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# Primateology, Biocultural Diversity and Sustainable Development in Tropical Forests

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**Abstract:**

The earth's climate has warmed significantly in recent decades, and human actions are responsible. Projections vary considerably; however, it is estimated that 75% of all tropical forests present in 2000 will be subject to temperatures higher than that presently supporting closed-canopy forests by 2100. These changes in climate, along with deforestation, have isolated many endangered species to areas that may become unsuitable with further global warming. To provide the scientific information to address such threats, long-term data, spanning two or more decades, are needed. Here we summarise the potential consequences of climate change for primates. Subsequently we provide an encapsulated review of the changes that have occurred in Kibale National Park, Uganda over the last three decades that are potentially the result of climate change. Kibale has gotten hotter and wetter, phenological patterns have changed with fruit being projected to be less abundant, leaves for folivores have become less nutritious, and parasite infections have intensified. Despite these deteriorating conditions, the primate community appears to be remarkably resilient and most species are stable or increasing in abundance, but we may be approaching a tipping point. We discuss the complex nature of the responses to climate change, and the value of long-term data in making appropriate conservation and management plans.

# What will climate change mean for primates?

## Global patterns of climate change and the impact on primates

The earth's climate has warmed significantly in recent decades, and human actions are responsible. This will have dramatic negative impacts on the earth's biodiversity and the primates are not an exception. The Intergovernmental Panel on Climate Change (IPCC) estimates that the earth warmed by 0.85 °C between 1880 to 2012 (IPCC, 2014) and under most of their scenarios temperatures are projected to increase by at least 1.5 °C by 2100 (IPCC, 2014). A recent forecast using updated projections for human population growth even estimated an increase of 3.2 °C by 2100 (Rafferty et al., 2017). Given where primates occur, estimates suggest that they will experience 10% greater warming than this global average and some primates will be experiencing a 50% greater temperature increase for every 1 °C of global warming (Graham et al., 2016); meaning a 4.8 °C increase using Rafferty et al.'s 2017 projection. Furthermore, rising temperature alters global patterns of air circulation, which affects rainfall patterns, and thus primates will also face changes in rainfall; however, precipitation change will likely be quite varied across the areas occupied by primates (i.e., from >7.5 % increases per °C of global warming to >7.5 % decreases) (Graham et al., 2016). Furthermore, there will be "climate change hotspots" and if these areas contain endangered species, the consequences will be very severe and extinctions are likely. For example, almost three-quarters of China's primates have populations that are less than 3000 individuals and most of these populations are in the south of the country where the climate is getting significantly wetter (Qian and Lin, 2005).

Understanding the consequences of these climate changes for primates is likely the most important question that primate conservation biologists must address in the next decade, but our abilities to predict primate responses to climate change is currently very poor (Wright, 2007). There are, however, estimates of what will happen to the tropical forests that support most primate species. Projections vary considerably, but considering a moderate greenhouse gas emission level, researchers predict that by 2100, 75% of all tropical forests present in 2000 will experience temperatures higher than the temperatures presently supporting closed-canopy forests (Wright et al., 2009). Some forests will get hotter and drier (e.g., much of Central America, particularly Mexico (Ramos-Fernandez et al., 2013)), while other areas will get hotter and wetter (e.g., much of East Africa (Hulme et al., 2001; Lovett et al., 2005)).

## Geographic Variation in Climate Change for Regions Supporting Primates

Climate change projections using the most likely emission scenarios agree that for Africa the rainforest regions will become 3–4 °C hotter over the next century (Zelazowski et al., 2011; Malhi et al., 2013). This will lead to forest retreat and woodland and savannah expansion, but the extent of the retreat and where it occurs will depend on rainfall. With regard to how rainfall patterns in Africa will change the picture is not clear. It seems fairly clear that East African forests will become wetter; however, climate models for West Africa and the Congo Basin produce conflicting results (Zelazowski et al., 2011).

Madagascar supports a very unique and unfortunately a very threatened primate fauna and climate change will only exacerbate the situation. Current predictions are that Madagascar will experience a temperature increases of 1.1–2.6 °C, which is well above the global average (Hannah et al., 2008). Models using such predictions suggest that 60% of the 57 species examined to date will have a considerable range reduction in the next seventy years due to climate change (Brown and Yoder, 2015).

