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Behavior Changes in Cercopithecidae and Platyrrhini in Response to Anthropogenic Climate Change

Clara Dell and Allen Rutberg

Tufts University Cummings School of Veterinary Medicine, Center for Animals & Public Policy, North Grafton, MA, USA

Abstract: Climate change has been unequivocally linked to human impact. Human actions have affected the environment and its inhabitants in a variety of ways around the globe and the response of various species can provide insight to what the future holds if we do not begin to mitigate the impacts of climate change. Monkeys are especially important as they function as ecosystem engineers, having a significant impact on plants and other animals in their habitats. Despite their importance, primates in South America and Africa remain understudied, yet are especially at risk as these regions have already undergone significant habitat loss. These regions are also Biodiversity Hotspots with the highest numbers of primate species on Earth. This systematic literature review assesses the current state of knowledge on how monkeys have changed their behavior in response to anthropogenic climate change. For this review, we scanned 3,461 titles, and 100 papers were read in full; seven of 100 papers provided relevant data. These studies primarily reported fertility changes and food substitutions when species were exposed to harsh conditions. The paucity of results from this review demonstrates that more research is needed on this topic. The effects of climate change on primates and their habitats must also be studied in conjunction with other anthropogenic stressors. As humans encroach on wildlife habitats, policies must be implemented to protect the habitats that are still viable.

Keywords: Primates, monkeys, South America, Africa, fertility, diet, range, systematic literature review

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Introduction

Climate change

With a rapidly increasing global population and accompanying resource use, the impact of human activity can be felt throughout the world and is making a major impact on our climate (Kalbitzer and Chapman 2018). The most recent Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science of climate change, states that global warming is unequivocally caused by human activities and influences (IPCC 2022). Furthermore, climate change is expected to become the number-one driver of biodiversity loss and decline over the next 50 years (Baisero *et al*. 2020).

Although anthropogenic climate change is often represented by global warming, it also encompasses changes in precipitation and the occurrence of extreme weather events (Lynch Alfaro 2017). These impacts continue to negatively affect the habitats of countless species and, when habitats are destroyed, animals must adapt or they risk extinction (Mantyka-Pringle *et al*. 2012). The ability of species to adapt is instrumental to surviving in a changing environment dominated by human impacts (McLennan *et al*. 2017). Although species will respond differently to the specific threats in their environment, the effects of climate change overall are expected to be major drivers of extinction (Pacifici *et al*. 2017).

Various studies have shown how several species have responded to specific outcomes of climate change, but there is no broad review of how animals alter their behaviors in response to the impacts of climate change. Because climate change is ongoing, it can be difficult to discern overarching trends in research that is focused on individual species or specific regions and spread across various journals.

Importance of primates

Current literature regarding how species adapt to the effects of climate change has been largely limited to smaller species, such as birds, amphibians, and insects (Mantyka-Pringle *et al*. 2012). However, non-human primates, and monkeys specifically, are a species-rich group and their wide range of specializations may make it difficult to predict how they will respond to climate threats (Estrada *et al*.

2017). Some suggest that monkeys may very well be resilient in the face of climate change because they are known to have behavioral flexibility (Carvalho *et al*. 2019) and are not necessarily dietary specialists (Milich *et al*. 2014). Additionally, monkeys have relatively large brains, a characteristic that has advantages in dealing with ecological challenges (Kalbitzer and Chapman 2018). However, other sources predict that extreme changes in weather patterns will put primates at increased risk (Estrada *et al*. 2018) and that monkeys have a more difficult time adapting and evolving because of their particularly slow life history, including long inter-birth intervals (Estrada *et al*. 2017). Although there are conflicting views regarding resilience and adaptability, monkeys are an incredibly diverse group. Because there are so many different species, we need a collective review to identify trends in the literature to begin to understand how monkeys are responding to climate change.

Monkeys are especially important to consider in relation to climate change as they play a key role in their habitats, influencing the structure, function, and resilience of ecosystems (Estrada *et al*., 2017). They are pollinators and seed dispersers and very much influence the floral diversity in their habitats (Estrada *et al*. 2017). One study has shown that plant species' composition in a given region was substantially altered by the extinction of local primates (Nunez-Iturri *et al.* 2008). By ingesting and subsequently defecating and dispersing seeds, monkeys can also help to increase tree cover, which can promote carbon production, helping to buffer against continued climate change (Wich and Marshall 2016). Losing such an integral player in an ecosystem can decrease the capacity of a given habitat to resist and recover from disturbances (Linero *et al*. 2020). Because extinctions of primate species can have cascading and dire consequences for their entire habitat (Reed and Bidner 2004), it is essential to understand how climate change is continuing to affect these animals.

