, then prey or nesting site availability may be compromised. Another possible implication of climate change is for community shifts, in which previously common species become suppressed or extinct, while other rarer species begin to propagate (Brown et al. 1997), which could create knock-on effects for trophic interactions within an ecosystem. Shifts in community structure might also result from climate induced changes to distribution and range (Parmesan et al. 1999), a process that will be investigated in this study.

1.3 Climate Change and Species Distribution Models

In attempting to predict the effects and severity of climate change, there have been many climate models and species distribution models created that serve to forecast its effects throughout the coming century. Climate models are based upon weather and environmental data, that aim to predict future conditions. One of the main resources for climate modelling are the Representative Concentration Pathways (RCP), which are predictive trajectories for atmospheric greenhouse gas concentration (van Vuuren et al. 2011). Species distribution models are numerical tools that combine and collate observed species occurrence or abundance data with environmental approximations, such as climate models, with a view to understanding how the range and distribution of a species will be affected in the future (Elith and Leathwick, 2009). This study will apply these climate projections onto the current habitats of primates, such as the tropical rainforests and open savannahs of Africa, with a view to understanding how population distributions may be affected. It will focus on evaluating the current state of primate distribution patterns and assess the impacts that climate change may have on them.

1.4 Ecology of the Genera Selected for Study

In focusing on three primate genera, *Cercocebus*, *Lophocebus* and *Papio*, it is anticipated that their differing habitat requirements will provide a contrast in the findings. *Cercocebus* and *Lophocebus* are colloquially known as mangabeys, they have similar ecological requirements. Within these two genera, there are multiple species and subspecies, whose natural range spans the extent of central Africa, from the southern coast of western Africa through the central belt towards Kenya, preferring to reside in areas of tropical forestation (Gautier-Hion et al. 1999; Shah 2003; Maisles et al. 2007). These forest dwelling primates are highly social and herbivorous. They exist in large groups ranging from 10-40 members, depending on species, and are sustained by diets consisting primarily of seeds, fruits and leaves provided by the forests (Chalmers, 1968; Wasser 1993; Ehardt 2001; Ehardt et al. 2005). *Cercocebus* are known to spend approximately 50% of their time foraging on the forest floor, whereas *Lophocebus* enjoy a marginally greater arboreal existence (Waser 1977; Horn 1987; McGraw 1994; Shah 2003). Mangabeys are generally in decline across all species. Of the eight species classified by the IUCN Red List, three are considered to be endangered: *Cercocebus lunulatus* (Oates et al. 2016a), *Cercocebus galeritus* (Butynski et al. 2008) and *Cercocebus sanjei* (Ehardt et al. 2008). One is listed as vulnerable: *Cercocebus torquatus* (Oates et al. 2008a), and two are near threatened: *Cercocebus atys* (Oates et al. 2016b) and *Lophocebus aterrimus* (Hart et al. 2008a). Only *Cercocebus agilis* (Hart et al. 2008b) and *Lophocebus albigena* (Oates et al. 2008c) are currently regarded to be of least concern. Many of these species are estimated to be undergoing a dramatic decline in number, for example, *Cercocebus lunulatus* is believed to have suffered a 50% population decrease in the last 27 years (Oates et al. 2016a), whereas *Cercocebus atys* and *Cercocebus torquatus* are adjudged to have declined by 20-25% and 30% respectively (Oates et al. 2008a; Oates et al. 2016b).

In contrast to the distribution of mangabey monkeys, *Papio* is ubiquitous throughout central and southern Africa. There are 6 known species of *Papio*: which are *Papio papio*, *Papio cynocephalus*, *Papio anubis*, *Papio ursinus*, *Papio kindae* and *Papio hamadryas* (Wilson et al. 2013). They are regarded as robust and versatile animals, this is evidenced by the range of different habitat in which they can be found. They are primarily ground dwelling animals, often only retreating to the canopy as a protective measure when sleeping (Schreier & Swedell 2008; Hamilton 1982). *Papio* have evolved to survive in a large variety of habitats, for example *Papio anubis*, the most extensively distributed

baboon, is found in such systems as the dry, arid conditions of the Sahelian woodland as well as varied environment of the forest mosaic (Aldrich-Blake et al. 1971). *Papio hamadryas*, however, has adapted to altitudinal habitats and is most commonly found in the mountainous regions of north east Africa (Zinner et al. 2001). The most pressing concern for *Papio* living in dry environments is the availability of water, and during dry seasons some species have been observed to travel in excess of 7 kilometres per day to locate a reliable source (Johnson et al. 2015). *Papio* are considered to be opportunistic omnivores, this characteristic is likely to provide great benefit to their hardiness and ability to survive as they are not constrained by the availability of a specific food source. Their diet can consist of anything from grasses, fruits and nuts, to invertebrates, small vertebrates and occasionally small livestock (Hill and Dunbar 2002). They are highly social creatures living in heavily structured dominance hierarchies that can grow as large as 200 members (Cohen 1969). The population trends of the *Papio* genus are generally positive, only *Papio papio* is considered to be of extinction concern and is classified as near threatened by the IUCN Red List, it is thought to have experienced a 20-25% range contraction within the last 30 years (Oates et al. 2008b). All other species of *Papio* are of least concern and are understood to have stable or increasing populations.

1.5 Rationale for the Comparison Between Genera

In choosing to compare mangabey monkeys with *Papio sp.* there lies a contrast in the perceived adaptability of each genus. Mangabey's are expected to have much stricter habitat requirements as they are constrained to the central belt of Africa, this is due to being specialised for life in tropical rainforests and thusly, they are limited by the resources provided within this environment. Therefore, it is anticipated that mangabey monkeys will be liable to experience a greater sensitivity to regime shifts and structural changes in their respective ecosystems. Conversely, as generalist species, *Papio* have demonstrated a clear robustness and ability to differentiate (Williams-Blangero et al. 1990) in order to survive and prosper across a wide array of varied environments, from the rocky mountainous regions of north east Africa to the open savannahs and tropical forests of the more central regions. Accordingly, *Papio* are assumed to serve as a control for study, as it is anticipated for them to be far less impacted by the effects of climate change than the mangabey species. A similar study (Thuiller et al. 2006) focused on estimating the future success and sensitivity of 227 African mammal species in the face of human-induced climate change, using similar climate change projections as this study will utilise. Their findings suggest

that by 2050, 10-15% of species are expected to fall to critically endangered, or extinct status in accordance with the IUCN Red List criteria, and by 2080 this estimate is anticipated to have reached approximately 25-40%. Therefore, it is of vital importance that the effects of climate change are investigated, forecast and where possible, mitigated for, so to prevent unnecessary and preventable catastrophes at species level in the region.

2. Aims/Objectives

The aim of this study is to investigate how climate change will affect the success of Africa's primates and attempt to predict the consequences of it on their ongoing survival.

Objective 1. To predict how climate change may affect the suitability of habitats for both mangabey and *Papio* in the future based on current trends and models.

Hypothesis 1. It is expected that mangabey habitats will be more negatively affected by climate change than those of *Papio*.

Objective 2. To evaluate the effect of climate change on mangabey distributions in the future.

Hypothesis 2. Mangabey distributions will retract as climate change becomes more severe.

Objective 3. To evaluate the effect of climate change on *Papio* distributions in the future.

Hypothesis 3. *Papio* distributions will be relatively unaffected by climate change.

3. Methods

The primate distribution data used for this study contains presence and absence of the *Cercocebus*, *Lophocebus* and *Papio* genera across 327 different sites within the sub-Saharan Africa region. It was compiled by Korstjens (2017), who employed extensive research techniques to corroborate the accuracy and reliability of the data. Site-specific survey data were used rather than species range maps due to the potential for inaccuracy in the latter. It is a valid assumption that a species likely does not inhabit the extent of its range in a uniform or equal distribution (Rapoport 1982), Hurlbert and White (2005) found that a species was only detected in 40.5% of its geographical range when a comparison study that contrasted survey based analysis with range maps was carried out. Mapping species richness and distribution through the application of distribution models, as with range maps, has the potential to produce data for much larger areas, however, the accuracy may be compromised depending on the factors taken into account. Many will only consider climate change and overlook other important the limitations of individual species, such as dispersal ability or species interactions (Graham and Hijmans 2006). Consequently, the decision to utilise survey data rather than range maps is expected to offer more reliable data, albeit across a smaller geographic area.

The first step in gathering the primate location data was to identify protected areas that had evidence for the presence of at least one cercopithecoid, each prospective site was selected based upon a combination of data provided by The United Nations Environmental Programme (UNEP) World Conservation Monitoring Centre (WCMC) Database on Protected Areas (WDPA) and the African Protected Areas Assessment Tool (APAAT), the WCMC is a non-profit organisation that specialises in collating, analysing and interpreting biodiversity and ecosystem services, the database was compiled using sources from over 600 providers, which include governmental bodies, international secretariats, non-governmental organisations as well as individuals. The data provided for the creation of this database is updated at least once every 5 years to ensure accuracy (UNEP-WCMC 2016). Similarly, the APAAT focuses on assessing and characterising the protected areas of Africa to aid decision making in the allocation of funds (Hartley et al. 2007). The data provided were aggregated from multiple sources such as the IUCN, White's Vegetation Map of Africa (White 1983) and the African Mammals Databank (Boitani 1999).

Scientific reports, local publications and surveys were then used to confirm the presence of any cercopithids in each location. In order to detect any gaps in the distribution data, a map was created with each site location plotted to highlight any areas that may have been overlooked. Further searches were then conducted in an attempt to obtain presence data for these areas, which were primarily of unprotected status, and therefore had not been listed within the previously mentioned databases. Of the 327 locations selected, there were confirmed instances of *Cercocebus* in 59 sites, 48 of them contained *Lophocebus* and *Papio* was present in 262. 28 of the sites contained both *Cercocebus* and *Lophocebus*, 51 held either *Cercocebus* or *Lophocebus*, 50 sites contained *Papio* in addition to either *Cercocebus* or *Lophocebus*. There were 43 sites inhabited by either *Cercocebus* or *Lophocebus* without *Papio* being present, whereas 226 locations contained *Papio* only. Finally, there were 22 sites contained neither mangabey genus or *Papio*.

The climate data were produced by WorldClim as part of their global climate database version 1.4. In total, 8 climate variables were used for this analysis, which are as follows: mean annual temperature (°C), mean diurnal temperature range (mean of monthly maximum temperature-minimum temperature) (°C), temperature seasonality (C of V), minimum temperature of the coldest week (°C), annual precipitation (mm), precipitation seasonality (C of V), precipitation of wettest quarter (mm) and precipitation of driest quarter (mm) at 5 arc minute interval (~9km) resolution. Single data points were then created for each identified site were then created using latitude and longitude values. The future climate prediction data were supplied by WorldClim's downscale Coupled Model Intercomparison Project Phase 5 (CMIP5). Published in 2011, CMIP5 provides a framework for coordinated climate change research via a multi-model estimations of potential climate change around the world (Hijmans et al. 2005). In order to obtain space and time dependent values for climatic variables within the CMIP5 framework, an earth system model is required. Earth system models are computer code based scripts designed to process differential equations that describe the physics of climatic factors in combination with global chemical and biological processes, such as atmospheric nutrient cycling, to provide accurate simulations for future environmental conditions (Heavens et al. 2013). WorldClim offers a variety of choice with regard to earth system model selection, each producing slightly different outputs and performance. For this study, the HadGEM2 family earth system model was chosen, a model produced by the UK MetOffice (Collins et al. 2008). The rationale for this was based upon Brands (2013) coupled multi-

model comparison review of seven earth system models, which suggests that HadGEM2 is best suited for supporting Africa based studies, generally outperforming the other alternatives.

Finally, future climate prediction data were required for analyses, there are four predominant environmental pathways that estimate global greenhouse gas concentration trajectories throughout the current century, until 2100, based upon potential greenhouse emissions. These are collectively known as RCP's, the four RCP's are RCP 2.6, RCP 4.6, RCP 6 and RCP 8.5, they take their names from the potential radiative forcing values found in literature, from 2.6 to 8.5 W/m² respectively (van Vuuren et al. 2011). Each pathway is considered a viable possibility of occurring depending on how industry and energy production is regulated globally over the coming years. Of the four RCP's, this study will demonstrate the average of the pathways RCP 2.6 and RCP 8.5 as these characterise the two most extreme forecasts for future climate change conditions.

In RStudio (version 1.0.136 for Windows), generalised linear models with logistic link function (GLM logit link; family: binomial) were employed to determine which combination of climatic variables affected and allowed for prediction of distribution patterns in each primate genera targeted in this study (Hijmans & Elith 2016). The best fit models for each genus were chosen based upon a combination of the total number of variables included in the iteration as well as the AIC_c values produced by utilising the dredge function of R's MuMIn package (Bartoń 2016). The models with the lowest AIC_c value that also contained at least 6 of the 8 climatic variables considered in this study were selected. Once the best fit models had been established, the resulting equations of the models could then be used to estimate appropriate habitat distributions for both the present day and potential future conditions for all three chosen genera. Once the equations had been created, ANOVA tests were performed in R by first creating a null model, null models assume that presence or absence is predicted just as well by a constant. Once the null model was created the "anova" function in R was used to test the comparison between the null model and the best fit model. The intention behind this process is to establish whether or not the best fit model is significantly better at predicting distribution patterns than the null model.

The data were then imported into SPSS (IBM SPSS Statistics 23) for analysis. Initially, both box and whisker plots, as well as histograms, were created to display a combined

view of the current suitability data and that of each RCP. This was done to identify a numerical threshold of habitat suitability. To further confirm the models are indeed a good fit in relation to the observed presence and absence data Cohen kappa and area under curve (AUC) values were also calculated. Having decided upon a suitability threshold, the distribution of the data was then determined. This was achieved by comparing the median suitability value with the mode for both presence and absence in each genera and RCP. A similar mode and median value indicates a normal distribution. Non-parametric Friedman tests were used to compare suitability of habitat between each of the RCP's, this test ranks the suitability value of each location against each other and creates an overall scale based upon how often each of the RCP values are greater than one another. Following the Friedman test, a matched pairs Wilcoxon signed rank test was used to establish how the climate predictions may have affected the suitability of the locations for each RCP of the three genera in comparison to the current data, it provides information on whether the majority of sites have become significantly more or less suitable than they are in the present day. In order to gain a deeper understanding of the distribution dynamics in question, the data were split into presence and absence categories before again performing both Friedman and Wilcoxon signed rank tests for each RCP against the current state. Finally, crosstabulation was used to identify how changes in future suitability may affect the total presence and absence in each site in comparison to the current data based upon the previously established threshold for suitability.

Once analyses were complete, it was then possible to create a visual depiction of the estimated future habitat suitability using the raster calculator tool in QGIS (QGIS Development Team 2016). This tool allowed for the creation of virtual maps of Africa that display a gradient of habitat suitability of each RCP and time period used in this study. To create these maps, each genera was assigned a suitability scale based upon histogram data derived from their suitability index calculations. For example, habitat suitability for *Papio* was divided into categories: Very suitable (+12), suitable (+7), less suitable (0) and unsuitable (-7). Similarly, *Cecocebus* was categorised: Very suitable (+13), suitable (+9), less suitable (+6) and unsuitable (0), whereas *Lophocebus* was classified as: Very suitable (+1), suitable (0), less suitable (-4), unsuitable (-10) and very unsuitable beyond that. Dividing the suitability index as such allowed for a clear depiction of the range of suitable habitats for each scenario. Again, using QGIS, it was then possible to create maps to display the difference in habitat suitability between current conditions and RCP 8.5 2070,

which was selected as the most extreme scenario included in this study. This was achieved by deducting the RCP 8.5 2070 layer from the current conditions with the raster calculator tool.

4. Results

The ANOVA tests (Table 1-3) for model suitability in comparison to the null model all showed strong significance and achieved P values of <0.001 for each of the RCP's within three tested genera, demonstrating that the variables utilised by each model was a good indicator for habitat suitability in each case.

Table 1. ANOVA output for each Papio RCP scenario and date range.

	Current	RCP 2.6 2050	RCP 2.6 2070	RCP 8.5 2050	RCP 8.5 2070
Df	6	6	6	6	7
F	27.352	28.747	28.224	27.143	23.560
p	<0.001	<0.001	<0.001	<0.001	<0.001

Table 2. ANOVA output for each Cercocebus RCP scenario and date range.

	Current	RCP 2.6 2050	RCP 2.6 2070	RCP 8.5 2050	RCP 8.5 2070
Df	6	7	7	7	7
F	30.986	27.230	27.080	26.888	27.440
p	<0.001	<0.001	<0.001	<0.001	<0.001

Table 3. ANOVA output for each Lophocebus RCP scenario and date range.

	Current	RCP 2.6 2050	RCP 2.6 2070	RCP 8.5 2050	RCP 8.5 2070
Df	7	6	8	7	6
F	23.121	28.801	22.090	25.396	28.805
p	<0.001	<0.001	<0.001	<0.001	<0.001

The presence and absence data for each tested genera and RCP typically pivoted around a suitability value of 0.0 (Fig. 1-3), where absence was in the majority, while presence was dominant above that value. However, whilst there was overlap beyond this threshold, ultimately it appeared to be the most suitable cut-off point. Therefore, it was established that habitat suitability values below 0.0 would be considered as unsuitable habitat conditions, whereas those above the threshold would be suitable conditions, for all three genera. The predictions made by each model for the current data were also regarded as a good fit based upon the calculated kappa and AUC values, which were $Kappa_{Pap}=0.72$, $AUC_{Pap}=0.88$, $Kappa_{Cerc}=0.71$, $AUC_{Cerc}=0.87$ and $Kappa_{Loph}=0.73$, $AUC_{Loph}=0.87$ respectively.

