

Impacts of climate change on African mammalian biodiversity

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Abstract

This study aim was to investigate the effects of climate change on African mammals' biodiversity. Using a systematic literature review (SLR), this study synthesized data from peer-reviewed studies, articles, and reports from academic databases, and the results were presented using content analysis.

The findings revealed that temperature rise, change in precipitation, and increase in extreme weather events all play a significant role in African mammal species distribution. Grazers like elephants, wildebeest and zebra are losing their space, food, and water berths, resulting in either forced migration, or a new human- wildlife conflict. The reduced prey availability and change in prey hunting behaviours are additional impacts on predators like lions and cheetahs. Temperature is pushing sensitive species like primates and large herbivores to cooler areas, but they often find themselves in non-viable fragments. Also, diseases such as malaria and ticks-borne diseases are also encouraged by climate change, as they expose African mammals to new health risks. Some conservation efforts, like the creation of protected areas and wildlife corridors, have been implemented, but these are often not large enough in scale to respond to the magnitude of the changes brought about by climate change.

Climate change imperils the biodiversity of African mammals through habitat loss, inability to migrate, and health effects due to the prevalence of extreme weather conditions. All of these impacts that will affect the long- term survival of Africa's unique wildlife require urgent conservative actions on the ground such as increasing wildlife corridors, policies adaptations and improved research and monitoring.

Keywords: Climate Change; Biodiversity; Mammals; Conservation; Wildlife; Africa

1. Introduction

Climate change is described as the long-term change of temperature and precipitation and other atmospheric conditions due to natural causes or human activity [1]. But, in the last few decades the pace of this change has increased due to human activities largely dependent on fossil fuel extraction, land use change, and industrial activities [2]. The worldwide impact of climate change is clear and can be seen in higher average global temperatures, more unpredictable global weather patterns, extreme heat waves, extended droughts, and powerful storms [3, 4]. Global temperature is projected to increase by between 1.3°C and 8.0°C by 2100 according to the Intergovernmental Panel on Climate Change (IPCC), with concomitant global sea-level rise that will impact coastal ecosystems and communities [5]. These changes are impacting ecosystems, changing the ranges of species, and posing a risk to biodiversity, including Africa's unique animals.

Biodiversity, defined as the "variability among living organisms, including among other things, ecological complexes of which they are part", is integral to ecosystem functioning and provides the foundation for the services humanity relies on for survival, including clean air, water, food and medicines [6]. Biodiversity is key for ecological processes, and is

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fundamental to ecosystem stability, especially vital in places such as Africa, where local populations depend on it. Africa's abundant diversity of mammals includes many species that are either endemic to the continent or that play important ecological roles [7]. In the global context, climate change has become one of the major drivers of biodiversity loss, within which Africa remains one of the most exposed continents. The continent's high dependence on natural resources, as well as low resilience to deal with the effects of climate change, positions it among the most vulnerable areas to the negative consequences of climate change [8, 9].

Africa experiences rising temperatures, shifting rainfall patterns, and severe weather as the reality of climate change. These habitat-disrupting climatic changes, are affecting savannas, deserts and tropical forests in Africa that are home for many species of mammals. There is a clear link between climate change and the loss of biodiversity across the African continent, as altered climate conditions affect the survival and distribution of species [10, 11]. Water, which is a precious resource for many African mammals, is being compromised by erratic rainfall and increased temperatures in some regions such as the Sahel. African mammals are also confronted with habitat and food source loss, as well as the emergence of climate-induced diseases [12].

1.1. African Mammalian Biodiversity

Africa is also known for its exceptional diversity of mammals, which include famous megafauna, such as elephants, lions, and rhinoceroses, as well as several smaller mammals, such as primates, rodents, and insectivores [13]; all these species play important roles in ecosystem processes and provide key ecological functions, such as pollination, seed dispersal, or controlling the populations of plants. For instance, elephants as a keystone species will impact the landscape by uprooting trees and making water holes that will itself help other species. The same holds for African herbivores; wildebeests and zebras are essential to preserve grassland ecosystems by recycling nutrients and preventing some plants species from over-growing [14].