Other species of non-human primates, such as apes and lemurs, are well-represented in the literature regarding how they are affected by and respond to climate change and its impacts (Bernard and Marshall 2020). The bias towards apes is likely related to their size, charisma, and phylogenetic proximity to humans, whereas lemurs have shorter lifespans, which increases the observable effects of climate change on populations over time (Bernard and Marshall 2020). This review will instead focus on the monkeys of South America and Africa.

Regions

Data from 1990–2005 indicate that tropical climates are suffering the greatest losses of species richness and biomass of primates specifically (Irwin 2016). Tropical animals, such as monkeys, often have narrower thermal tolerances than temperate species, as their natural habitats undergo relatively little seasonality beyond high annual rainfall and warm temperatures (Kamilar and Beaudrot 2018; Bernard and Marshall 2020). Tropical species in general are expected to face more rapid climate change, which may outpace the ability to disperse to new suitable habitat (Ribeiro *et al*. 2018). Thus far, we have seen a significant loss of the monkeys' ranges due to climate change in both the Neotropics (Mexico and Central and South America) and Africa (Carvalho *et al*. 2019). Both of these regions are important hotspots of biodiversity loss where mammals are especially at risk from climate change (Pacifici *et al*. 2017).

Although monkeys are found in the Americas, Africa, and Asia, this review will discuss only the Biodiversity Hotspots of South America and Africa. Climate models show that South America and Africa are more prone to dry conditions, while Asia is generally expected to experience increased rainfall (Korstjens and Hillyer 2016). South America and Africa have the highest concentrations of primate species richness (Gaffney 2011; Graham *et al*. 2016) and these regions also hold some of the highest concentrations of Endangered and Critically Endangered monkeys, as determined by the International Union for Conservation of Nature (IUCN) (Graham *et al*. 2016). Asian monkeys are more vulnerable to direct human interference than the other groups (Estrada *et al*. 2017). These combined factors make for a better comparison between South America and Africa.

The purpose of this systematic literature review is to identify any behavioral changes of South American and African monkeys in response to anthropogenic climate change. We expect to find how monkeys adapt to climate change in the context of three categories: greater home ranges, altered time budgets, and increased food substitution. We also hypothesize specifically that Cercopithecidae in Africa will be better equipped to deal with a shifting climate and will have shown fewer behavioral changes than Platyrrhini (in South America). Cercopithecids are known to use a wider range of habitats and to be more omnivorous than their American counterparts (Mattison and Vaughn 2016). This may indicate that the Cercopithecidae will already be familiar with traveling long distances and eating a wide variety of plants (both leaves and fruit) and small animals.

Methods

We carried out a systematic literature review to synthesize and assess the existing research on the topic of behavior in response to anthropogenic climate changes in the Platyrrhini and Cercopithecidae. We sought all available information published in English to understand the trends within this theme. To compile this review, we used three internet search engines: Google Scholar, Web of Science, and PubMed. Articles that were not available online were obtained through inter-library loans via Tufts University. Multiple searches using key terms were performed on each search engine, using Boolean operators and Medical Subject Headings (MeSH terms) on PubMed to identify alternate phrasing of the concept of climate change.

Inclusion criteria consisted of primary/original research, academic book chapters, peer reviewed articles,

Table 1. Search Terms

climate change OR climate change effects OR changing habitats/habitat change OR anthropogenic change	*AND*	*South America OR central Africa OR Amazon OR African OR Old World OR New World*	*AND*	*primates OR monkeys*	*AND*	*behavior OR diet OR range OR dispersal*

Ph.D. dissertations, conference proceedings, and government reports, all available in English. Criteria for exclusion included other anthropogenic stressors and causes of habitat or behavior change, apes or lemurs instead of monkeys, Central America (including Mexico) or Asia, and non-peer reviewed articles. We excluded models and simulations, as they do not provide empirical answers to the research question. We also excluded papers that did not explicitly tie behavioral changes to climate change, even if they discussed what a particular species does differently in certain environments; explicit connection to climate change was necessary. The map displayed in Figure 1 was used to determine geographical inclusion: studies included must have been performed in the light blue (or higher density, as determined by the "primate richness" key) areas of either the South American or African continents. Studies performed in national parks or reserves were included, as long as monkeys were free-ranging (regardless of land ownership and designation) and accounts of captive monkeys were excluded.