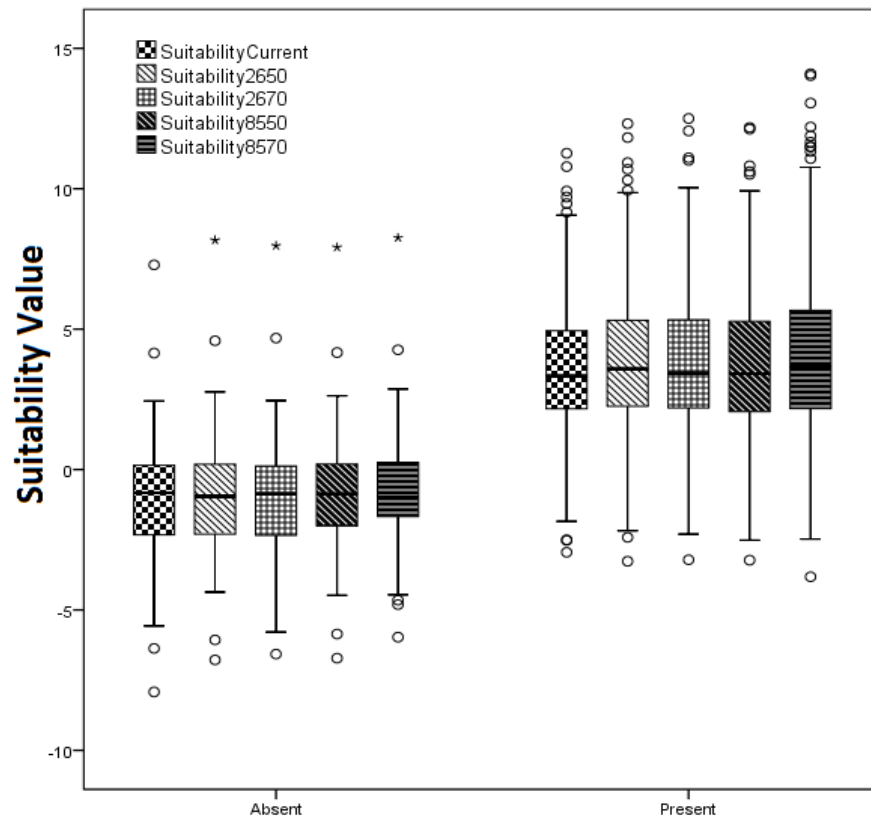


Figure 1. The habitat suitability index for locations in which *Papio* is currently absent and currently present for each of the RCP scenarios and date ranges selected in this study.

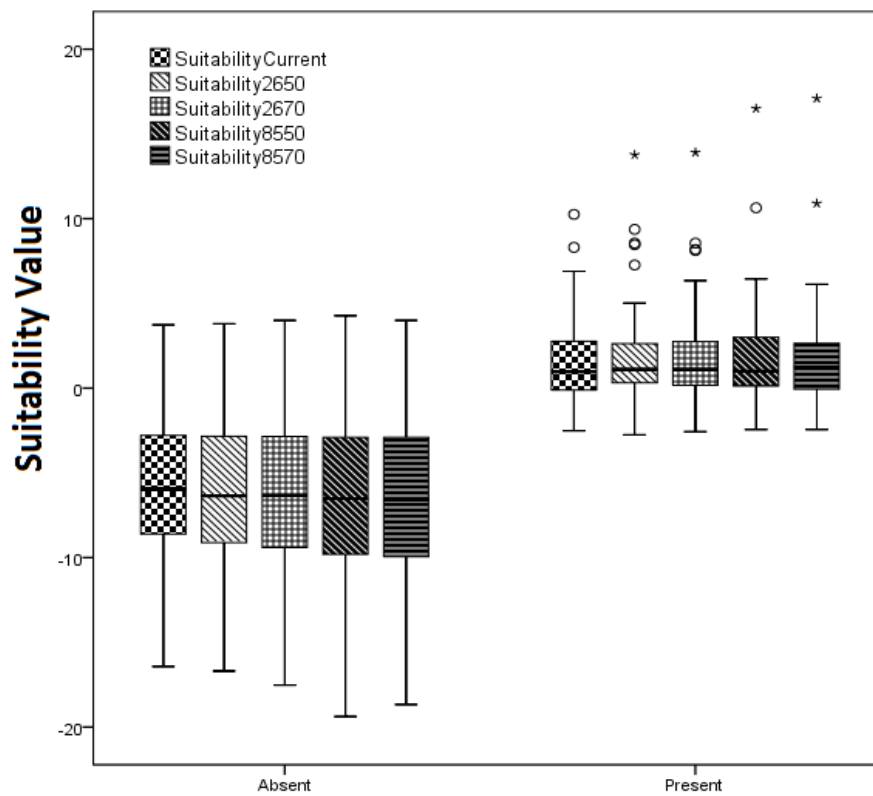


Figure 2. The habitat suitability index for locations in which *Cercocebus* is currently absent and currently present for each of the RCP scenarios and date ranges selected in this study.

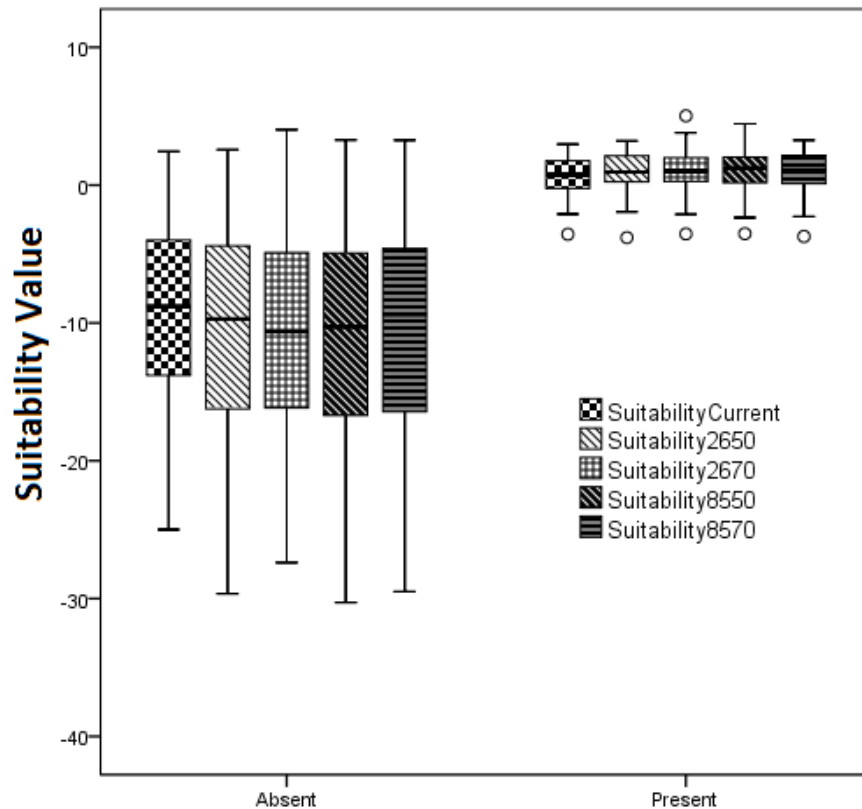


Figure 3. The habitat suitability index for locations in which *Lophocebus* is currently absent and currently present for each of the RCP scenarios and date ranges selected in this study.

When assessing the future climate suitability, the matched pairs Wilcoxon test indicates that the presence suitability conditions for *Papio* are significantly likely to increase by sizable amounts for all RCP considered, the RCP 2.6 2050 scenario in particular suggests that over 75% of presence sites could increase in suitability (Table 4a). For *Cercocebus*, absence locations are likely to become far less suitable in all RCP outcomes, as approximately 66% of these sites are considered to develop less suitable habitat conditions across all scenarios (Table 4b). The presence models indicate that roughly 33% of sites will grow to be less suitable, whilst 66% have had their suitability value increased. The suitability outcomes for *Lophocebus* are similar to those of *Cercocebus*, however the absence suitability values that have exhibited a negative result are slightly greater in quantity. The presence suitability appears to also suggest that approximately 33% of sites will encounter worse habitat conditions in comparison to the present day, whilst the remainder are expected to improve (Table 4c).

Table 4. Comparison of suitability values for sites where the genus is absent or present using a Matched pair Wilcoxon outcomes for absence and presence in all RCP scenarios for a) *Papio*, b) *Cercocebus* and c) *Lophocebus*.

$N_{Reduced}$ represents the amount of primate locations that have decreased in suitability when compared with the current suitability index in each of the RCP scenarios.

$N_{Increased}$ represents the amount of primate locations that have increased in suitability when compared with the current suitability index in each of the RCP scenarios.

a)	RCP 2.6 2050		RCP 2.6 2070		RCP 8.5 2050		RCP 8.5 2070	
	Absent	Present	Absent	Present	Absent	Present	Absent	Present
$N_{Reduced}$	37	63	36	94	28	110	26	73
$N_{Increased}$	28	199	29	168	37	152	39	189
Z	-1.572	-9.254	-0.591	-6.695	-1.480	-4.490	-1.212	-7.825
p	.116	<.001	.554	<.001	.139	<.001	.25	<.001

b)	RCP 2.6 2050		RCP 2.6 2070		RCP 8.5 2050		RCP 8.5 2070	
	Absent	Present	Absent	Present	Absent	Present	Absent	Present
$N_{Reduced}$	174	21	182	27	197	21	193	19
$N_{Increased}$	94	38	86	32	71	38	75	40
Z	-5.204	-2.212	-7.974	-1.381	-9.726	-2.030	-8.678	-2.189
p	<.001	.027	<.001	.167	<.001	.042	<.001	.029

c)	RCP 2.6 2050		RCP 2.6 2070		RCP 8.5 2050		RCP 8.5 2070	
	Absent	Present	Absent	Present	Absent	Present	Absent	Present
$N_{Reduced}$	214	17	242	15	253	13	199	15
$N_{Increased}$	65	31	37	33	26	35	80	33
Z	-10.498	-2.585	-12.940	-3.015	-13.364	-3.631	-8.858	-1.877
p	<.001	.010	<.001	.003	<.001	<.001	<.001	.061

The Friedman tests reveal that *Papio* is expected to experience an upturn in habitat suitability in both RCP 8.5 model predictions (Fig. 4a&b), especially for the 2070 scenario in which the mean rank is significantly larger than in current conditions. However, there is little correlation within the presence data here, as RCP 2.6 2050 far outranks RCP 2.6 2070 and RCP 8.5 2050 (Fig. 4b), therefore conclusions drawn from it should be treated with some care.

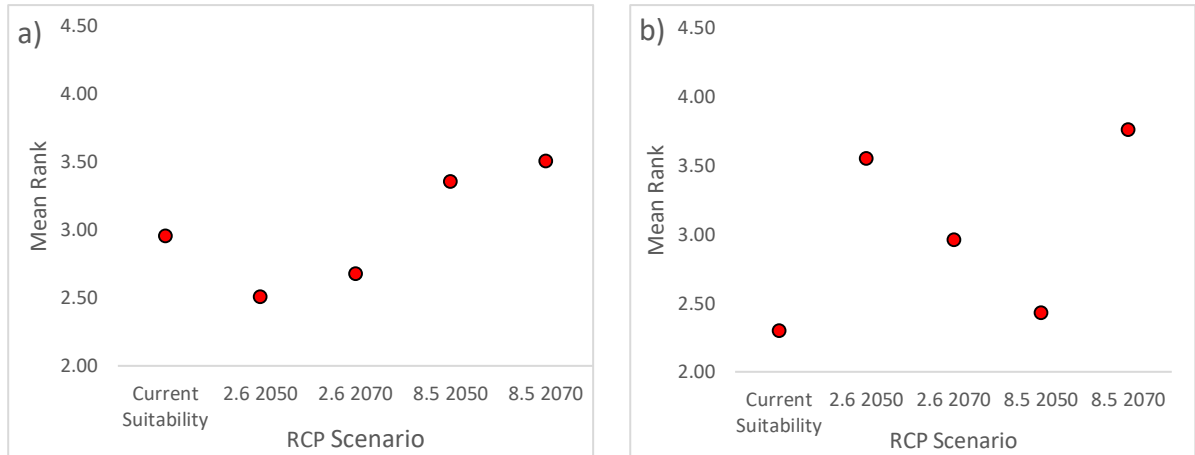


Figure 4. Friedman tests for *Papio* a) absence locations b) presence locations, showing current conditions and each of the four RCP scenarios ranked by suitability against one another.

Absence data (Fig. 5a) for *Cercocebus* displays a distinct drop in ranking as the RCP scenarios increase in severity. Both RCP 2.6 outcomes show a mildly suppressed habitat suitability in comparison to current conditions, whereas both RCP 8.5 rankings outline a marked decrease in the level of suitable locations. However, the presence rankings (Fig. 5b) present a contrast to those produced by the absence data. Every RCP shows a mean improvement in the suitability values when compared with current habitat suitability, this suggests that conditions where *Cercocebus* currently reside may improve in the future.

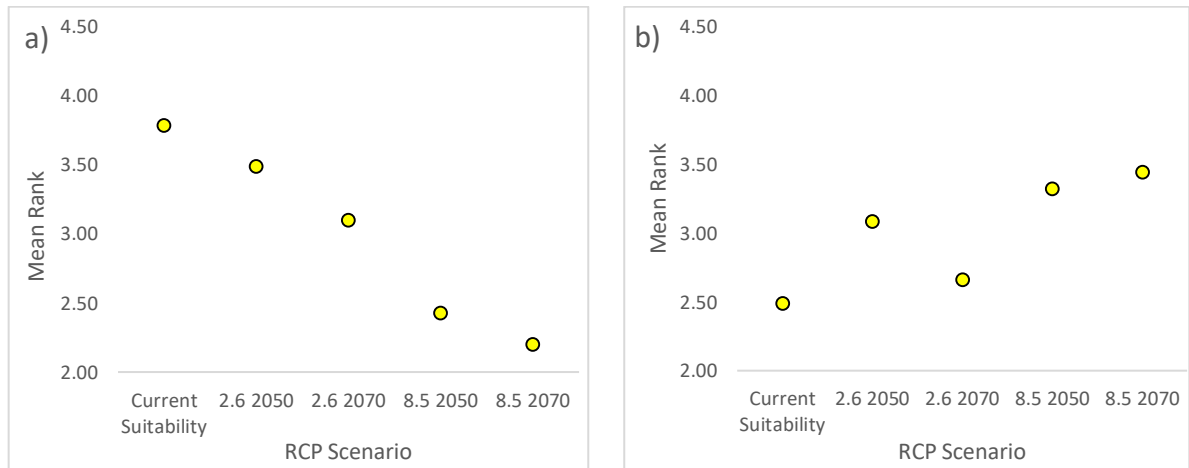


Figure 5. Friedman tests for *Cercocebus* a) absence locations b) presence locations, showing current conditions and each of the four RCP scenarios ranked by suitability against one another.

Finally, the *Lophocebus* rankings are once again similar to those of *Cercocebus*, however there is slightly less uniformity as the RCP scenarios grow from RCP 2.6 2050 through to RCP 8.5 2070. Nonetheless, overall, all 4 future prediction models indicate that absence

conditions (Fig. 6a) are likely to lead to a decrease in habitat suitability, whereas all of the presence models (Fig. 6b) suggest an improvement over the current situation.

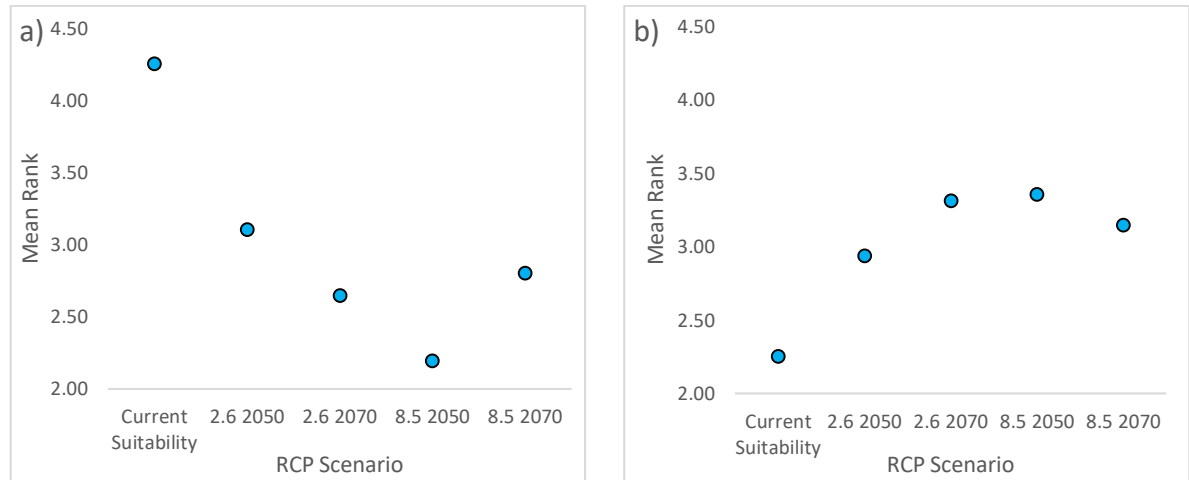


Figure 6. Friedman tests for *Lophocebus* a) absence locations b) presence locations, showing current conditions and each of the four RCP scenarios ranked by suitability against one another.