Even considering that, the African continent is home for distinct ecosystems, with different mammalian communities. Savannas, found primarily in the majority of sub-Saharan Africa, are dominated by grassland interspersed with trees. Within these ecosystems, large herbivores such as elephant, giraffe, and antelope, and predators like lions and cheetahs, are supported. [14, 15]. Gorillas, chimpanzees, and other monkeys live mostly in Central and West Africa's tropical rainforests, especially [16]. Desert and semi-arid areas, like the Sahara and Kalahari Desert, are also home for endemic mammals such as desert adapted rodents and carnivores, like the fennec fox, ground pangolin and aardvark [17].

The diverse and extensive ecosystems of Africa are of critical importance to the continent's mammalian biodiversity. Unfortunately, these habitats are threatened by climate change, which is shifting a delicate equilibrium in these ecosystems. Changes in the timing and quantity of rainfall, extreme temperature variability, and habitat destruction from climate-induced desertification places many species, especially those adapted to very specific habitats, at a life-or-death situation.

1.2. Conservation Status

With human encroachment and climate change on the rise, endangering biodiversity, conservation of African mammals has emerged as an urgent endeavor. In recent decades, African populations of mammals have seen dramatic declines owing to habitat destruction, poaching, and human-wildlife conflict over the past few decades [18, 19]. The safeguarding of African mammals continues to constitute an important challenge as well, despite several conservation initiatives such as the foundation of national parks, wildlife reserves, and treaties of international cooperation. While species such as the African elephant and rhino are severely poached due to illegal ivory and horn trafficking, pangolin is hunted for its illegal-made of scales, and others, are also suffering from the fragmentation of their natural habitats, due to agricultural extension and urbanization [20-22].

Climate change is, on top of these forms of -par- anthropogenic pressure, being another layer of threat to Mammals of Africa. Species' ranges are constricting or changing to unfamiliar environments as the climate warms and precipitation patterns become increasingly variable. For instance, increasing temperatures on the savannas are already impacting water availability, a limiting factor for large herbivores. Also, drier areas like the Sahel will experience more intense and frequent drought spells, thereby endangering the existence of species adapted to a specific set of moisture conditions [10-12].

Conservation action will now need to combine both climate change and "normal" biodiversity threat responses. Corridors around wildlife, more critical habitat protections, and better climate adaptations will be critical to maintain Africa's mammalian biodiversity. Climate change impacts can be addressed, and Africa's most iconic species can be

preserved for future generations if governments, conservation communities, and local communities work together to find solutions. Political will, funding and capacities for wider implementation of these processes are posing challenges.

1.3. Aim of the Study

This work sets out to explore and collate information on how climate change impacts African mammalian biodiversity. More specifically:

- To determine which are the most relevant climate change drivers for African mammals, including temperature increase, variation in precipitation, and extreme weather events.
- To determine the effects of climate change on African mammals such as shifts in habitats, migration, reproductive behaviours and climate- associated diseases.
- To assess the success of contemporary conservation measures in confronting the “climate change crisis” in: conservation of habitats, wildlife corridors, etc. as a means to ameliorate the effects of climate change.

2. Methodology

Data collection, assessment, and analysis were carried out using a Systematic Literature Review (SLR) methodology. The rationale for this approach is to include all relevant studies in order to have an overview of the current knowledge without bias. As a result, the criteria for including resources in this review were: peer-reviewed journals articles, books and technical reports from the last 20 years. The selected studies were included due to their relevance in the context of climate change impacts on African mammals, specifically on the species level, on ecological impacts, or on conservation strategies. Only reports written in English and that offered some form of empirical data or significant analysis were included. Data was obtained via a content analysis, organized by climate themes including climate factors (i.e., temperature, precipitation, extreme events), vulnerability of species, changes in habitat, and conservation.

3. Results and Discussion

3.1. Temperature and Habitat Shifts

Temperature variation, a direct effect of climate change, plays an important role already on African mammalian species, especially those in narrow climatic range ecosystems. Global temperature increases are influencing the distribution, behaviors, and viability of many species. Temperature is also an important factor for metabolic activity, reproduction, and feeding behavior in mammals. Unique ecosystems on the African continent, such as savannas, deserts, and tropical forests are especially vulnerable to minor increases in temperature, as well [23-25].