For Latin America the situation appears to be particularly grim given that Central America, the Amazon, and south eastern Brazil are considered hotspots for climate change (Graham et al., 2016). Many of the primates in south eastern Brazil are already endangered, largely as a result of habitat loss and fragmentation. For Mexico, Belize, and Guatemala, climate models predict an increase in annual temperature of 1.5 °C by year 2030, 2.3 °C by year 2060 and 3.7 °C by year 2090, and a rainfall decrease of 6.7% by year 2030, 9.0% by year 2060 and 18.2% by year 2090 (Ramos-Fernandez et al., 2013). For areas of dry forest, such as the Calakmul Biosphere Reserve, these sorts of changes will likely be too great for the area to continue to support forest – by the year 2090 the area would only receive 880 mm of rainfall annually (Reyna-Hurtado et al., 2010).

Asia is climatically influenced by a number of atmospheric circulation systems, making generalizations for the entire region very difficult. However, the Philippines, the Mekong River Delta in Vietnam, most of Cambodia, North and East Laos, the Bangkok region of Thailand, and West Sumatra, South Sumatra, West Java, and East Java are considered the most vulnerable regions in Asia (Yusuf and Francisco, 2009). A number of these regions support diverse primate communities, so the situation for primate conservation in Asia is grim.

It is relatively easy to imagine that in areas becoming hotter and drier, primates will become physiologically stressed (McFarland et al., 2014), food trees will die (McClellan et al., 2005), and primates will die along with them or they will attempt to move. It is estimated that nearly all primates will experience climate change related reduction in range size and, among mammals, primates are some of the least able species to keep pace with these changes due to limited dispersal abilities (Schloss

et al., 2012). These estimates do not include landscape permeability, and for many populations isolated by fragmentation and surrounded by agricultural or grazing lands, movement will not be possible. Climate related loss of habitat is supported by data from the Amboseli National Park, Kenya, where the average daily maximum temperature increased by 0.275 °C per year (an order of magnitude greater than that predicted by climate change models (Altmann et al., 2002), and there was a dramatic loss of tree cover (Altmann et al., 2002), which may have driven the concomitant decline in local vervet populations and movement of the baboon populations (Struhsaker, 1973; Altmann and Alberts, 2005).

In contrast to the situation where the climate gets hotter and drier, what happens in situations where climate gets hotter and wetter is not so clear, but it is potentially equally negative for primates. Kibale National Park, Uganda (hereafter Kibale) has experienced climate change well above the global average. The area receives 300 mm more rainfall per year than at the start of the last century and the average maximum monthly temperature has increased by 4.4°C in the last 40 years (et al., 2010a; Rothman et al., 2015). Corresponding with this change in climate, a number of tree species stopped fruiting (Chapman et al., 2005a), meaning that there was less fruit available for the frugivores. One possible example of the localized effects of climate change on primate fruiting trees in Kibale is that of *Trilepisium madagascariense*. This species has stopped fruiting at a site to the north of the park, but continues to fruit at a site to the south where it is drier because of a natural north-south decline in rainfall associated with a decline in elevation. This has corresponded with a decline over time in blue monkey populations (*Cercopithecus mitis*), but not redtail monkey (*C. ascanius*) or mangabey populations (*Lophocebus albigena*) (Chapman et al., 2000; Chapman et al., 2010c). It is unknown if these changes are a function of climate change and why the response would vary among these frugivores.

### Unexpected or Cascading Effects of Climate Change on Primates

While changes that will have an obvious effect on primate populations are of great concern (e.g., physiological stress from hot temperatures, loss of habitat as a result of drying, decrease in the availability of water), it is also important to proactively seek to understand the subtle, unexpected, or cascading effects of climate change. One such unanticipated effect of climate change is the deterioration of the nutritional quality of plant parts, which are a major food source of most primates. Much of what we know about how plants respond to changes in climate (CO<sub>2</sub> levels, temperature, and rainfall) are based on greenhouse experiments and vary depending on plant species and soil nutrients. In general, experiments reveal that increased temperature and elevated CO<sub>2</sub> levels result in a reduction in leaf protein and an increase in fiber (Buse et al., 1998; Curtis and Wang, 1998; Dury et al., 1998; Kanowski, 2001; Zvereva and Kozlov, 2006; Robinson et al., 2012). Similarly, analysis of trees along rainfall gradients in tropical regions document that both nitrogen content (primarily protein) and nitrogen-to-fiber ratios decreased with increasing rainfall (Santiago and Mulkey, 2005). Similar effects on leaf chemistry have been found for increasing temperature (Weih and Karlsson, 2001; Craine et al., 2010). Local

biomass of folivorous primates has been repeatedly shown to correspond with the protein to fiber ratio of available trees (Oates et al., 1990; Chapman and Chapman, 2002; Gogarten et al., 2012), thus one would expect folivorous primates' biomass will decline in areas experiencing increased temperature, rainfall, and CO<sub>2</sub> levels.