The predicted changes in suitable locations for each genus is quantified by the crosstabulation, this displays how many locations in which it is currently considered suitable are expected to become unsuitable after implementing each RCP model and vice versa. For example, *Papio* is predicted to see a gain in suitable habitats (Fig. 7), as 18 currently unsuitable locations are expected to become habitable sites for each of the RCP's, whilst only 8 or 9 currently suitable locations will be lost. Of the 327 total locations, 3 of the 4 RCP's show that 272 currently suitable locations will remain that way, whereas RCP 2.6 2070 indicates there will be 271. It is anticipated that for all 4 RCP's 47 currently unsuitable locations will continue to be unsuitable. This represents a net gain of 10 suitable locations for all RCP's except for RCP 2.6 2070, which predicts a gain of 9.

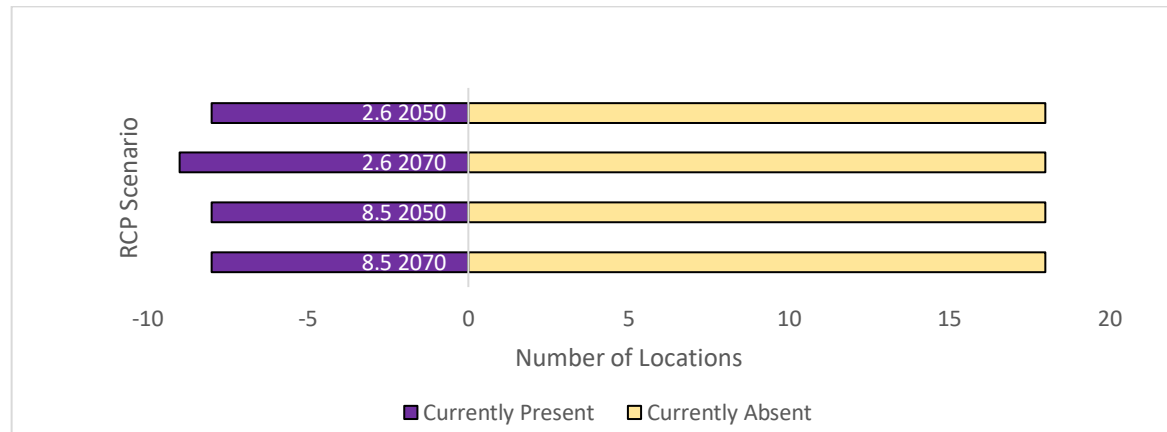


Figure 7. Crosstabulation output for *Papio* showing the quantity of current presence sites that have become unsuitable and current absence sites that have become suitable for each RCP scenario.

Conversely, *Cercocebus* is expected to see a net loss in suitable sites (Fig. 8). Each of the RCP models has produced identical values for each of the 327 locations included in this study. Of the 59 locations that are currently suitable for *Cercocebus*, 47 will continue to be so and 9 previously unsuitable sites are expected to become habitable, however, 12 will likely be lost. This presents a net loss of 3 suitable sites in each scenario.

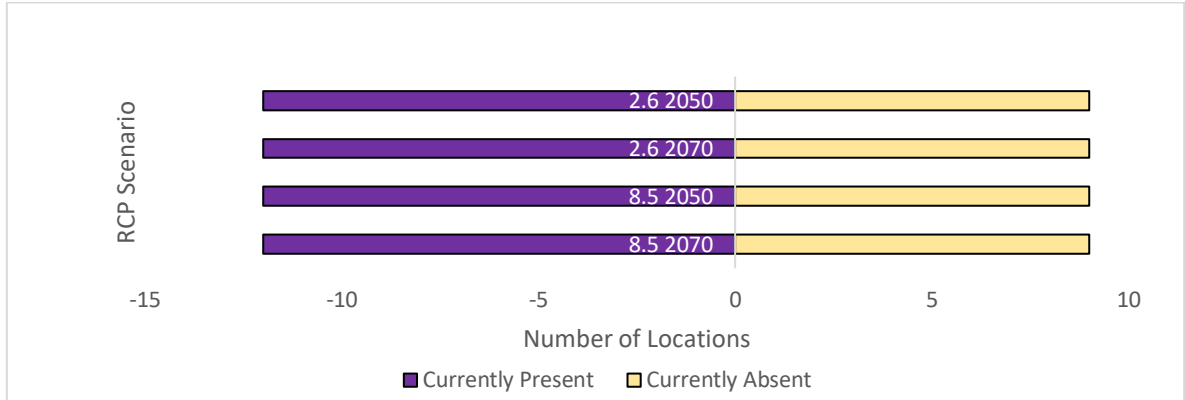


Figure 8. Crosstabulation output for *Cercocebus* showing the quantity of current presence sites that have become unsuitable and current absence sites that have become suitable for each RCP scenario.

The *Lophocebus* models show that the net effect of climate change is finely balanced (Fig. 9). Whilst there will be a change in the location of suitable sites, in contrast to the *Cercocebus* findings, *Lophocebus* is forecasted to achieve a net gain of 1 site in each of the 4 of the RCP's. It is predicted that 9 of the currently suitable sites will be lost while 10 unsuitable locations will be gained in the process.

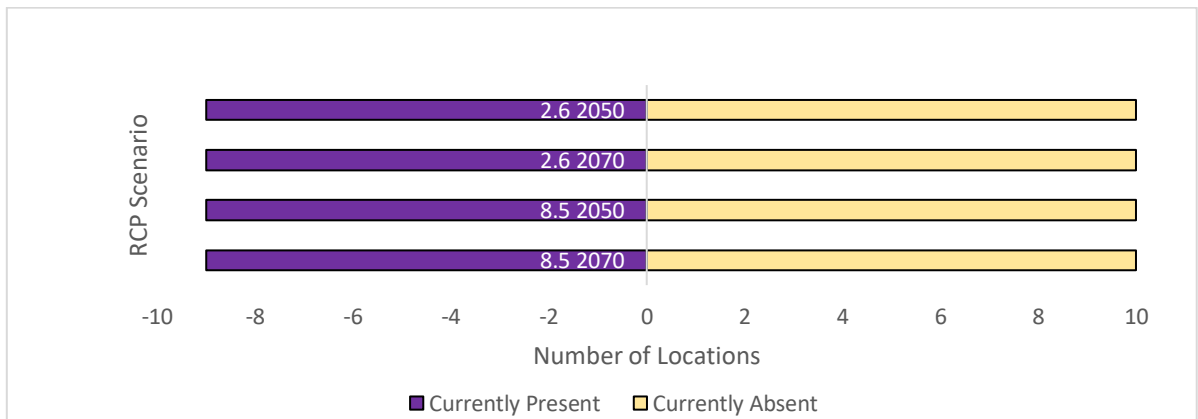


Figure 9. Crosstabulation output for *Lophocebus* showing the quantity of current presence sites that have become unsuitable and current absence sites that have become suitable for each RCP scenario.

The maps (Fig. 15) produced using the suitability indices derived from the generalised linear models give a spatial representation of which areas of Africa are suitable, and which are not. The current *Papio* habitat (Fig. 10) supports the ecological literature that describes

them as being ubiquitous throughout sub-Saharan Africa, barring the central tropical forested region, as the distribution of presence and absence sites fit that assumption.

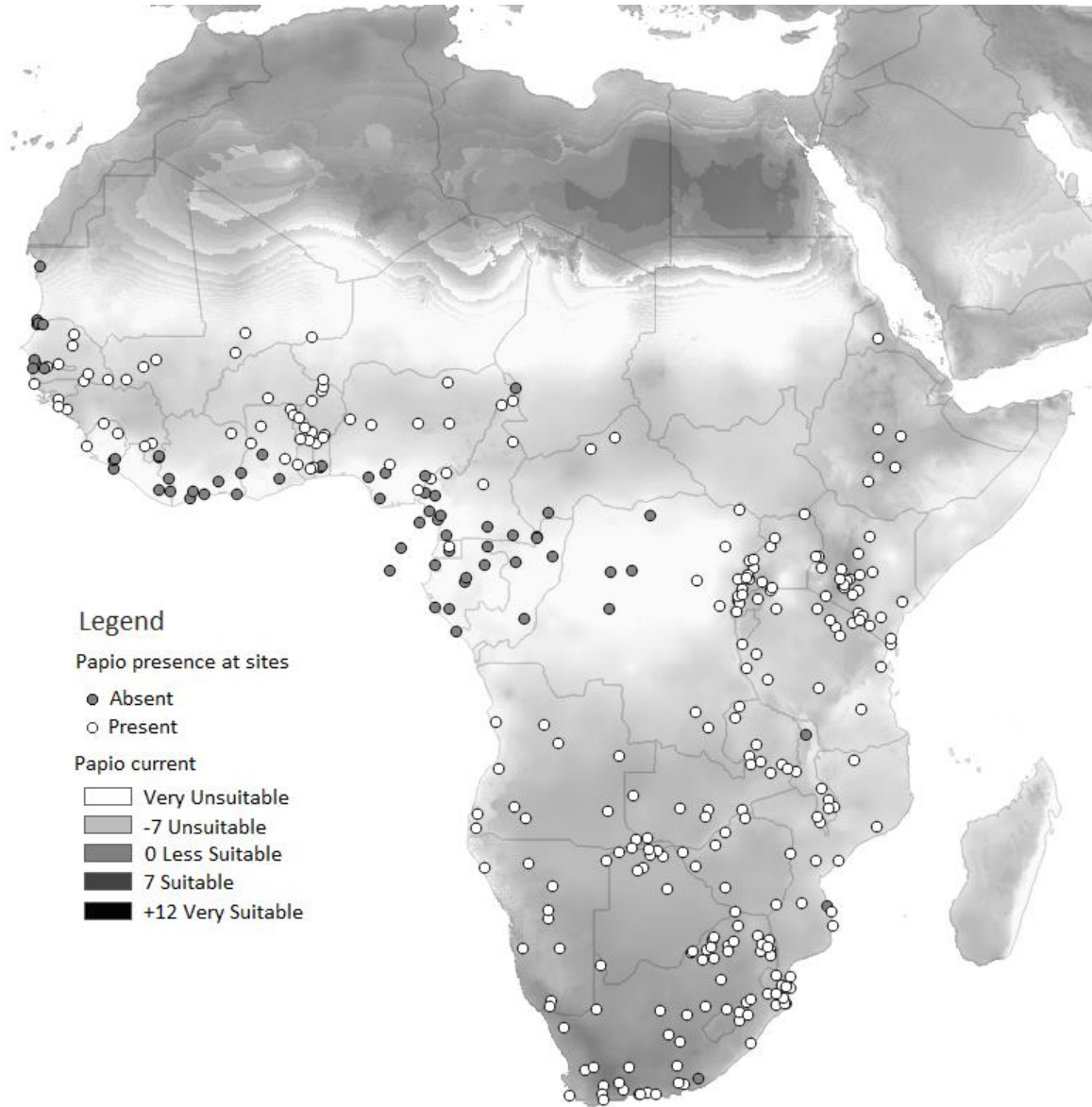


Figure 10. Current suitability values for *Papio*, with presence and absence at sites for this genus.

Their projected habitat for RCP 8.5 in 2070 (Fig. 11) is promising, as supplemented by the statistical analysis, the map shows a small amount of retraction in suitable habitat around the central tropical forest region, whilst making distinctive gains toward the southern extent of the continent. Overall, there is a clear gain in suitable habitat, particularly across regions in which *Papio* is already thriving.

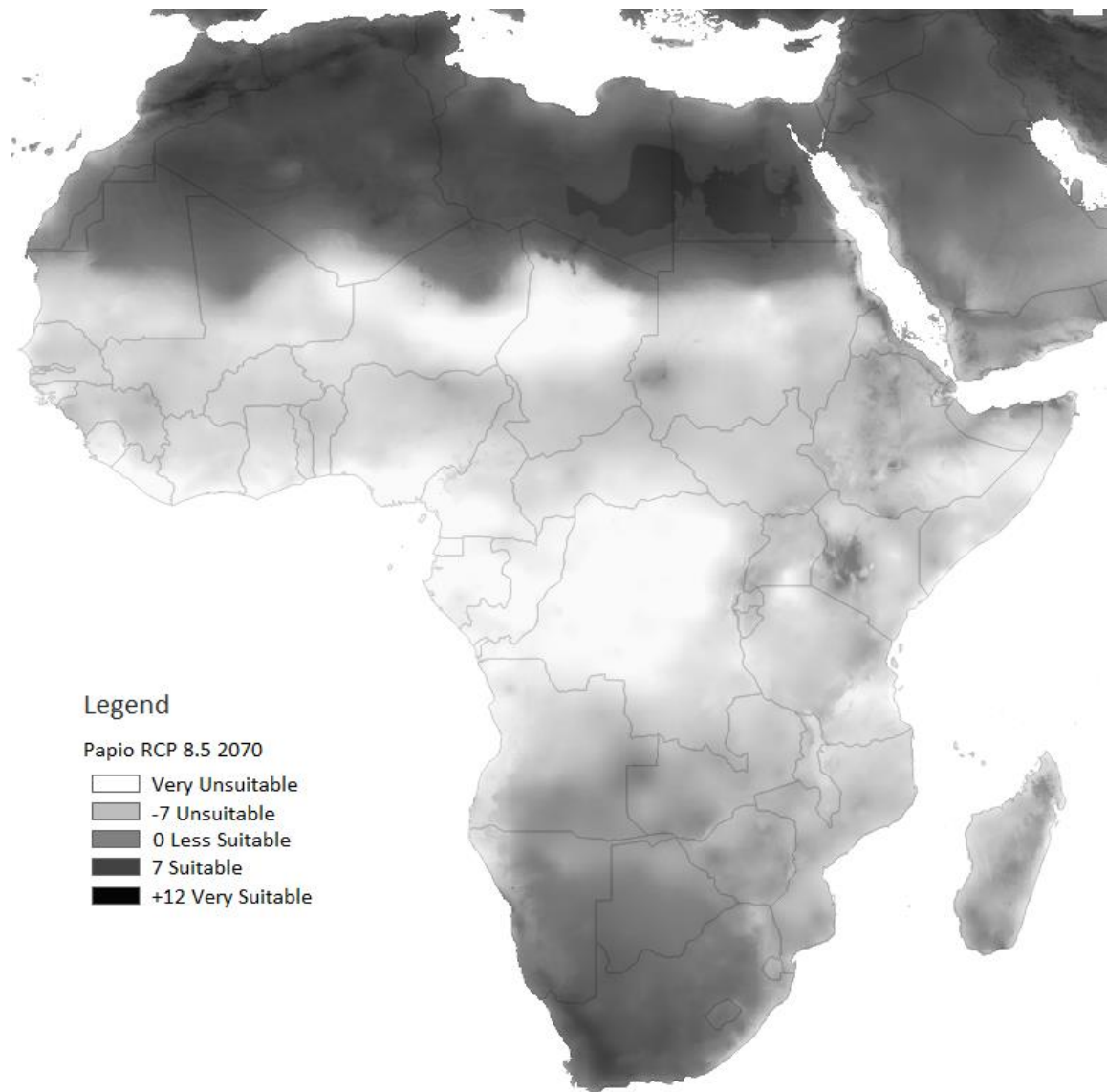


Figure 11. Projected suitability values for *Papio* under RCP 8.5 conditions in 2070.

In contrast to *Papio*, the current suitability index (Fig. 12) for *Cercocebus* displays a large area of very suitable habitat in central and western Africa, with very little elsewhere across Africa. This demonstrates that the range of *Cercocebus* is limited to this specific area and that the region in which they live is almost the complete inverse of *Papio*.