The most documented example of a habitat shift due to temperature is with elephants in southern Africa. Elephants are also beginning to trend toward higher altitude where temperatures are cooler and water sources are more available. This is not a smooth transition, as elephants also are more likely to be involved in human-wildlife conflict in areas newly occupied by elephants. In Kruger National Park, elephants changed their patterns of movement, and this induced changes in their feeding and mating behaviours [26]. The rising temperatures in the park's lowland areas have affected adaptations for elephants; foraging into cooler, high-altitude areas have increased pressure on local resources. Also, as new areas often cannot sustain a large population of elephants, this could end up over-exploiting vegetation and even water resources with implications for the larger ecosystem as well.

Rising temperatures are also affecting the hunting and social behavior of big cats, including lions and leopards [27]. Herbivores are shifting their movements to predilect the regular seasonal timing of predator-prey interactions in East Africa, as a result of higher temperatures and extremely fluctuating weather conditions, thereby altering lion hunting probabilities. This disparity in prey availability can lead to lower reproductive success and increased nutritional stress in lion populations [28]. Also, higher temperatures are affecting territoriality and pride dynamics as lions will start moving to cooler areas and will adapt their movement in response to higher temperatures. Though lions are instinctually nocturnal hunters, heat stress can be a reinforcing factor in this behavior, with individuals becoming more active at night and covering longer distances, potentially increasing energy expenditure [29].

Primates, like mountain gorillas in Central Africa are not immune to these problems as temperatures increase. The cooler temperatures have made the regions of Rwanda and Uganda climate favorite for gorillas [30], but they are already affected by changes in their food sources, as the vegetation they rely on is being modified by the rise in temperature, and are becoming less comfortable in their high-altitude habitats as it is getting warmer. For instance, the Mountain

Gorilla Project reports a reduced availability of food due to increased temperatures in the Virunga Mountain, which impact on gorilla reproductive rates and lead to higher mortality among younger gorillas [32].

Increased temperatures are causing a disturbing process referred to as "woody encroachment" where shrub and tree species are invading areas once predominated by grasses. This is particularly true in the case of savannas in Southern Africa where increased temperatures and concentrations of carbon dioxide have intensified this process, resulting in reduced access to foraging area for herbivores such as zebras and antelopes [33]. Not only this, but as habitat decreases and habitat becomes less suitable for grazing, these herbivores disperse, leading to further predation-prey dynamics disruptions.

3.2. Altered Rainfall and Drought Patterns

Most importantly, alterations in the rainfall patterns have one of the greatest climate-change related impact on African mammals, by affecting their distribution and survival. Changes in precipitation, with lower rainfall, seasonal irregularities and increase of droughts, are directly affecting water and food resources availability, which are vital for the survival of herbivores and carnivores in the continent [34, 35].

The impacts of changing precipitation patterns have been especially dramatic in areas where rainfall has always been erratic, like the Sahel. Unpredictability is determined by long drought periods alternating with short rainy seasons. Herbivores like wildebeest and zebra, highly dependent on the seasonally growing grass, have a harder time adapting to these changes [36, 37]. During drought seasons, the animals are forced to migrate in search for greener food; however, in most cases, this migration leads them to clash with the human population or find themselves in areas where food and water sources are no longer adequate.

This trend has had immense consequences in the Greater Amboseli ecosystem, where the migratory population of wildebeests has dropped by over 85% from 16,300 individuals in 1977 to less than 2,400 in 2014, largely as a result of habitat loss during droughts, lack of water, and obstructed migratory corridors [38, 39]. Such disruptions impact predator's populations, and many other ecosystem processes such as nutrient cycling and vegetation regeneration.

Droughts are also more common in Southern Africa, impacting fragile ecosystems. The Kalahari Desert for instance has become drier in the last decades with extreme water shortages for species such as the elephants and lions. Elephants are in turn moving more towards human localities in search for water sources at the expense of creating more human-wildlife conflict [40, 41]. There, in Botswana's Okavango Delta, elephants are stressed out and migrate differently in response to decreased available water due to prolonged drought conditions. While in 2020 more than 330 elephants have also perished from drinking stagnant waterholes infected with toxic algae due to climate change, this is an increasingly recognized threat to wildlife due to lower quality water in the future [42].