Once the criteria were determined, articles selected for further review based on the title from each search were transferred to EndNote (EndNote Web, Clarivate Analytics). Groups were created for each attempted search, then combined into a larger group for each search engine where duplicates were removed. Search engine groups were combined to again identify and remove any duplicates. Of this final group, all abstracts were read to further narrow down relevant work. Abstract review dictated which articles were to be read in full, producing the final-result papers for this review. Papers classified as results were reread to confirm their relevance.

Results

We scanned 2,249 titles from Google Scholar, 458 from Web of Science, and 754 from PubMed for a combined 3,461 titles. After duplicate removal, we read 267 abstracts and subsequently 100 papers in full. Additional sources obtained outside of the formal searches were either the result of initial searches during the preliminary stages of the project or were sent directly or recommended from those familiar with the research question. Stages of the review and search numbers are outlined in a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart, see Figure 2.

Of 100 papers read in full, zero indicated that climate change has had or will have little to no effect on the primates, their habitats, or their behaviors. Seven papers published between 2009 and 2017, including two book chapters, reported changes in the behavior of primates in response to climate changes. Although three of these papers provided information on more than one species, we found three studies

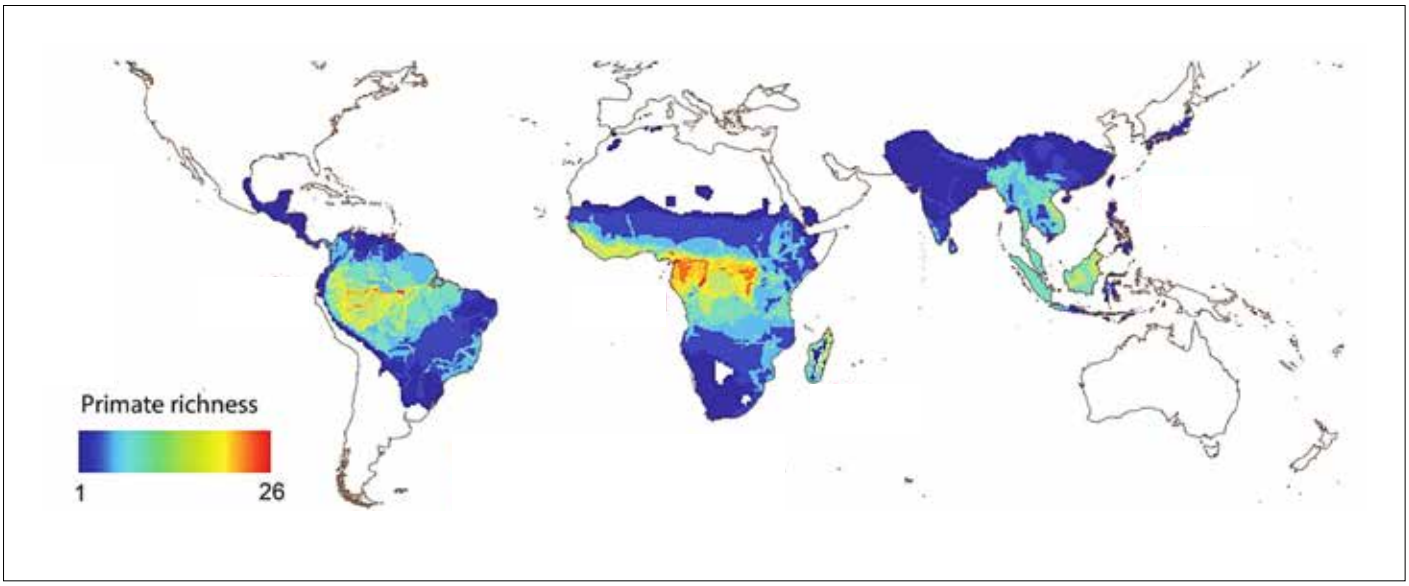

Figure 1. This graphic helped inform which regions would be included in the synthesis. Light blue and higher densities were included in the review. From Estrada *et al*. 2017. Impending extinction crisis of the world's primates: Why primates matter. *Sci. Adv.* 3(1). © The Authors, some rights reserved; exclusive licensee AAAS. Distributed under a CC BY-NC 4.0 license http://creativecommons.org/licenses/by-nc/4.0/". Reprinted with permission from AAAS.