For primates that rely on insects, studies have found that insect populations respond to climate change with changes in range, abundance, and phenology (reviewed in Andrew et al., 2013). In fact, one study of insects in southern Africa forecasts reduced insect diversity as a consequence of climate change (Pio et al., 2014). A 27 year study documented a 76% decline in flying insect biomass in protected areas in Germany (Hallmann et al., 2017). Such changes would be expected to negatively impact primates who forage extensively on insects, or for which insect consumption provides an important portion of their protein supply. One example comes from Barro Colorado Island, Panama, where a large proportion of the local capuchins (*Cebus capucinus*), but not the howler monkeys (*Alouatta palliata*) died after unusually high amounts of rainfall (Milton and Giacalone, 2014). The most likely explanation for this decline in the capuchin population was the negative effect of the rain on the arthropod population during a time when capuchins were heavily dependent on this protein source.

Most primates rely on eating fruit to some degree. Unfortunately, there does not appear to be an easy answer to the question of how climate change will affect fruit availability, and it is premature to try to generalize. How the fruiting pattern of trees will be influenced by climate change is complex and will vary among species. Studies have shown that a continued intensification of the El Niño effect and extreme weather events caused by climate change posed an additional threat to the lemurs of Madagascar (Dunham et al., 2008, 2011). In Kibale, where climate change is significant, at a community wide level fruiting declined from 1970 to 1985, but increased between 1990 to 2002. However, the patterns of response among species was highly variable. For example, *Pouteria altissima* exhibited a relatively regular pattern of fruiting during the 1970s but rarely fruited in the 1990s, while the proportion of the *Funtumia latifolia* population that fruited increased over time.

In general, studies have focused on community level patterns, but not all fruiting tree species will respond the same to climate change, and the preferences for different fruiting species varies among primates, as does the importance of the tree to support the primate population. As a result, deciphering how specific frugivores will respond to climate change is very difficult because the importance of specific trees for the foraging ecology and population dynamics of any primate has rarely been quantified (Shanahan et al., 2001; Rode et al., 2006; Hanya and Chapman, 2013).

Figs (*Ficus* spp.) are known to be important for many species of primates (Janzen, 1979; Bleher et al., 2003; Diaz-Martin et al., 2014). This may be because figs contain many essential nutrients and minerals (O'Brien et al., 1998) and can provide a nutritionally balanced staple food in some areas (Felton et al., 2009). While there is

no evidence that figs act as keystone species (Gautier-Hion and Michaloud, 1989; Chapman et al., 2005a), ripe fruits are eaten by many frugivorous primates (O'Brien et al., 1998). It seems likely that figs will be particularly vulnerable to climate change because not only are the trees themselves going to be physiologically affected by changing climate conditions, but most fig species rely on one species of fig wasp for their pollination (Janzen, 1979). If the obligate fig wasp population is affected by changing climatic conditions, then the trees have no substitute pollinators.

The hotter temperatures associated with global warming may trigger a short-term regulatory response in that primates will change what they need to eat (Raubenheimer et al., 2012). For example, primates living under hotter temperatures may select foods with a higher water or salt content. A number of primates have been shown to have a low salt intake and to eat unusual foods like decaying wood, soil, aquatic plants, or eucalyptus bark to obtain salt (Oates, 1978; Rode et al., 2003; Rothman et al., 2006), so an added salt demand may be stressful on these animals.

Climate change may not only change variables like fruiting periodicity, the composition of leaves, and what primates require in their foods, but may also change what is available for them to eat. Experiments suggest that global warming reduces plant diversity (Gedan and Bertness, 2009), which may affect the foraging strategies and persistence of all primates. Climate change models have also predicted reduced diversity of fruiting angiosperms, which may reduce fruit availability for frugivorous primates (Vamosi and Wilson, 2008). In addition to affecting species important in primate diets, climate change will contribute to the increasing warming and aridification of the tropics and to interact synergistically with human-altered landscapes to reduce important wildlife habitat (Brodie et al., 2012).

## Population consequences of climate change

It is critical that conservationists understand how climate change will effect primate population size. Unfortunately, obtaining this information is very difficult and it requires very long-term research, and thus there is very little data to make informed management decisions. Recently, Campos et al. (2017) investigated the effects of climate change on the fertility and survival rates of seven primates species. They found strong climate signals in the fertility rates of three species (blue monkeys - *Cercopithecus mitis*, Verreaux's sifaka - *Propithecus verreauxi*, and northern muriqui - *Brachyteles hypoxanthus*) and evidence of its impact on infant survival for the sifaka. These authors conclude that there is only weak evidence that these primate populations are responding strongly to climate variability.