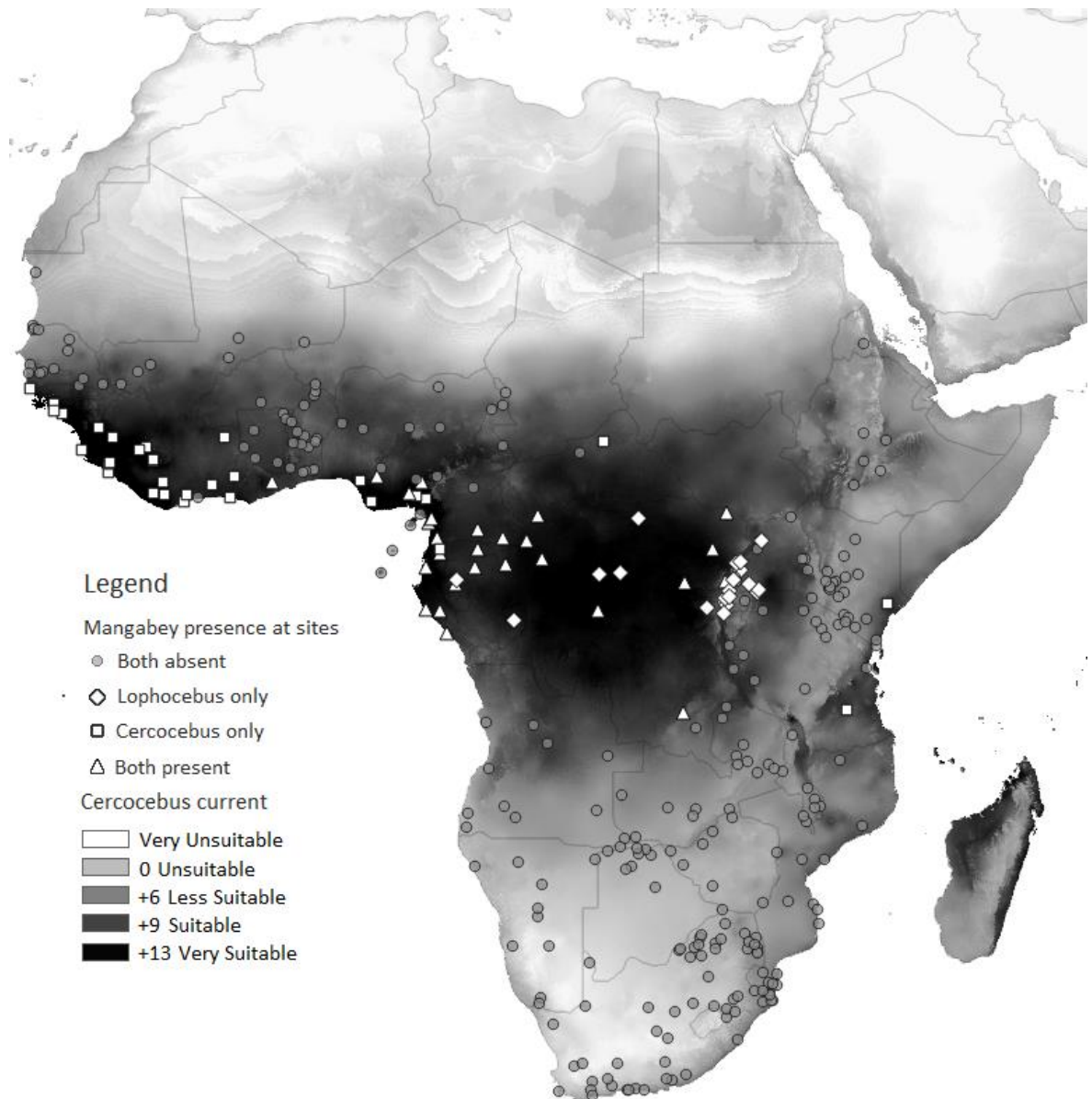


Figure 12. Current suitability values for *Cercocebus*, with presence and absence at sites for both *Cercocebus* and *Lophocebus*.

By 2070, under the RCP 8.5 conditions (Fig. 13), it is apparent that the large, dense central region that is currently suitable for *Cercocebus* today is quite severely diminished and it appears that their remaining very suitable habitats are largely restricted to the coastal forests of western Africa, as well as the heart of the central forest. Range contraction of suitable locations appears to be occurring from all directions.

Lophocebus currently occupies a very small region of central Africa (Fig. 14), with their most dense population located in the Western Rift Valley of western Uganda, however they have a presence throughout the tropical forest as far as the western coast of Gabon. Their suitable habitat is far more limited than that of *Cercocebus* and especially *Papio*.

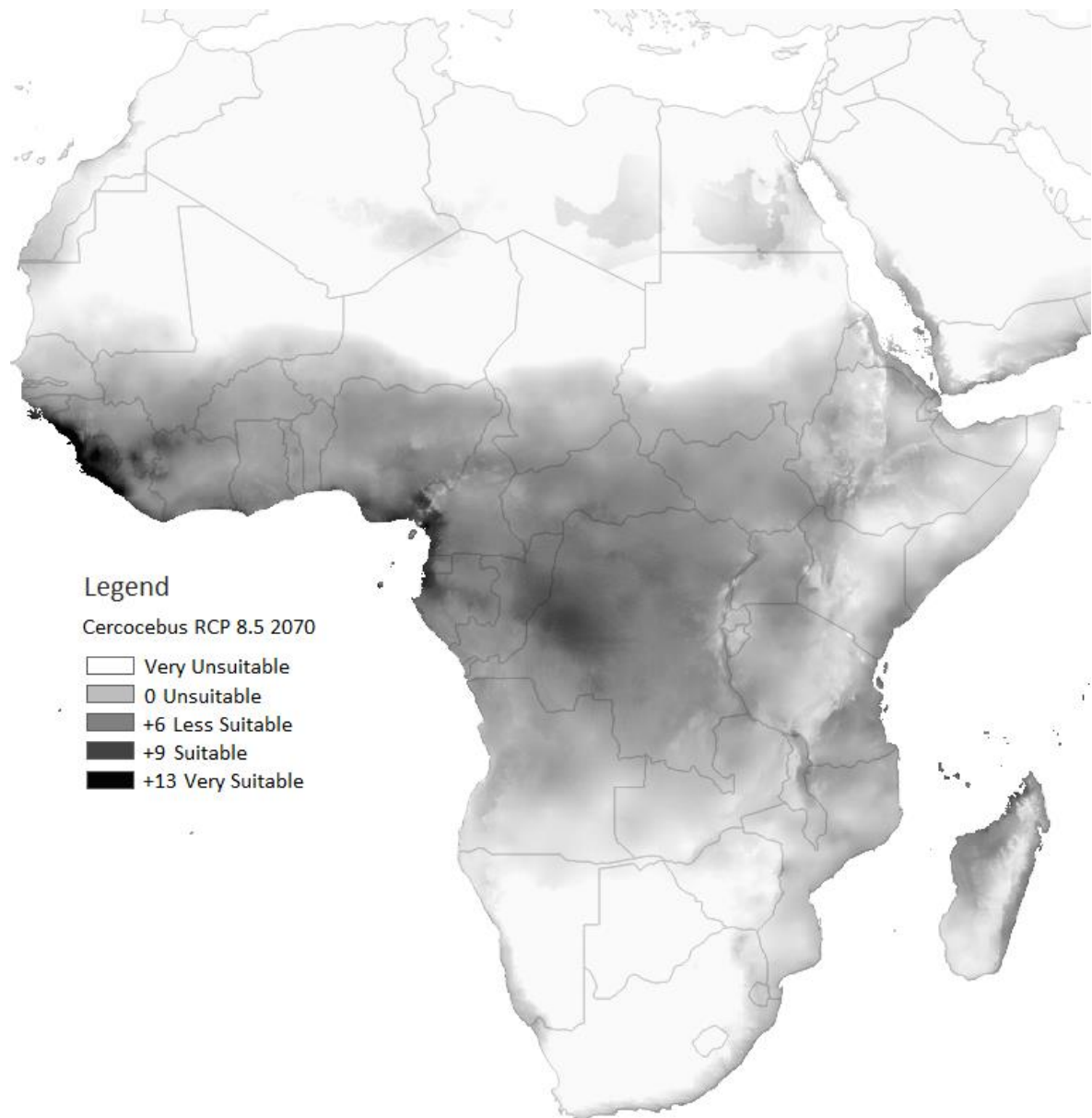


Figure 13. Projected suitability for *Cercocebus* under RCP 8.5 conditions in 2070.

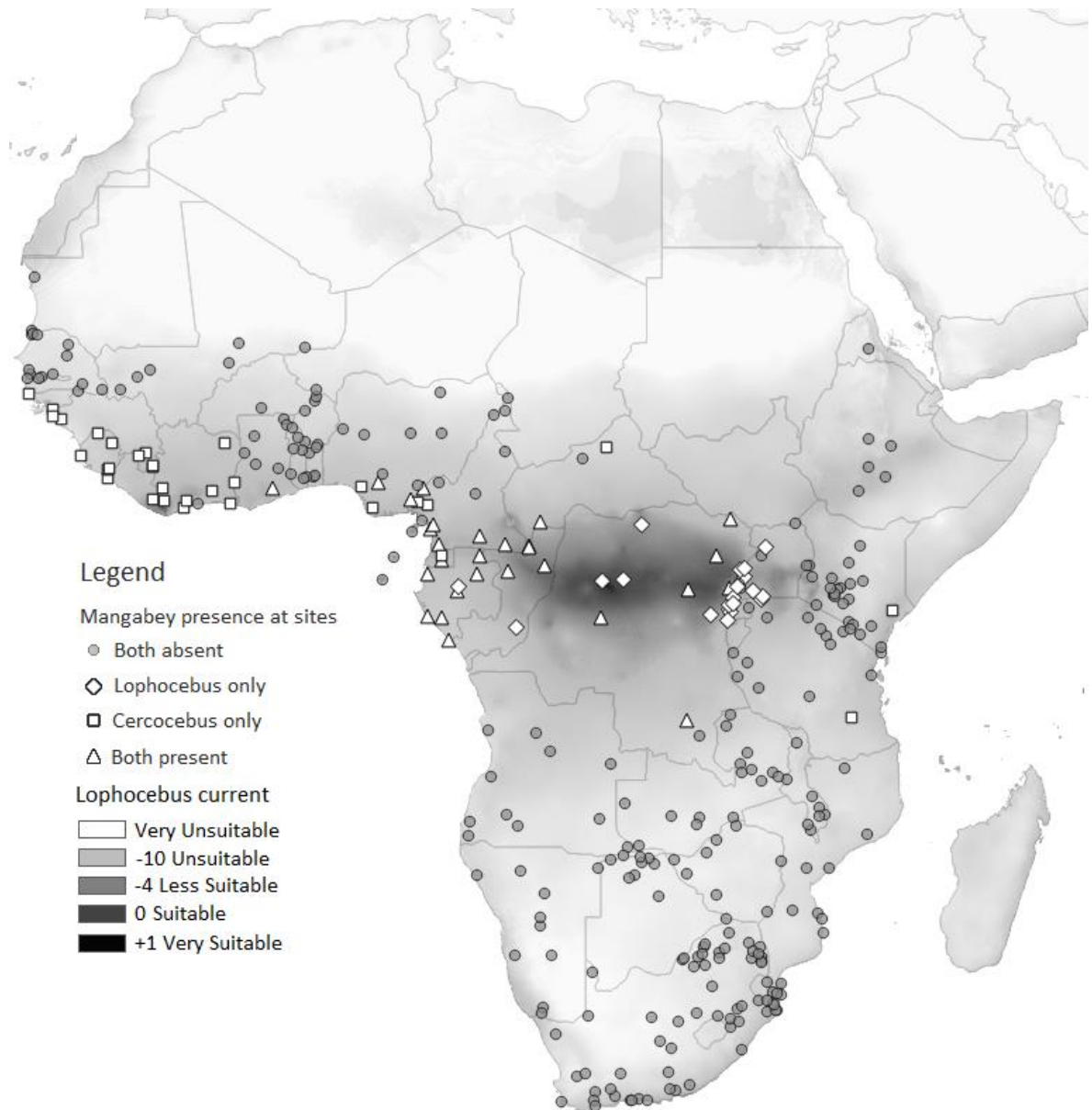


Figure 14. Current suitability values for *Lophocebus*, with presence and absence at sites for both *Cercocebus* and *Lophocebus*.

The situation for *Lophocebus* has changed drastically by 2070, under RCP 8.5 conditions (Fig. 15). It appears that there is no longer a small patch of suitable habitat within the tropical forests. The data suggest that the forests are still more suitable for *Lophocebus* than the surrounding areas, however, there is no longer a single location that would be deemed suitable habitat in accordance with the suitability index as defined in this study.

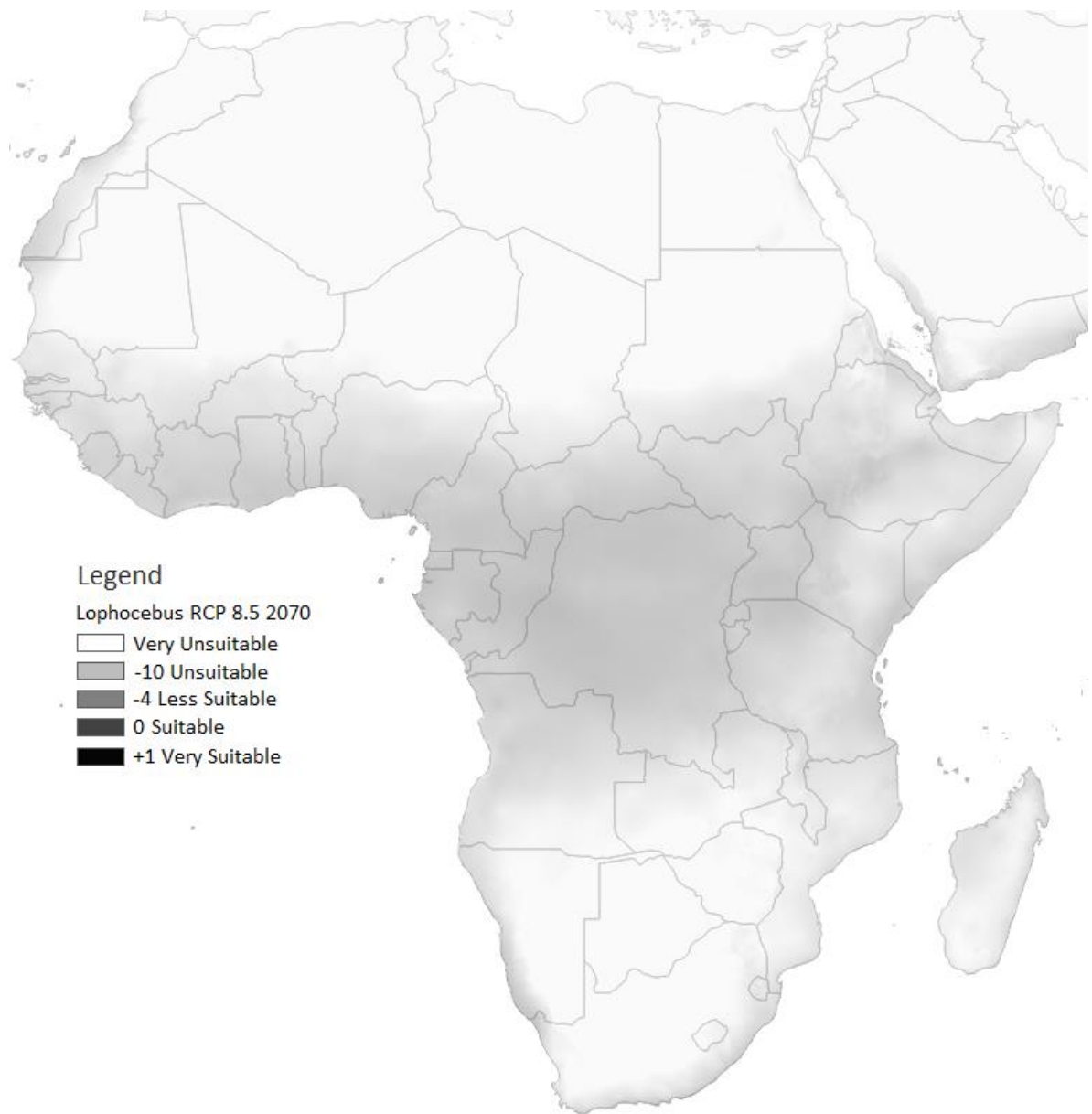


Figure 15. Projected suitability for Lophocebus under RCP 8.5 conditions in 2070.

The changes in habitat suitability becomes more apparent once the RCP 8.5 projections for 2070 are deducted from the current suitability index. As anticipated, *Papio* (Fig. 16) displays increases in suitability of up to 1.3 consistently throughout sub-Saharan Africa. There were no notable decreases in habitat suitability, only varying degrees to which it improved. As expected, the most noticeable increases in suitability are located in southern Africa, however there is also a visibly improved region in the central forested area of the continent.