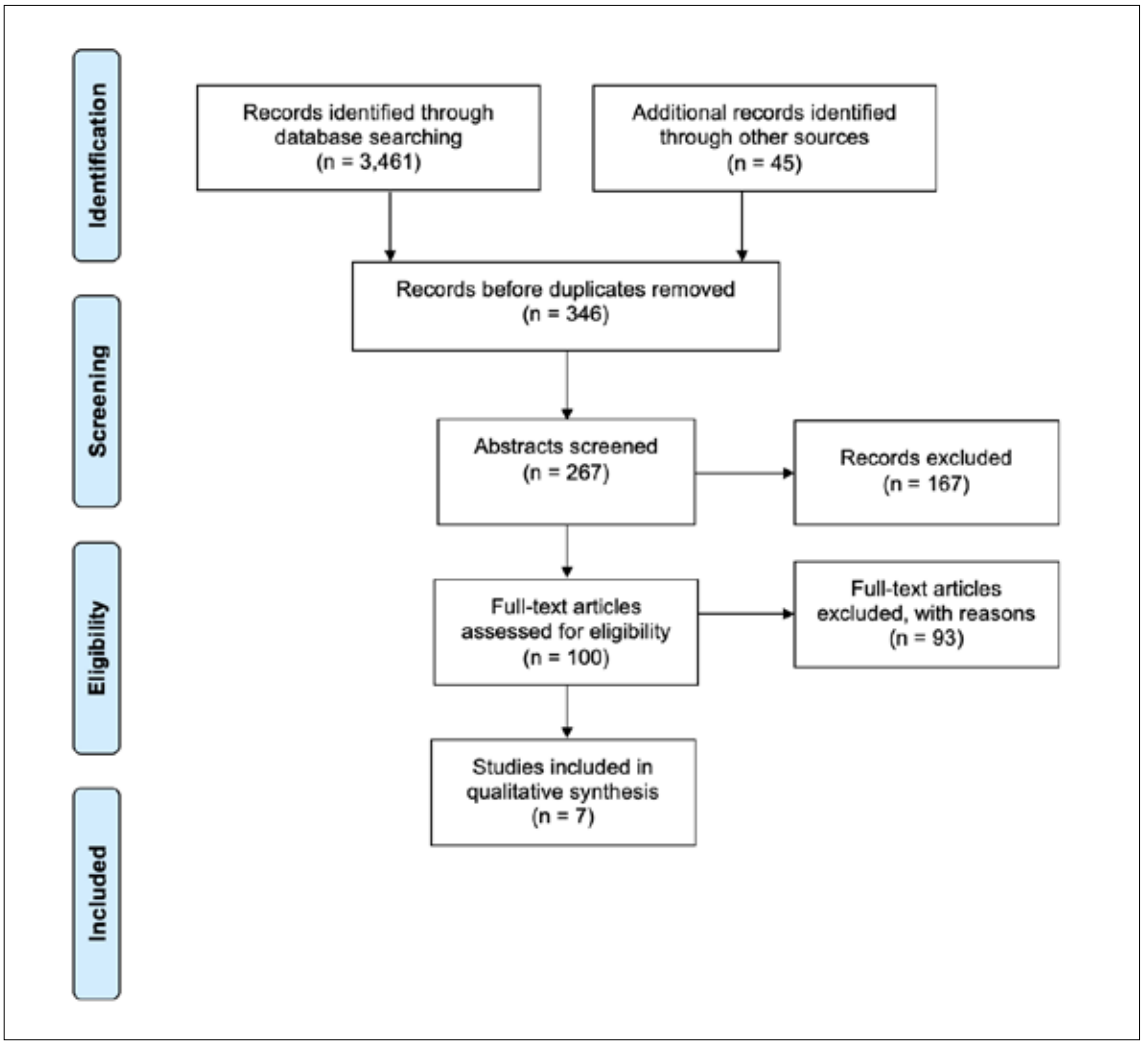

Figure 2. PRISMA Flow Diagram, 2009 version (Page *et al*. 2021).

about South American monkeys, three studies about African monkeys, and one study with results for both regions. Study sites from included results are shown in Figure 3. All results detailed climate caused changes in fertility or food substitution in both/either South America and Africa. These findings did not fully support the hypotheses that were focused specifically on ranging, diet, and time budgets.