Central African tropical forests, home to flagship species, such as gorillas and chimpanzees, are already undergoing variations in intensity due to timing of the rainy seasons. This alteration affects the growth of plants that gorillas rely on for food. Gorilla populations in Virunga Mountains, one of the last strongholds for mountain gorillas, are becoming increasingly stressed as food resources are no longer predictable. In this area, one study showed how warmer and drier conditions in the last decades negatively affected food availability and as a result gorilla birth and survival rates [30].

3.3. Habitat Loss, Fragmentation, and Species Migration

Among various factors, habitat loss and fragmentation due to climate change remains one of the most important drivers of biodiversity decline in African mammals. Climate change is causing ecosystems to change and is fragmenting previously continuous habitats and limiting the amount of space in which species can flourish. These transformations incoherent migration, lower genetic diversity, and higher extinction risk of several species.

Among the primary drivers of habitat loss, one major mechanism impacting the loss is the indirect effect of climate change on the types of vegetation and desertification. Desertification is increasing in the Sahel because of extended periods of drought and alteration in the rainfall patterns. As a result of this transformation in these environments, grasslands lose their value as important feeding grounds for herbivores like antelopes and gazelles [43, 44]. As these herbivores search for appropriate food, they are inevitably coming into conflicts with people, whose agricultural enterprises have moved into the wildlife's habitat. In addition, grassland loss impacts predatory species such as lions, which rely on herbivores for food. As a result, lions in those areas are decreasing due to lack of food sources and escalated human-wildlife conflict.

In Southern Africa in particular, one of the main threats is the fragmentation of the savanna by advancing agriculture and human settlement. As rainfall patterns are modified due to climate change and the occurrences of extreme events such as wildfires augment, these savannas are starting to become less favorable for large herbivores like elephants or wildebeests [45, 46]. For instance, in Kruger National Park, Climate-induced changes in the vegetation have modified grazing resources distribution, triggering competition amongst species. The "squeeze" effect of conventionally having less area for other species has also been seen in elephants, who are major ecosystem engineers within the savanna landscape, and have begun to be pushed into smaller patches of available habitat [26].

This is exacerbated by the fact that protected areas tend to be within a mosaic of fragmented lands. Elsewhere in Africa, conservation has concentrated on the creation of national parks and reserves, although these protected areas frequently remain disconnected and lack connectivity. With changing species distributions due to climate change, isolated reserves are also a hindrance to species migration and adaptation to new conditions. Wild African dogs, dependent on large territories hunting, are for instance extremely threatened because of habitat fragmentation. In Kruger-Limpopo, the restriction of space available to these species has also resulted in decreased numbers, as they can no longer traverse the landscape to search for prey [47].

Beyond habitat loss due to climate change, species' migratory patterns are also being affected. Species that were once able to move across continuous and undisturbed landscapes are now confined by and within barriers associated with human activities. Elephants, which used to move freely across large sections of Southern and East Africa, are also now having their historic migration corridors shrink due to possible climate change induced water and food availability. They are now stopped by human settlements and agricultural developments, severing the pathway for migration. This not only compromises their own survival, but also has an effect on the larger ecosystems, as elephants help in shaping the environment through tree uprooting and grassland maintenance [48-50].

Among primates, chimpanzees and gorillas are also experiencing habitat fragmentation. These species are being pushed into smaller and more fragmented patches of habitat as rainforests in Central Africa are decreasing as a result of climate change. In the Virunga Mountains, for instance, forest cover loss has been cited as a factor for decreased food availability for gorillas, hence impacting their reproductive rates as well as infants' death rates. Plus, the fragmentation of habitats also restricts the chance of these primates to disperse and keep genetic variability, which is another crucial aspect for their long-term persistence [30, 32, 48].