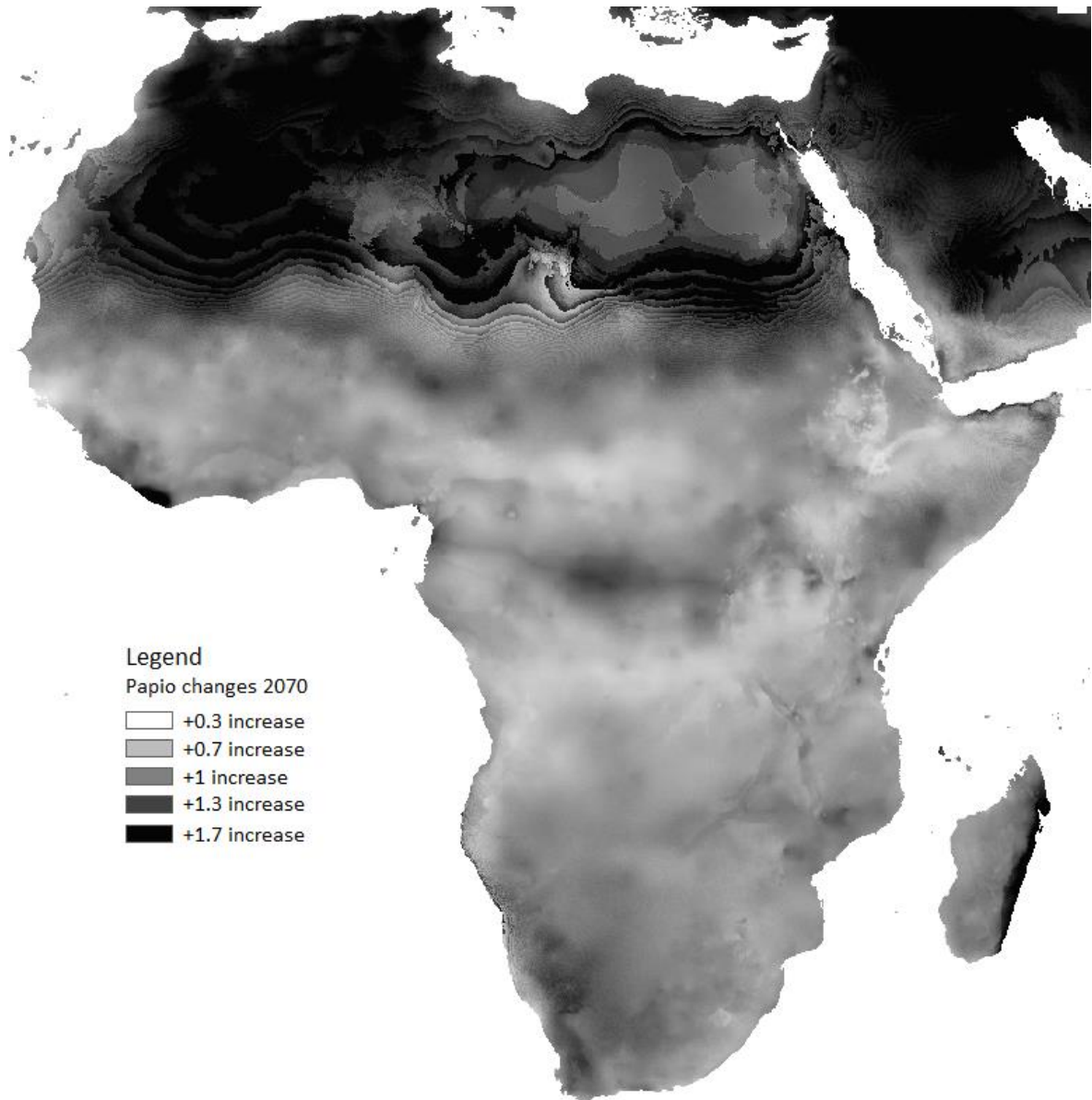


Figure 16. The estimated absolute changes in *Papio* habitat suitability, achieved by deducting the RCP 8.5 2070 suitability indices from current values.

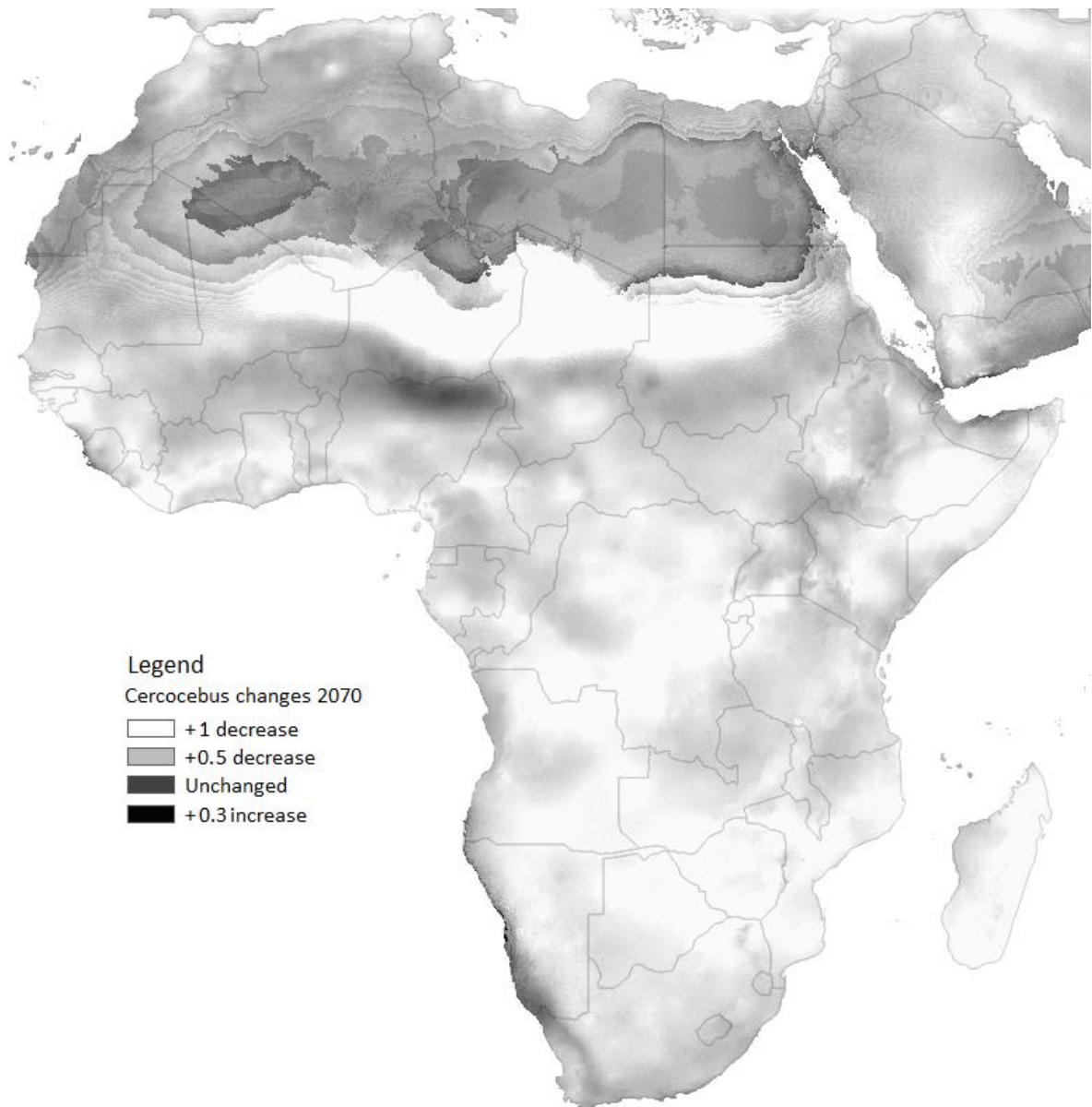


Figure 17. The estimated absolute changes in *Cercocebus* habitat suitability, achieved by deducting the RCP 8.5 2070 suitability indices from current values.

It is also evident that outside of a few isolated regions on the western coast of Africa where the suitability index appears to remain unchanged, *Cercocebus* is experiencing a fall in habitat suitability throughout (Fig. 17), the largest decreases appear to be occurring in the central and southern regions of the continent, particularly near the areas in which they are currently present in central Africa.

Finally, *Lophocebus* demonstrates a consistent decrease in habitat suitability (Fig. 18), similar to that of *Cercocebus*. There doesn't appear to be any significant locations in which habitat viability has improved, while the majority of central Africa has undergone a fall of

0.5-2.5 suitability. It is particularly worth noting that the forested region of the Democratic Republic of Congo that had appeared to be the most suitable area in current conditions, now shows a significant fall of more than 2.5 by 2070, under RCP 8.5 conditions.

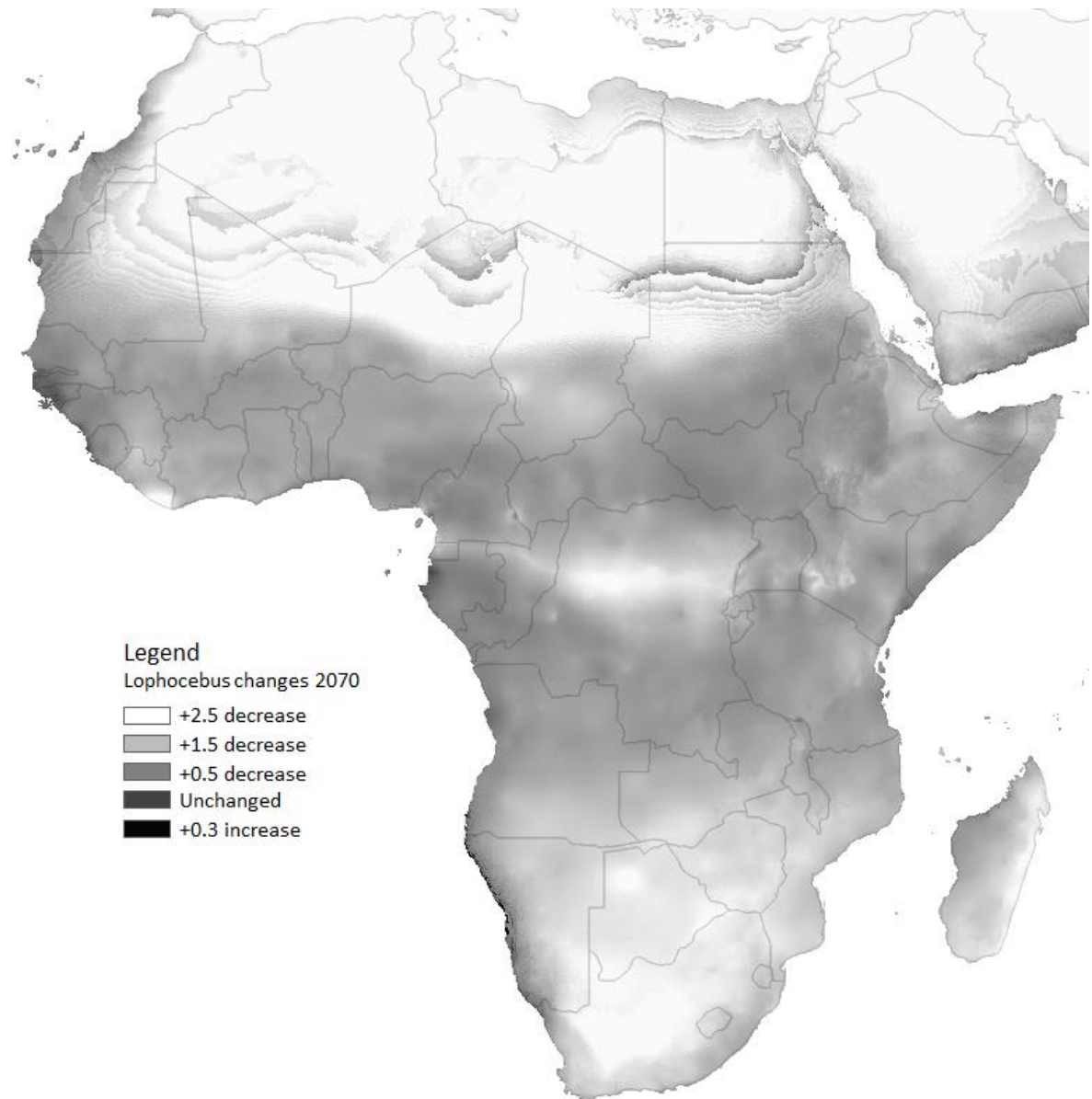


Figure 18. The estimated absolute changes in Lophocebus habitat suitability, achieved by deducting the RCP 8.5 2070 suitability indices from current values.

5. Discussion

This study was devised as a way of investigating the responses of differently adapted primates to the potential impacts of future anthropogenic climate change, with a view to understanding how wildlife may be affected if action is not taken to mitigate the issue. Whilst mangabey monkeys are largely restricted to tropical forests, *Papio* are a lot less exclusive in their chosen habitat and are commonplace throughout much of sub-Saharan Africa, enjoying a diverse variety of home environments that range from woodland and forest to open mountainous regions. The species distribution models used for this study have previously produced reliable results and are regarded as effective indicators of a species response to climate change in sub-Saharan Africa (Garcia et al. 2016). The models were primarily based around forecasted future temperature and precipitation rates, those expected to be most impactful for each genus were implemented into each model allowing for a more tailored and potentially accurate prediction.

5.1 How the Results Compare to Expectation

As a consequence of inhabiting a more defined and specific environment, which, as a tropical forest, is known to be sensitive to fluctuations in weather patterns (Hilbert et al. 2001; Allen et al. 2010; Tan et al. 2013), it was hypothesised that the two mangabey genera would experience a greater reduction in their distribution than that of the more robust *Papio*, which is not expected to be greatly impacted by comparison, if at all. The results indicate that this is generally accurate. For *Papio*, there is a significant increase in habitat suitability for sites in which they are currently present in each of the RCP scenarios, all of which are suggesting that the number of presence sites will increase in suitability by approximately 50-75%. However, the models do not suggest these changes will be uniform in nature. There is a considerable increase in suitability for the RCP 2.6 2050 model and yet the 2070 model has predicted a significant decrease from that point, which is not necessarily a surprise to discover as 2050 is supposedly the peak for carbon emissions in this scenario and a decline is expected to begin thereafter (Baek et al. 2013). Whereas the RCP 8.5 tells a different story, suggesting a relatively minor increase of presence suitability in 2050 followed by a substantial increase in 2070. All of the models indicate that *Papio* will continue to succeed in the northern, eastern and southern areas surrounding the central African belt, outside of the tropical forested regions. Overall, the outlook for *Papio* is broadly positive. Whilst there are some areas that are expected to become less

suitable, the increases in suitable habitats far outweigh the decreases, as expected for a genus that is not currently considered to be an extinction concern with a population that is believed to be rising.

By comparison, the suitability index for *Cercocebus* has determined that a decrease in habitat suitability should be expected across all RCP scenarios, with the declines growing in severity as both carbon emissions and time increase. The central African forested regions of Gabon, Democratic Republic of Congo and the Republic of Congo appear to remain as strong suitable habitat conditions throughout the different future conditions, however, the peripheral areas on the northern and southern extremities of their range appear to be receding slightly. This suggests that as climate changes, their range will likely undergo a contraction from both directions, toward the equator. Their home range on the western coast of Africa, through Guinea and Sierra Leone also appears to remain suitably intact, however the inland regions between the west coast and the central forest appear to have significantly lost habitat suitability. These latitudinal changes complement the hypothesis put forward by Beaudrot et al. (2014), who suggested that primate species that live along the equator will find it more difficult to disperse effectively, this is believed to be due to the stability of the tropical environment which allows for a far greater level of specialisation. The further away from the equator a species lives, the more adaptable it is likely to be, due to a higher level of environmental variation. In this case, *Cercocebus* is not gaining many more suitable sites outside of its current latitudinal range, possibly due to a reduced adaptability as an equatorial habituated genus. *Lophocebus* have the smallest range of the three genera considered in this study, the highest density of *Lophocebus* is currently found in and around Rwanda and south-western Uganda, yet they have been sighted as far west as Ghana, and the most suitable habitat for this genus was determined to be found across the northern region of the Democratic Republic of Congo. However, this region quickly loses suitability in the subsequent models, leaving *Lophocebus* with very few notable ranges of very suitable habitat. This suggests that although *Lophocebus* is expected to gain marginally more suitable sites than it loses overall, the location of the sites is important. Rather than enjoying a small range of very favourable conditions as they currently do, the suitable habitat locations appear to have diffused out across the region, resulting in a greater range of more sparsely distributed, highly fragmented habitats. This is an important distinction, as smaller fragmented habitats have potential to expose *Lophocebus* to possible Allee effects, a phenomenon in which an isolated, fragmented or

low population density leads to further decreases in population, and ultimately may even lead to extinction events if not addressed. The mechanisms for the Allee effect can vary on a case to case basis, for example, a small population may find themselves more susceptible to predators than a larger group or it may become more difficult to find mates and reduce inbreeding (Stephens and Sutherland 1999). Habitat fragmentation must be a consideration when seeking solutions to conservation issues such as these. While mangabeys are able to tolerate non-ideal conditions temporarily as they attempt to locate a suitable home, fragment size has been positively correlated with mangabey species abundance due to resource availability (Wieczkowski 2004) and therefore the future outlook for *Lophocebus* may not provide as positive an outcome as it initially appears.