Although the number and type (diet, range, etc.) of result for each region was intended to measure whether Cercopithecidae were better equipped to respond to climatic changes as hypothesized, it was deemed inappropriate to draw any conclusions in the differences between these groups based on this small sample size. However, results from South America tended to show that climate change has primarily impacted reproduction and population trends whereas results from Africa largely showed behavioral shifts (in diet).

South America (Platyrrhini)

Wiederholt and Post (2009) reported that increased El Niño events were associated with population declines for woolly monkeys in Meta, Colombia, and southern muriquis in Caratinga, Brazil, one year following the events. A closer examination by Wiederholt and Post (2011) showed that drought conditions and El Niño years also delayed the birth season for both northern muriquis and woolly monkeys, resulting in lower birth rates, and that the higher temperatures associated with these conditions were also a contributing factor to low birth rates for northern muriquis, and the overall El Niño effects led to more male offspring born to woolly monkeys (Wiederholt and Post 2011). The findings from Wiederholt and Post's 2009 study were corroborated by Campos *et al*. (2017), who found that the warm and dry conditions associated with El Niño Southern Oscillation events meant decreased fertility for northern muriquis, in Caratinga, Brazil. Finally, Shanee and Shanee (2014) found that yellow-tailed woolly monkeys in Amazonas, Peru, typically frugivores, were more likely to eat leaves and insects in an extended dry season marked by low fruit production and windstorms dislodging ripe fruit.

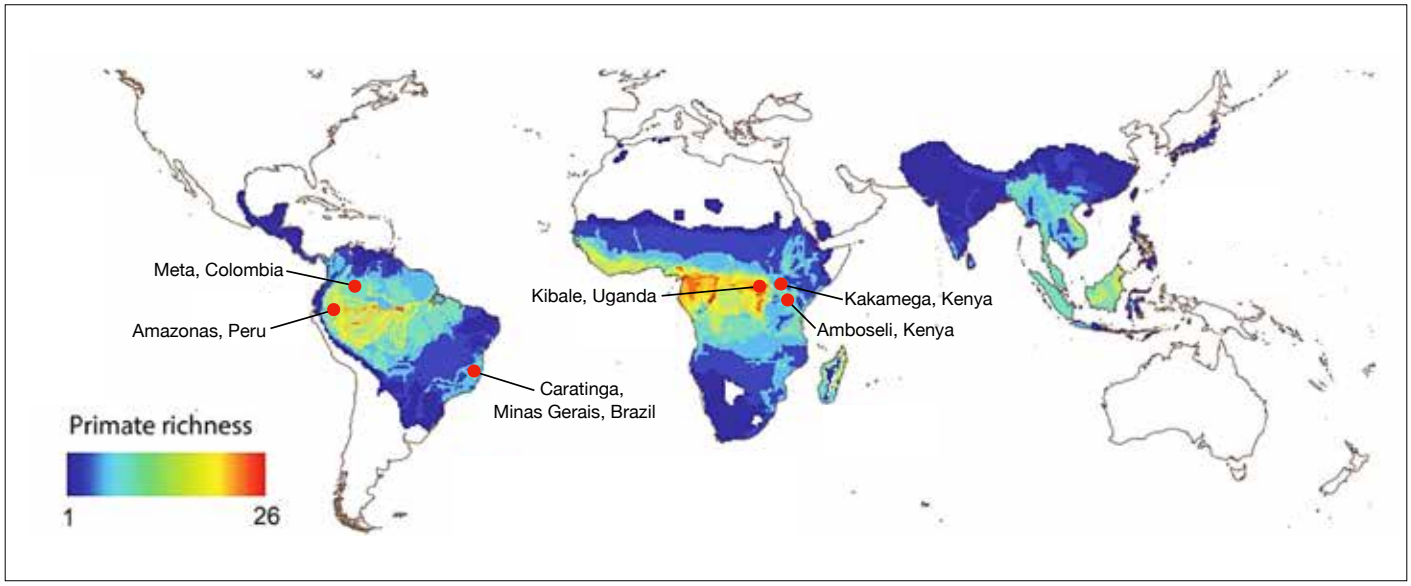

Figure 3. The graphic from Estrada, *et al.*, 2017 that informed inclusion criteria edited to display study sites referred to in Results.