3.4. Climate Change-Induced Disease and New Threats

In addition to physical environmental impact, climate change also plays a role in the dissemination of diseases that affect African mammalian species. Alterations in temperature, precipitation, and extreme weather events generate conditions for the spread of pathogens, pests, and vectors of diseases. Also, as the global temperature increases, many of these pathogens are extending their range into new territories and bringing novel risks to the continent's wildlife.

Among these, one of the major changes is the increasing incidence of vector-borne diseases. Mosquitoes and other disease-carrying vectors are finding conditions of warmer temperatures and changing rainfall patterns increasingly favorable. Increasing temperatures and changing climatic conditions are resulting in upward movement of mosquito vectors, especially *Anopheles* species, in forested highlands in Uganda. This spreading, into cooler, higher elevation areas incur the risk of wildlife, particularly great apes, chimpanzees and possibly mountain gorillas, being infected with malaria. Moreover, research conducted close to chimpanzees' nests sites in Kibale National Park found mosquitoes positive for *Plasmodium* DNA, supporting the idea of suitable ecological conditions for transmission [51]. In the same manner, African tick-bite fever, another tick-borne disease, is also spreading as temperatures rise and ticks are found in areas where they previously did not exist [52].

Besides vector-borne diseases, climate change is also increasing the incidence of zoonotic diseases, transferred between animals and humans. The occurrence of outbreaks of human and wildlife diseases such as Ebola, Rift Valley fever, malaria, cholera, plague, and hantavirus has, for example, been associated with climate and weather variations as well [53, 54]. Increased temperatures combined with irregular rainfall patterns provide perfect breeding conditions for the insects and rodents that are the vectors of these viruses. The impact of these diseases on primate populations such as chimpanzees, and gorillas has been dramatic, with mass die-offs in some populations of these species.

Also, African mammals are shifting their behavior, reproduction, and disease dissemination, due to climate change. Increased temperatures lead to physiological stress responses in animals that may depress immune function and leave them more susceptible to disease. For instance, in Southern Africa, Elephants have shown increased levels of stress in extremely hot conditions, which could potentially lead to lower reproduction rates and illness resistance. Increased heat

also alters mating behavior in some species, as individuals adjust their reproductive cycles according to food or water availability, leading to mismatched timings and reproductive failure [55, 56].

One of the most worrisome drivers are changes in migration patterns as a consequence of climate change, which could lead mammals to experience new pathogens. Larger herbivores, like elephants and antelopes among others, will move to locate food and water in modified climates, possibly exposing previously isolated populations of pathogens.

3.5. Conservation Efforts and Their Effectiveness

Many conservation measures have been undertaken throughout Africa to protect its mammals, as the threats of climate change continue to grow. Such efforts respond to not only the immediate effects of climate change – including habitat loss – but also more general to ecological changes, such as species' distribution and behavior. Strategies that are employed in addressing the impact of climate change on African mammals include the creation of protected area networks, wildlife corridors, and transboundary conservation landscapes.

Wildlife areas and national parks continue to be the backbone of conservation efforts. They are vital to protect species from poaching or habitat destruction or over-exploitation. For instance, South Africa's Kruger National Park and Tanzania's Serengeti National Park are indispensable safe havens for elephants, lions and rhinos. Though relatively safe places, the borders of these parks are ceasing to be adequate to sustain wildlife as the environmental conditions change.

Wildlife corridors have been identified as a potential solution to this problem by connecting fragmented protected areas and offering a means for migrating animals to adapt to new conditions based on shifts in climate. In Southern Africa the establishment of the Great Limpopo Transfrontier Park, uniting the Kruger National Park in South Africa with a park in Mozambique and a park in Zimbabwe is regarded as a conservation success story [57]. In addition, such corridors promote the movement of elephants and other species between countries, give them access to resources, and minimize the chances of genetic isolation. Moving the species across the borders – these corridors are an important tool for adaptation to climate change.

In addition to, or as an alternative to, protected areas and corridors, the role of local communities in conservation also gained importance. More recently, conservation projects have directly engaged with local communities to encourage sustainable land use and mitigate human-wildlife conflict. Community conservation schemes from Botswana, for instance, have been effective at integrating communities into the management of wildlife and in the process, they have contributed to the conservation of elephants and other wildlife [58, 59]. Many of these programs have as component, eco-tourism that has the added benefit of providing an income while sensitizing communities of the importance of biodiversity.