5.2 Evidence for Climate Change Affecting the Success of Primates

There have been numerous studies that shed light on the vulnerabilities primates may have to climate change and the extent of their sensitivity to it. The impacts of a changing climate on primates can manifest in many different ways. For example, food availability is believed to have been a major factor in the rapid mortality of a *Cebus capucinus* population in Panama, as large, unprecedented levels of rainfall reduced arthropod peak abundance and leaving the capuchin population lacking a good source of protein (Milton and Giacalone 2013). Similar was found in Argentinian forests containing *Alouatta caraya*, in which flooding was seen to decrease the availability of mature leaves (Pavé et al. 2012). Wiederholt and Post (2011) found a link between dry conditions, higher temperatures and El Niño years with a delayed birth season in the new world monkeys *Brachyteles hypoxanthus* and *Lagothrix spp.* These delays were then subsequently linked to lower birth rates as well as skewed offspring sex ratios, both factors have potential to affect long term sustainability of these populations. Similarly, birth rates and first year offspring survival (King et al. 2005) may be affected by rising temperatures and fluctuating precipitation patterns in *Propithecus edwardsi*, a threatened Madagascan lemur species (Dunham et al. 2010). Other studies have focused on the thermoregulatory capacity of primates and how rising temperatures and sun exposure have implications for their activity budgets. A study of *Pan troglodytes* in Uganda (Kosheleff and Anderson 2009), recorded a distinct reduction in feeding activity along with an increase in terrestriality and resting behaviours as the sun exposed temperature increases. While this may not have as resounding an effect on mangabey monkeys underneath the denser forest canopy, there may be scope for sun exposure to impact the time spent arboreally as with chimpanzees, particularly in

Lophocebus as they currently enjoy a more arboreal existence in comparison to *Cercocebus*. The study offers strong evidence for demonstrating how changes in weather conditions are capable of causing behavioural adjustments in the individual. A similar study explored the activity patterns of *Ateles geoffroyi* across a series of habitats in a variety of countries, it found that temperature, precipitation and forest fragmentation are all capable of influencing the time spent feeding, travelling and resting to various degrees (González-Zamora et al. 2011).

There are also many reasons that could explain the expected decline in suitable habitat for the mangabey monkeys from a geospatial point of view, such as a receding forest area brought about by altered climate conditions. As previously mentioned, they rely on the tropical forests of central and west Africa. There is much debate over how climate change will affect the range of these forests in the future and which climate factors specifically exert the greatest influence on this. Zelazowski et al. (2011) determined that although African tropical forests are likely more resilient to climate change than those of South America, their expansion and retraction is largely dictated by precipitation levels and that moderate, sustained levels of precipitation are more favourable than the largely fluctuating downpours and drought periods throughout the year that have been predicted (Paeth and Thamm 2007). The study concluded that African forests have the potential to experience either a range expansion or a contraction over the coming century depending on the model utilised in the analysis. However, Lwanga (2003) investigated the effects of a severe drought on the success of tropical trees in central Africa and found that there is serious risk of dieback in the forest area if climate change continues as expected, these findings suggest a grave future for the habitat of both mangabey genera.

5.3 Limitations of the Ecological Modelling Approach

It is important to note, however, that there are several theoretical limitations to a study such as this with regard to both the methods employed, and the interpretation of results, when attempting to make predictions for the future dispersal patterns of a primate genera. Bioclimatic modelling is based upon the theory of ecological niches. Ecological niches aim to quantify the environmental requirements for a species to survive (Hutchinson 1957). Whilst climate is vitally important to the success and stability of a habitat type, it is ultimately just one aspect of an ecological niche. Thus, bioclimatic modelling likely fails to incorporate all of the environmental factors affecting the survival of a species, such as the

chemical composition of soils and topography of the land, as well as biotic influences such as interspecific competition and trophic interactions. If a species is compelled by a changing climate to migrate into an area of high competitor or predator abundance, additional unforeseen pressures, which have not been considered by the bioclimatic model, may emanate as a result (Leathwick and Austin 2001; Anderson et al. 2002). For example, while this study utilises precipitation forecasts when modelling distribution, the availability of freshwater sources is not considered. Other studies have demonstrated that it is far more difficult to accurately predict the distribution patterns of freshwater reliant species (Thuiller et al. 2006). Freshwater availability is of particular concern to the genera *Papio*, as evidenced by their observed behaviour in travelling very long distances to secure it (Johnson et al. 2015).

Distribution is also largely dictated by the ability of the species to move with a changing climatic environment. This applies to both the dispersal and recolonisation capacity of the native fauna as well as the rate at which the natural flora on which it depends can shift with the climate (Collingham et al. 1996; Higgins et al. 2003). Mangabey monkeys have been known to possess a degree of flexibility in their ability to overcome habitat change in the past by increasing their home range and moving through nonforested habitats to reach neighbouring forests as necessary (Kinnaird 1992; Wieczkowski 2010), albeit a study on the dispersal ability of new world mammals found that primates were overwhelmingly the weakest in this regard (Schloss et al. 2012). It should also be acknowledged that if viable habitat conditions are shifting spatially with climate, it is not as simple as to assume that new habitat locations are suitable for mangabeys purely on climate conditions alone. If a species is unable to traverse a particularly long distance, or cross a natural barrier such as a mountain range or large water body to reach the agreeable habitat without human intervention, then it may be disingenuous to suggest that those inaccessible areas be considered as providing a potentially viable habitat environment at all.

Similarly, environmental regime shifts and anthropogenic land transformation are factors that are difficult to currently predict in future scenarios and have potential to drastically affect the suitability of a habitat. There is scope to incorporate these regime shifts into a bioclimatic model as they are often driven by climatic factors such as temperature and precipitation, however, stochastic disturbances, such as increases or decreases in fire regime and the altered recovery time from these events may be difficult to quantify. There is evidence that the distribution and abundance of trees may be greatly affected by such

disturbances, and that changes in atmospheric CO₂ levels are likely to exacerbate the issue (Bond et al. 2003). Additionally, land transformation for agriculture and urban development is a factor that must be considered. It is expected that by 2050, between 10-30% of tropical and sub-tropical biomes worldwide will have been converted into cultivated systems (MEA 2005). Land transformation of this kind is particularly unpredictable as it is largely dictated by economic opportunity afforded by changes in national markets, as well as shifts in local economies and governmental policy (Lambin et al. 2001).

Subsequently, it should be acknowledged that the changing suitability of a habitat location under the influence of climate change does not occur within a vacuum, and therefore, the successful balance of an ecosystem relies upon an incredibly complex series of factors that are extremely difficult to quantify and account for in their entirety. The effects of climate change on one species may have a significant impact on the future of those with which it interacts (Davis et al. 1998), leading to indirect climate effects on the target species of the study. Therefore, current predictions inferred from a bioclimatic distribution model may or may not bear any real resemblance to actual distributions as they occur in the future (Pearson and Dawson 2003).

5.4 Consequences of a Decline in Primate Populations

With this in mind, the ramifications for a decline in *Cercocebus* and *Lophocebus* abundance still should not be underestimated. Many terrestrial, or semi-terrestrial primate species play an important role in maintaining the health and function of tropical forest as primary seed dispersers, a service that is not believed to be offset by other frugivorous species in their absence (Levey et al. 2003; Astaras and Waltert 2010). Previous studies have unearthed direct correlations between hunting intensity on herbivorous mammals and seed dispersal and recruitment rates (Wright et al. 2000), suggesting that effective seed dispersal depends upon a healthy population of dispersers in order to flourish. It is believed that without these services, plant species composition will be greatly impacted due to the native wildlife's role as a regulator. The levels of interaction between frugivorous mammals and different plant species will naturally vary due to food preference, this serves to control the abundance of certain plant species and allows others an opportunity to compete. Without this force in play, the structure and composition of a forest may be drastically altered (Wright et al. 2000). Fragmentation also appears to have a detrimental

effect on tropical seedling recruitment in animal dispersed tree species (Cordeiro and Howe 2001), which means we may then possibly see a vicious cycle of suppressed seed disperser populations causing forest fragmentation, which in turn stifles the population further and so on.

6. Conclusion

Based upon the findings of this study, it is clear that conditions in sub-Saharan Africa are changing indiscriminately. The pace at which these changes occur is of particular concern, and as it is exceedingly likely to be a consequence of human behaviour, it is vital that both the causes and remedies for it be examined. If nothing is done to attenuate this problem, then there may be little cause for optimism where the success of already struggling primates is concerned, such as that of the *Cercocebus* or *Lophocebus* genera. As the evidence suggests, the probability of seeing a climate induced habitat change is high and is typically more severe as carbon emissions increase. The full consequences of these potential changes to distribution patterns may not become clear until it has already happened, however, there is a very realistic possibility for extinction in the less adaptable primate species, particularly those located within close proximity to the tropics. It should be acknowledged that this study covers just a small subset of a greater primate population in the sub-Saharan Africa region, each species will react differently to climatic changes and it is vital to gain as thorough an understanding of those most vulnerable as soon as possible. Therefore, it is clear that there is still much research to be carried out with regard to the effects of climate change on African wildlife. In the future, in the interest of building a more detailed impression of how endangered African habitats will change, it may be worthwhile to examine other factors that affect the distribution of primates in combination with the climate data presented here, such as topography, soil composition and freshwater availability. Ultimately, all quantifiable outcomes should be assessed as thoroughly as possible when researching the primate distributions and range changes, with a broader selection of study species to provide a more accurate image of the impending situation. This will allow for any plans to reduce the levels of carbon emission and mitigate the problems they cause to be genuinely effective. It is also important that conservation work in this area begin as soon as possible, time is a key factor, climate change is occurring in the present and appears to only be increasing in severity as more time passes.

There is a belief that it may already be too late to make a worthwhile difference to the global carbon emission output and that the damage has already been done. This is likely true to an extent, as even the most optimistic RCP scenario, RCP 2.6, has shown that there is a strong likelihood of distribution shifts and a potential for extinctions across the coming few decades. The differences between the best and worst case scenarios that have been

analysed in this study are relatively minor. This suggests that we have already been responsible for causing some irreversible alterations to the environment and will ultimately have to find a way to cope with this. However, that does not mean that there is no hope left and that we, as a global species, should wash our hands of the situation.

While this study focuses solely on three primate genera in sub-Saharan Africa, it is just a small snapshot of a much larger issue. Rising temperatures have consequences for global food production, particularly temperature sensitive animals such as fish, which will migrate, shift in composition and possibly die out as they require precise environmental conditions in which to regulate body temperature. This has ramifications for both food security and the many economies that rely on the fishing industry worldwide. Pollinator species are also extremely sensitive and require adequate conditions in order to reproduce effectively. They will also be acutely impacted by, and partly responsible for, changes to the floral composition as climate shifts, which then has a knock-on effect for all wildlife and the ecosystems on which they rely.

Therefore, the implications for not changing our attitudes toward maintaining a sustainable planet are expected to be considerable. It is a certainty that if nothing is done to reduce our carbon footprint as a species, Earth will continue to see increasing temperatures, rising sea levels and more extreme weather phenomena. These are all precursors to droughts and flooding, that will ultimately result in a humanitarian crisis as disease propagates and food security is compromised.

With this in mind, there are many avenues in which humanity can approach the issues highlighted in this study. Firstly, it is important that local communities are kept involved and are consulted in any measures taken to protect primate habitats, such as the creation of protected areas. Without the collaboration of local communities, for whom there is a significant chance of financial hardship if restrictions are imposed, there is little chance of conservation policy to be enforced with any degree of success. It is also important that humans across the globe acknowledge that they have a responsibility for the welfare of the environment. Reducing energy usage and moving away from fossil fuels is the only realistic solution to this problem in the long term. This can be achieved on both a large and small scale, even changing energy usage habits at an individual level can and will make a difference, evidence suggests that up to 73% of global energy use could be saved by employing best energy efficiency practices when selecting a car or insulating a home

(Cullen et al. 2011). In addition to this, there must be a greater emphasis on renewable energy in the future. It should be accepted that the modern world requires an extremely large amount of energy production to function day to day, and this is unlikely to change in the future. Therefore, it is of the utmost importance that the methods for achieving these levels of energy production be as environmentally sound as possible because the planet cannot sustain our current practices indefinitely. Renewable energy production has seen a deal of progress in recent decades and comes in many different forms depending on what is suitable to the location, such as solar power, wind power, hydropower or geothermal power amongst others. Investing in the infrastructure for this now should be a key priority for governments around the world.