Table 2. South America

Climate changes & sites	**Behavioral changes & species**	**Study**
El Niño conditions in Meta, Colombia, and Caratinga, Brazil -Tropical moist forest	Population declines for woolly monkeys one year following	Wiederholt and Post (2009)
Drought and El Niño years in Meta, Colombia, and Minas Gerais, Brazil -Tropical moist forest	Delayed birth season and lower birth rates for northern muriquis and woolly monkeys	Wiederholt and Post (2011)
El Niño conditions in Meta, Colombia -Tropical moist forest	More male offspring born to woolly monkeys	Wiederholt and Post (2011)
Higher temperatures in Minas Gerais, Brazil -Tropical moist forest	Lower birth rates for northern muriquis	Wiederholt and Post (2011)
Warm and dry conditions in Caratinga, Brazil -Tropical moist forest	Decreased fertility for northern muriqui	Campos *et al*. (2017)
Extended dry season in Amazonas, Peru, including low fruit productions and windstorms dislodging ripe fruit -Tropical cloud forest	Yellow tailed woolly monkeys eating more leaves and insects (instead of fruit)	Shanee and Shanee (2014)

Table 3. Africa

Climate changes & sites	**Behavioral changes & species**	**Study**
Extreme heat in Amboseli, Kenya -Open savanna	Yellow baboons less likely to cycle and conceive	Kalbitzer and Chapman (2018)
Increased rainfall and lower temperatures in Kakamega, Kenya -Tropical rainforest	Increased fertility in blue monkeys	Campos *et al*. (2017)
Elevated temperatures, rainfall, and CO_2 levels in Kibale, Uganda -Tropical moist forest	Reduced protein and increased fiber in leaves: colobines increasing food substitution/not eating the same leaves as usual	Rothman *et al*. (2015)
Increased rainfall in Kibale, Uganda -Tropical moist forest	Red colobus eating more highly estrogenic plants; higher rates of aggression and copulation and less time spent grooming	Wasserman *et al*. (2012)

Africa (Cercopithecidae)

Kalbitzer and Chapman (2018) showed that yellow baboons in Amboseli, Kenya were less likely to cycle and conceive in periods of extreme heat. Conversely, Campos *et al*. (2017) showed that increased rainfall and lower temperatures increased fertility in blue monkeys in Kakamega, Kenya. In Kibale, Uganda, Rothman *et al*. (2015), found that higher than usual temperatures and increased rainfall also increased CO_2 levels, which were linked to reduced protein and elevated fiber levels in leaves, causing colobines to eat leaves they do not typically consume. Also in Kibale, Uganda, Wasserman *et al*. (2012) found that increased rainfall caused red colobus monkeys to eat more highly estrogenic plants (as confirmed through fecal tests). This increased consumption was positively correlated with estradiol and cortisol levels, as well as higher rates of aggression and copulation and less time grooming.

Two findings were initially included in the results section but were later determined not to fit the criteria and were removed from the formal analysis. Korstjens and Hillyer (2016) describe a study done in the Chaco region of Argentina that found during a drought, owl monkeys gave birth less frequently and ate leaves more frequently, though they are typically frugivores (Fernandez-Duque and Van der Heide, 2013). Additionally, Wiederholt and Post's 2009-research also included a study site located in Guárico, Venezuela. At this site, population declines for red howler monkeys were observed in the same year as El Niño events. Because both the Chaco region and state of Guárico do not fit the geographic inclusion criteria as defined by the light blue area in Figure 1, we excluded these findings from the results. Although these findings were not part of the systematic review, they help to illustrate the behavioral changes in Platyrrhini in response to climate change.

Discussion

Ultimately, the sample of studies fitting the search criteria was too small to yield any meaningful differences between the South American and African monkeys in response to anthropogenic climate change. As was consistent with previous literature, searching for the effects of climate change on monkey behavior demonstrated a notable gap in the research, although the existing data preliminarily show that the behavior of monkeys in South America and Africa can be affected by climate change. The underlying trend of these results shows that the changing seasonality in these environments affects food availability and ultimately reproduction.