These are very important conservation programs, but they also have their issues. Funding is one of the most difficult challenges. Funding for conservation initiatives tends to be external and often not sustainable over the long-term. As a result, there is an urgent need for conservation approaches that are more adaptive and integrative. While wildlife corridors and other similar ventures have yielded encouraging results, many conservation and protection areas are still isolated, and habitat destruction continues to outrun conservation efforts. Plus, most African countries inability to cope with the consequences of climate change due to lack of policies and funds undermines this response.

The absence of coordinated international efforts also compromises the implementation of conservation activities. Despite a number of treaties such as the Convention of the Biological Diversity (CBD), as pointed out in [60], due to an emphasis on the protection of biodiversity, these agreements are not always implemented. Indeed, combating climate change will necessitate cooperation at the national and international levels to safeguard African mammals and other wildlife from survival.

Conservation attempts in Africa – through protected areas, wildlife corridors, and community-based conservation have been somewhat effective, but will need to adapt and bolster these methods to contend with and mitigate the emerging threats of climate change. Adequate finances, better international collaboration, and new conservation technologies are needs to ensure that Africa's mammalian biodiversity withstand the impacts of climate change.

4. Conclusion

The impacts of climate change on African mammals are broad, supporting the idea that it poses a major and increasing threat to biodiversity at the ecosystem, species distribution, behavioral, and survival levels. These factors increase challenges for African mammals through key pathways of exposure such as increased temperatures, changes in precipitation patterns, increased occurrence of extreme weather events, and changes in ecosystems. Increasing temperatures, along with irregularity of rainfall patterns, are making traditional ranges untenable for many species, especially those that exist in niche environments such as savannas, forests, and mountains. The intermittent availability of food, water, and breeding sites only compounds these pressures on the species already negatively impacted by habitat destruction, poaching, and human-wildlife conflict.

The need to combat climate change is both urgent and crucial in Africa as well, where ecosystems are being more susceptible to climate induced responses. It is also the continent of some of the most important and diverse mammal species for the ecological stability of the world. But, in the absence of immediate and wide-ranging climate change mitigation, many of these species will likely see population collapse or local extinction. Thus, the necessity to focus conservation attention has never been higher; the cost of inaction will only increase with time.

Recommendations

- Conservation and Adaptation Strategies

The establishment and growth of protected areas remain vital to protect these important habitats from human encroachment and climate change. Nonetheless, as habitats are becoming increasingly fragmented, wildlife corridors to allow for dispersion of species between protected areas need to be established. These corridors would enable mammals to migrate with climate change and would preserve genetic diversity as well as access to resources such as food, water, etc. Also, adaptation measures must also be designed for those sensitive species, such as translocation to more favorable habitats or facilitating ecosystem resilience through habitat restoration interventions.

- Policy Recommendations

Policies should be consolidated nationally and internationally to face climate change. Nations' biodiversity strategies should include climate change mitigation and adaptation as a key element to develop, anticipating climatic impacts in the establishment and management of protected areas. At a global level, more collaboration through agreements like the Convention on Biological Diversity should be fostered, with climate change being recognized as a core threat to biodiversity. Funding for conservation and climate change adaptation projects in African countries should be ramped up to increase the attainability of conservation objectives.

- Research and Monitoring

Ongoing research and monitoring programs are vital to follow the progressive effects of climate change on African ecosystems and mammalian species. More detailed work assessing species' behavior, movement patterns, breeding success, and health in the context of climate change is needed to learn about and gain insights into species- specific responses to climate change. Also, tracking the impacts of climate change on the availability of habitats, water, and food is important to readapt conservation efforts as new information is available. Funding needs to support long-term research as well as monitoring systems that provide real time information on climate impacts that can allow for adaptive management in real time.

Overall, climate change is a significant and pressing threat to African mammalian biodiversity. But, through sound conservation and adaptation practices and policies, bolstered frameworks, and greater investment in research and monitoring, the impacts of climate change can be reduced and the continent's rich mammalian diversity preserved.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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