7. References

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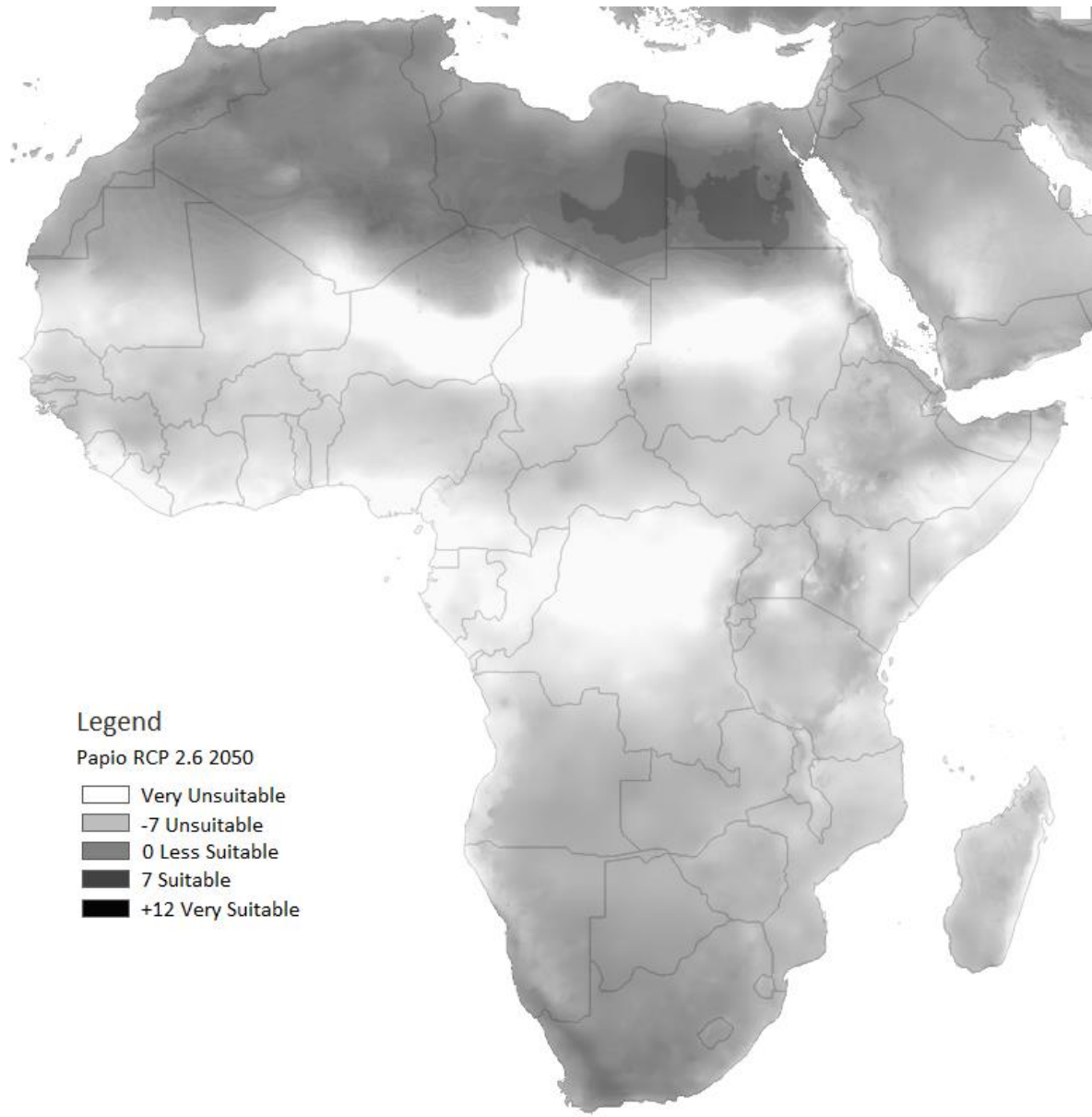
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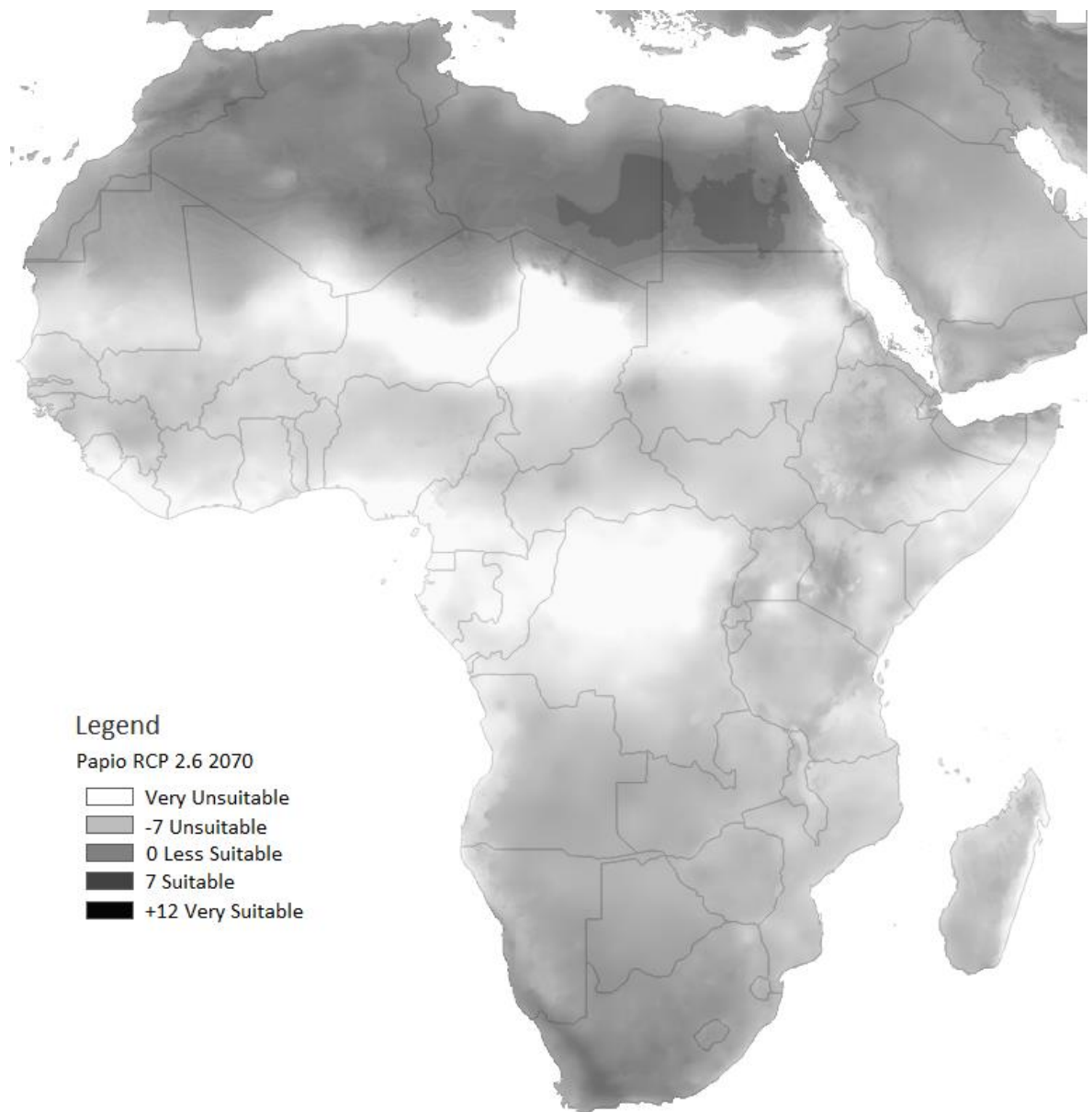
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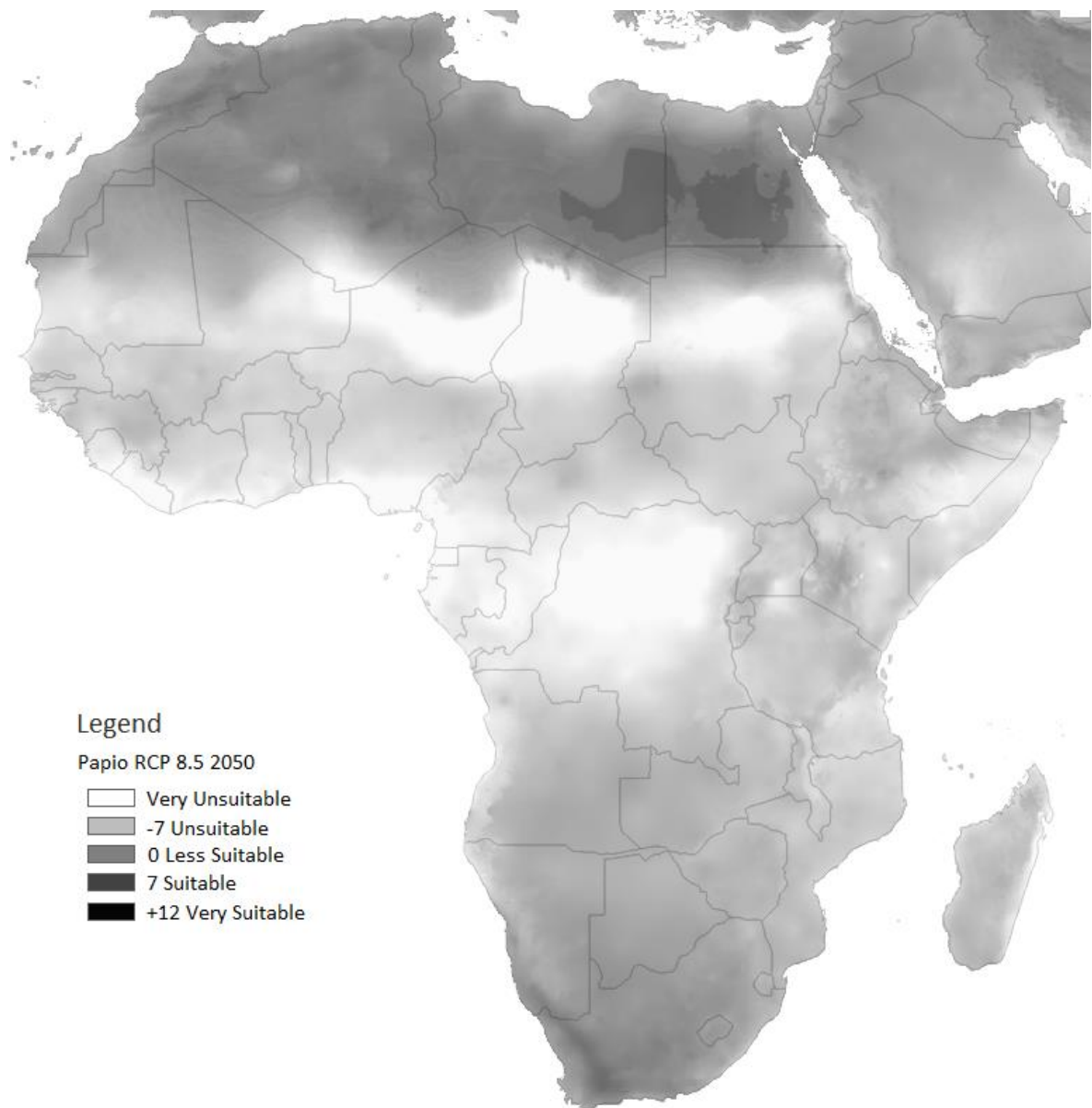
8. Appendices



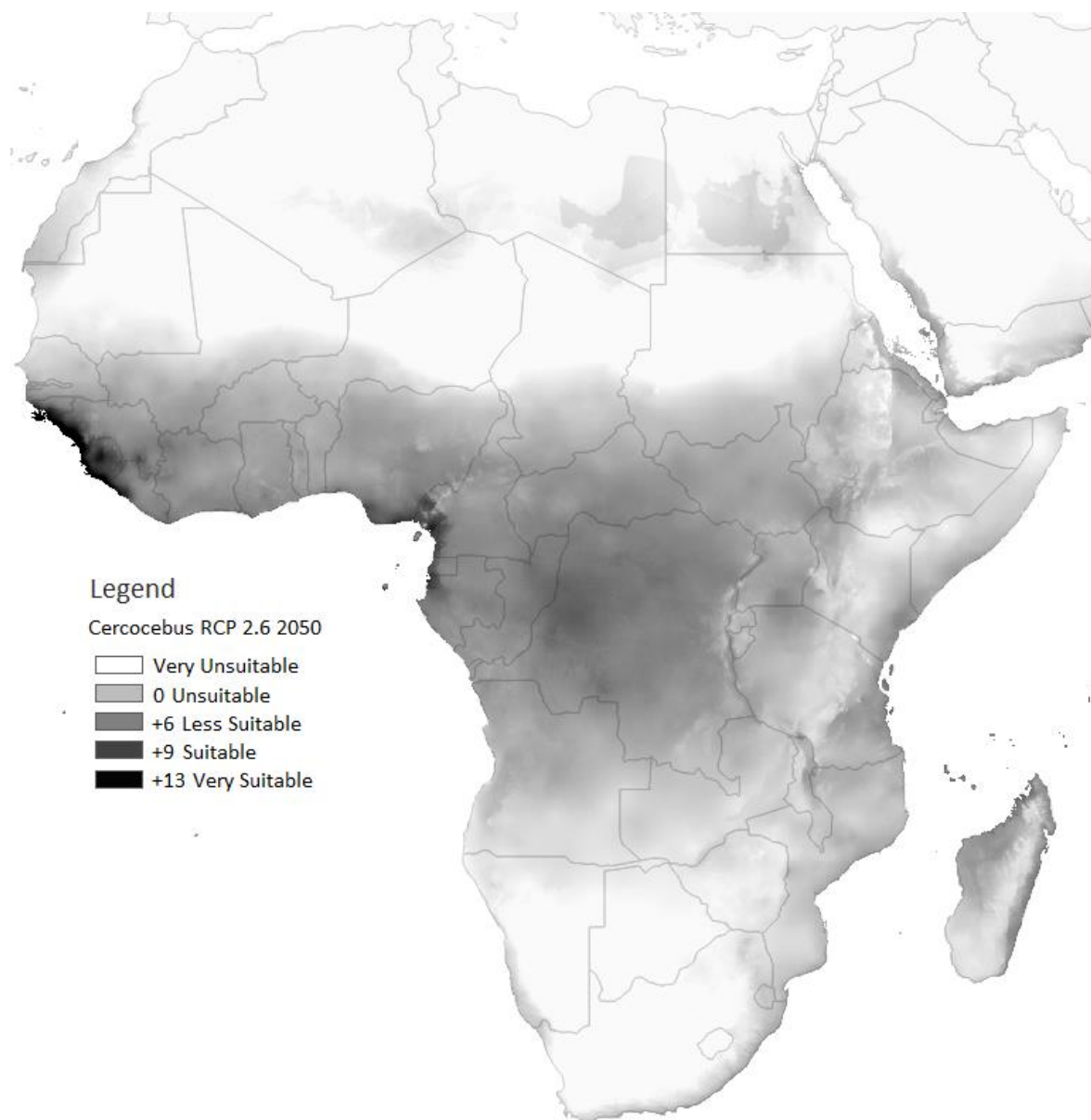
Appendix 1. Projected suitability for Papio under RCP 2.6 conditions in 2050.



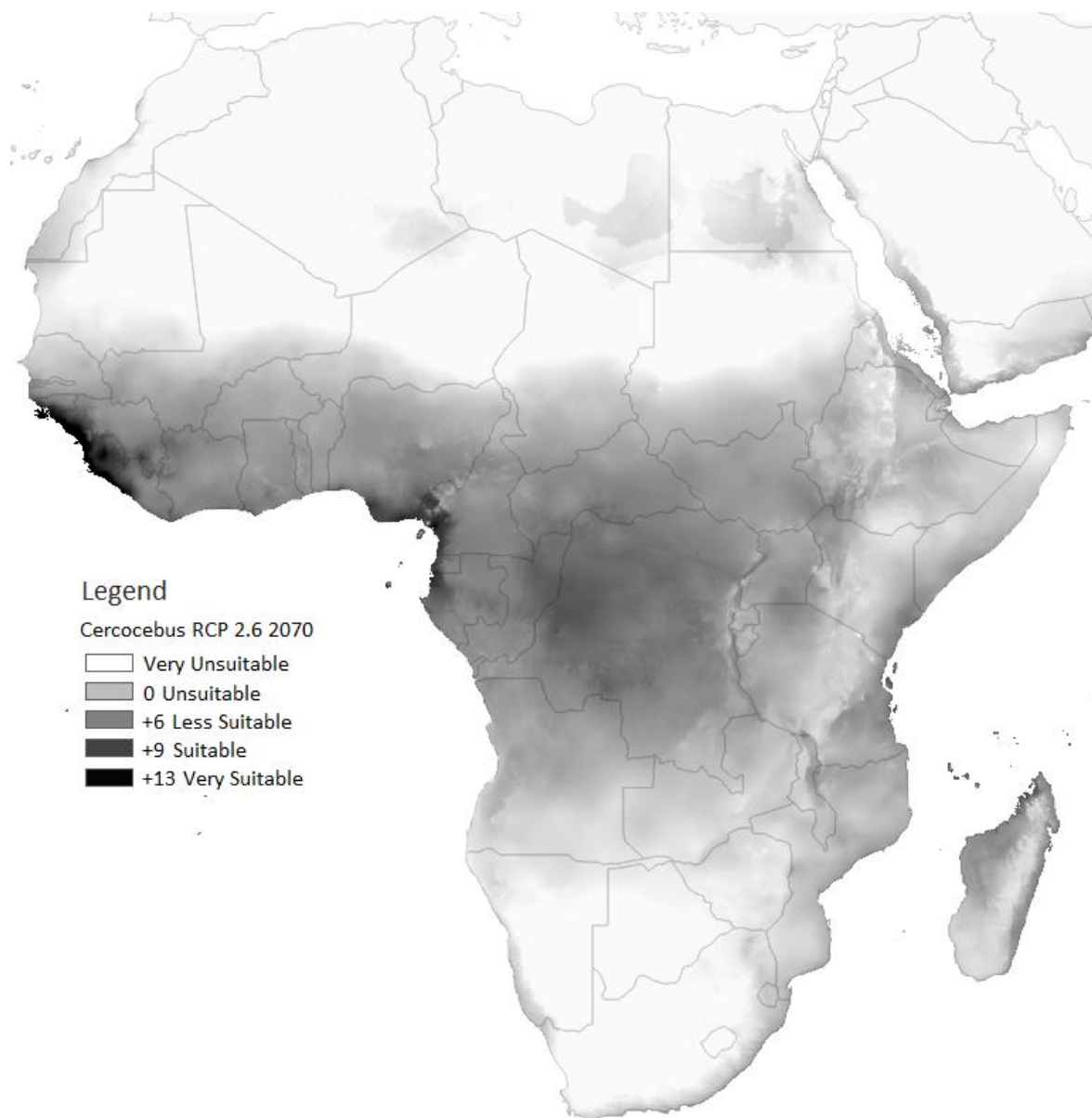
Appendix 2. Projected suitability for Papio under RCP 2.6 conditions in 2070.



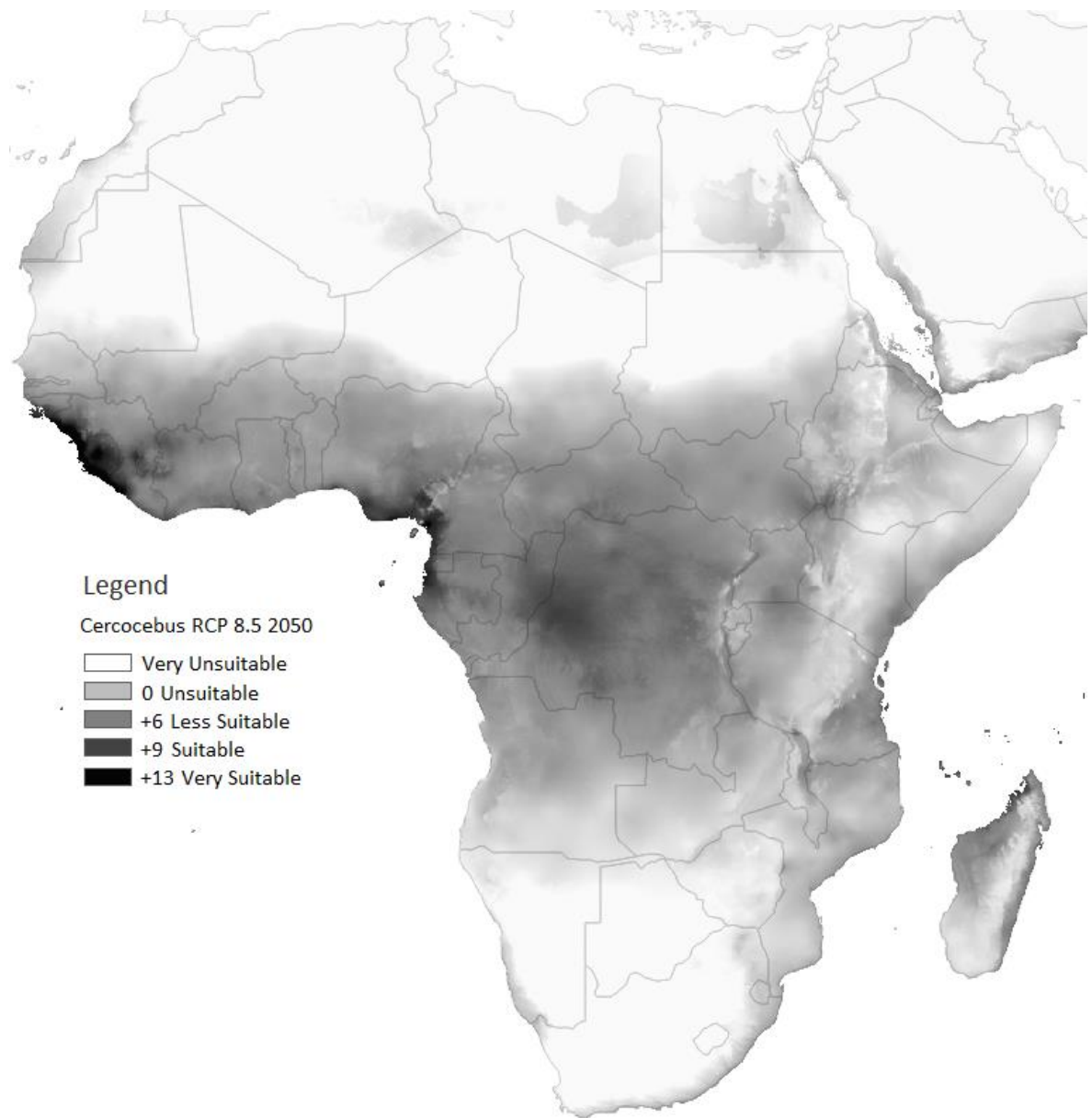
Appendix 3. Projected suitability for Papio under RCP 8.5 conditions in 2050.