With so many monkey species already endangered, decreased fertility can have grave implications for the future of the species; understanding the climate-based mechanisms that impact fertility is a high priority for species survival. Fertility reduction may be especially problematic for many species of monkey, the average growth of which is slow compared to other mammals (Altmann and Alberts 2005). Seasonal fluctuations associated with climate change can also result in gestation during non-optimal times leading to decreased fetal survival (Wiederholt and Post 2011). With decreasing fertility rates and fewer individuals born into a group, it is increasingly difficult for a given species to sustain a population and adapt to a changing climate. More specifically, seasonal breeding in monkeys is generally understood to be timed alongside maximum food availability, which is dictated by climatic conditions (Wiederholt and Post 2011). Because food quality and availability have been shown to be significant determinants of reproductive success, food density can be used as a measure for overall habitat quality, a major factor in predicting local group extinctions (Lee and Hauser 1998).

Alberts *et al*. (2005) found that vervet monkeys, which are seasonal breeders and specialized feeders, became locally extinct in response to tree loss and habitat degradation in Kenya. Baboons in the same area, however, which are dietary generalists and able to reproduce throughout the year, were able to adapt. Although this specific study does not explicitly discuss climate change, we can see that breeding patterns play a key role in response to habitat changes. This 2005-study by Alberts *et al*. also serves as an example of the differences in individual species and further demonstrates that Cercopithecidae do not all behave in the same way, thus a comparison cannot be drawn between Cercopithecidae and Platyrrhini. The limited and dispersed locations shown in results for both South America and Africa also show that each continent cannot be represented as a single entity. It is worth noting, however, that the diversity of habitats included in this review offer the prospect of better understanding where climate change may have its strongest effects.

Future directions and limitations

Although this search elicited a small number of results, it holds grave implications. The scarcity of relevant papers clearly indicates that more research needs to be done to prepare for and adapt to ongoing climate change. Options include field studies conducted over longer periods of time incorporating multiple elements of the ecosystem as it operates synergistically. Future and long-term studies must not only account for the monkeys' behaviors, but also the availability and quality of food in specific habitats over time. Future research could also take the opportunity to focus on the specifics of dietary choices, including nutritional quality of leaves eaten by monkeys, as seen in studies by Rothman *et al*. (2015) and Wasserman *et al*. (2012).

Among the papers that emerged from this review, Campos *et al*. (2017) compared climate data alongside observational data in a study of seven primate species. This study design produced valuable information and could be applied to additional species in the future. Additionally, not many species have such a long history of observations, meaning emerging changes in response to climate change may not always be obvious.

Various accounts of changing behaviors may have not appeared in the literature search. Google Scholar, one of the three search engines used, imposes a 100-page (1000-result) limit, meaning any relevant titles listed after the first one hundred pages were not considered. However, most titles assessed for relevance were selected from the first ten to twenty pages of each search. Another limitation of this review is the sole inclusion of articles available in English. Studies in other languages may have included studies conducted by local researchers or accounts by local civilians who are able to observe monkey behaviors more frequently or consistently, demonstrating clear changes over time.

This systematic literature review synthesizes a limited body of research regarding the effects of anthropogenic climate change on monkey behavior. All species have experienced and adapted to environmental stress through behavioral plasticity, food substitution, and dispersal, but these tools may be inadequate in the face of climate change, especially for an animal that lives long and reproduces slowly (Kamilar and Beaudrot 2018). The ability to understand and accurately predict how population dynamics will change, including causes and cascading effects, in response to climate change is central to creating effective conservation strategies (Kalbitzer and Chapman 2018). The early stages of growth in this field of research may indicate a budding relationship between the biological and social worlds, reflecting a shift in biological science that recognizes the need to consider human dimensions of biodiversity conservation (McLennan *et al*. 2017). This research and relationship do not amount to much without enforcing policy surrounding these findings and it is imperative to act now. The future success of monkey populations in tropical regions depends not only on science and policy, but largely on reforming our cultural practices to more closely align with the constraints of the planet on which we live.

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Authors' addresses:
Clara Dell, Tufts University Cummings School of Veterinary Medicine, Center for Animals & Public Policy, 200 Westboro Rd. North Grafton, MA 01536, <clara.dell@alumni.tufts.edu>; and **Allen Rutberg,** Tufts University Cummings School of Veterinary Medicine, Center for Animals & Public Policy, 200 Westboro Rd. North Grafton, MA 01536, <allen.rutberg@tufts.edu>.

Corresponding author: Clara Dell
E-mail: <clara.dell@alumni.tufts.edu>

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