While this is a robust and long-term study, there are reasons not to let this study make us complacent: 1) Primates are typically very flexible species in terms of their activity patterns and diets (Chapman et al., 2002b; Chapman and Rothman, 2009), thus they can tolerate change. However, they are likely only tolerant up to a tipping point that is unknown. The tipping point could be a long-way into the future, or it could be very soon. 2) The primates that were studied are all protected, yet

most primates are not protected and the impact of climate change on these unprotected populations that are experiencing multiple perturbations, such as hunting and habitat degradation, are unknown. 3) All animal populations are buffered from the cascading change that will result from climate change by the tolerance of the plants they depend on, and once this tolerance is exceeded, declines in primate populations could occur rapidly.

### **The Impact of Climate Change on the Primates of Kibale National Park, Uganda**

We use our long-term research in Kibale to provide an encapsulated example of the responses of a primate community to changes in climate, tree phenology, food quality, and disease. With respect to climate, Kibale receives 300 mm more rainfall per year than at the start of the century and the average maximum monthly temperature has increased by 4.4°C in the last 40 years (Chapman et al., 2010a).

While climate was changing, there was no consistent change in community-wide fruiting levels between 1990 to 2014, but the annual fruiting varied over 3.8-fold and this was related to variables that would be affected by climate change (Chapman et al., in press-b). For instance, while both temperature and rainfall showed positive effects on fruiting, solar radiance was the best predictor of fruiting. Projected changes in rainfall associated with climate change, and coincident increase in cloud cover suggest that phenophase dynamics will be affected by climate change and that fruit will become scarcer. ENSO (El Niño–Southern Oscillation) was also significantly associated with annual ripe fruit production and ENSO events are increasing in intensity and frequency (Cai et al., 2014), which again suggests fruit availability in Kibale will decline in the future (Chapman and Chapman, 1999; Chapman et al., 1999; Chapman et al., 2005a, Chapman et al., 2005b, Valtonen et al., 2013; Chapman et al., in press-b).

Rothman et al. (2015) show a general increase in fiber and a decrease in protein in trees compared to data collected 15 and 30 years previously. Because many folivores select leaves with a high protein to–fiber ratios (Chapman et al., 2002a; Gogarten et al., 2012), declining leaf quality would be expected to have a major impact on red and black-and-white colobus abundance. A 31% decline in colobus monkey abundance would be predicted based on the predictive model between colobine biomass and the protein-to–fiber ratio of the mature leaves from common tree species in an area (Chapman et al., 2004).

Connections between climate and disease are well established in the human medical literature, with specific diseases occurring during certain seasons, or erupting in association with specific weather conditions. For example, in sub-Saharan Africa, meningococcal meningitis epidemics erupt during the dry season (Patz et al., 1996) and in North America heavy rains are associated with outbreaks of waterborne diseases in humans (Hunter 2003). A study in Kibale found high levels of parasitism in black and white colobus (*Colobus guereza*) in wetter locations and since Kibale



is getting wetter, it is reasonable to predict that the level of parasitism will increase in the primate populations (Chapman et al., 2010b). The protozoan parasite community was assessed in five species of primates of Kibale in the 1970s (Freeland, 1979), and nearly four decades later a reassessment revealed that while protozoans were absent in colobines in the 1970s, they were a common infection almost 40 years later (Chapman et al., 2012). All of these findings suggest that the primates will be experiencing deterioration of health in association with climate change.

All of these results suggest that the primate populations of Kibale should be declining, yet detailed surveys indicate the exact opposite – the primate numbers in the park are increasing (Chapman et al., 2010c; Chapman et al., in press-a). This suggests that these species are able to respond to changes in the environment, but it begs the question at what level of change will the animals not be able to respond and we will witness a decline in numbers.

## Conclusions

Climate change is occurring and with 60% of all primate species being threatened with extinction (Estrada et al., 2017) and since many of these species only occur in small isolated populations, climate change will mean that conserving primates will be an even greater challenge. It seems almost a certainty that with the disappearance of Miss Waldron's red colobus (*Procolobus badius waldroni*), the world has witnessed the first primate species to be driven to extinction through human actions (McGraw, 2005) – let the world not lose more. Let society increase its awareness and efforts to conserve the remaining primate species. To do that, we must know what climate change will have in store for these threatened populations.

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