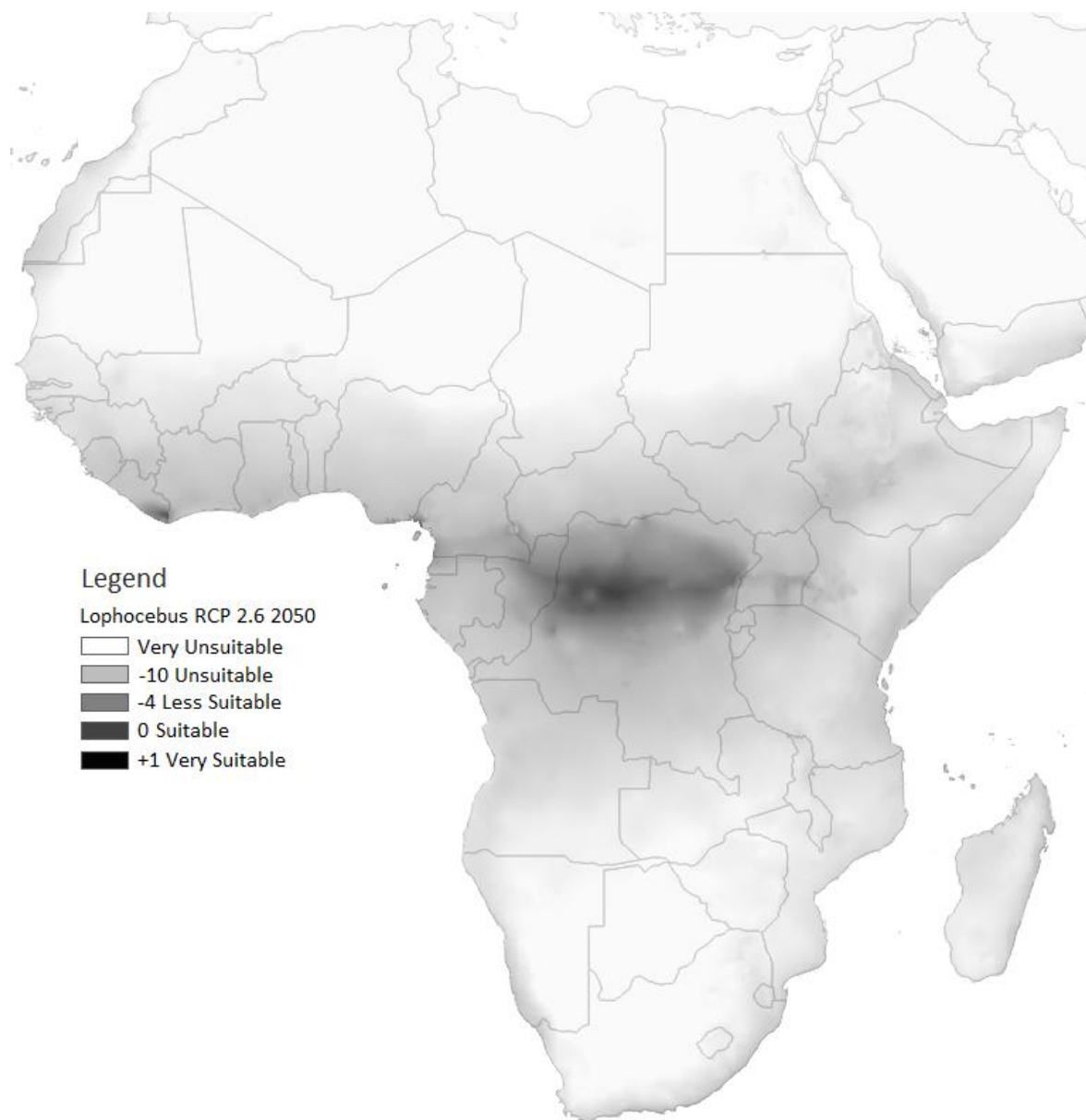
Appendix 4. Projected suitability for Cercocebus under RCP 2.6 conditions in 2050.



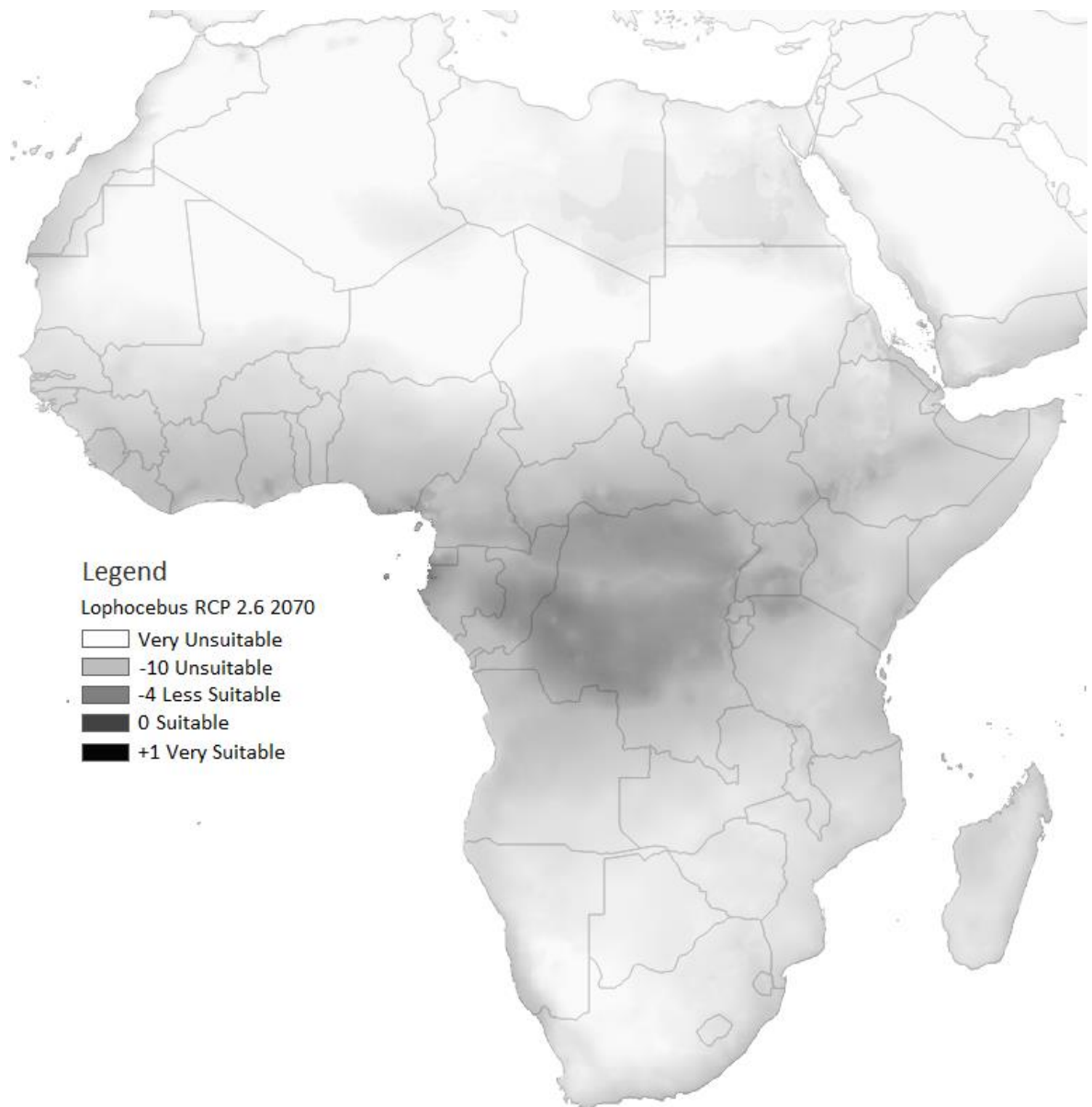
Appendix 5. Projected suitability for Cercopithecus under RCP 2.6 conditions in 2070.



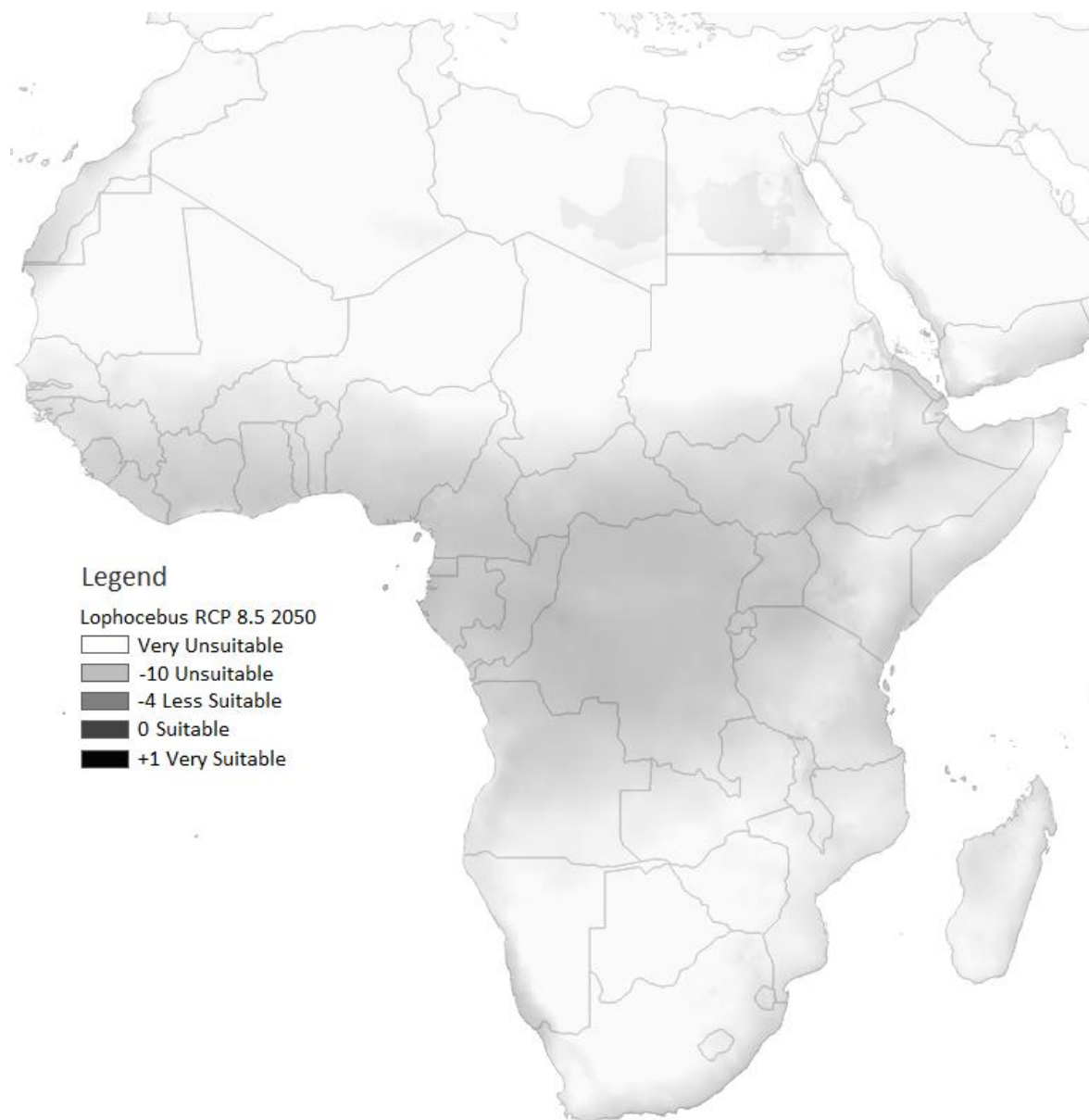
Appendix 6. Projected suitability for Cercocebus under RCP 8.5 conditions in 2050.



Appendix 7. Projected suitability for Lophocebus under RCP 2.6 conditions in 2050.



Appendix 8. Projected suitability for Lophocebus under RCP 2.6 conditions in 2070.



Appendix 7. Projected suitability for Lophocebus under RCP 8.5 conditions in 2050.

8.1 Evaluative Supplement

The path to completing this research project was filled with many obstacles along the way. As I had intended to undertake a project focused around primates, finding a suitable location at which to gather my data was crucial. In total, dozens of institutions were contacted throughout the spring and summer of 2016, leading to three detailed research proposals being written and submitted during this period. However, for each of these, the study was ultimately found to be logistically or financially unviable and had to be abandoned. This entire process resulted in my research project not beginning until September 2016, having lost months of valuable time through the summer. Albeit, I feel there was much to be taken from this situation. Such as, how to effectively write a research proposal and communicate with research facilities. Time management was also imperative, having sacrificed a substantial portion of my time attempting to pursue other projects.

The study itself was intended to help explore the ongoing global climate crisis as this is arguably one of the most pressing concerns for science in the modern day. Overall, I believe that the study and the findings produced here are of significance and therefore the project as a whole can be deemed a success. The strengths of the project lie in the highly-detailed dataset and industry standard climate models. The dataset was compiled through the hours of meticulous work of others, the product of which exhibits a high attention to detail. There were no generalisations made in creating the location data and every instance of a primate being present at a particular location can be supported with the appropriate literature. Therefore, it should be seen as very robust and conclusions drawn from it reliable. The climate models are used in many research projects across the globe, they are also the product of thorough scrutiny and as a result, they are ubiquitous throughout the climate modelling sector, which should allow for the conclusions of this study to be uniform with similar studies on the topic.

The genera selected for the study were also very fitting. The two mangabey monkeys, *Cercocebus* and *Lophocebus* are the focus of the study insofar as they are expected to be most affected by climate change and habitat degradation. This is due to their well-defined ecological niche restricting them to a relatively small region within the tropical forests of Africa. Their risk of extinction is generally quite high, as demonstrated by their conservation status detailed by the IUCN Red List, so the threat of climate change is a significant one. Without an appropriate genus to focus this study on, the findings of the

study may not have been able to reveal the severity of the issues we're facing. The other genus selected for this study, *Papio*, was also very suitable as a highly adaptive generalist, pervasive throughout the region of sub-Saharan Africa. The ecology of *Papio* allowed the genus to be used as a foil for the mangabeys in the study because it was deemed unlikely to be greatly affected by climate. As was eventually evidenced in the findings.

The study also included many moving parts, there were multiple software packages utilised, and techniques employed, that I had previously never encountered or was not particularly confident with using, such as coding with R and RStudio, statistical analysis with SPSS and geospatial graph production in QGIS. Each one enabled me to acquire a new skillset that will doubtless be vital for any future projects in this sector. Modern technology and techniques such as these are vital for effective work on this subject, and I believe I will be able to build on the skills acquired during this project as technology continues to advance.

Whilst I believe the study to be rooted in a sound scientific base, there are limitations to what has been achieved. The greatest limitation faced when undertaking this study is the application of the ecological niche models. This is because modelling will never be a perfect science when predicting ecological distributions. For example, stochasticity, human interference and unforeseen natural phenomena are all extremely difficult to model with any degree of accuracy, and therefore, it is possibly more appropriate to use distribution models as an indicator to reinforce findings made elsewhere, or to justify policy change, rather than as a tool from which to base assumption.

Another limitation was the scope of the project. While the genera selected for this study were carefully chosen to be representative of a wider primate population, it focused on just three genera, of which, one is already particularly limited in its range and population. Wildlife distributions will likely respond differently to environmental changes even at species level, for example, *Papio* ranges throughout Africa outside of the dense tropical forests, through a variety of different biomes as a genus that contains at least six different species. It is probable that each species within the *Papio* genus have very diverse habitat requirements and will react very differently to climate change. Therefore, it requires a level of caution when drawing conclusions on the findings of this study as broad generalisations across genera have been made.

Finally, the study also only accounted for climatic influence on their distribution whereas ecological niches are determined by a myriad of complex factors. While it is important to isolate and quantify the various factors that may exert an influence upon the distribution of wildlife, it also fails to explore other explanations for habitat loss, such as deforestation or trophic interactions. That is to say, the findings based upon climatic factors alone should surely have a useful application in understanding one of the reasons for changes in primate ranges, but it is unlikely to tell the whole story and should not be treated as an absolute. In addition to this, it is also assumed that there will not be any unforeseen complications with the target genus' migratory capacity and natural barriers. The findings lack nuance and detail, suggesting that all suitable habitat is able to provide a viable home, which may not necessarily be true in all cases.

Overall, I feel that the project has been a success, the findings are likely to prove valid in providing useful information to those looking to investigate the effects that climate change may have on the genera that were selected for study. Modern techniques have been used in order to achieve the results presented here, which has focused on a very pressing, contemporary topic in climate change. I believe there is a lot more potential for important work to be completed in ecological niche modelling, in the face of climate change, using these methods, as it is a field of science that appears to be growing, not just in technological advancement, but also in urgency as we head into the coming decades.