

# Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review

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## ABSTRACT

**Introduction:** Biodiversity and biodiversity-based ecosystems services are intrinsically dependent on the climate. During the twentieth century, climate change has posed major threats to biodiversity in Africa, and impacts are expected to increase as climate change continues and perhaps even accelerates.

**Outcomes:** Our review shows that the multiple components of climate change are projected to affect all levels of biodiversity, from genes over species to biome level. Loss of biodiversity as a result of climate change can alter the structures and functions of African ecological systems. As a result, the provision of biodiversity-based ecosystem services and the well-being of people that rely on these services are being modified. Of particular concerns are “tipping points” where the exceedance of ecosystem thresholds will possibly lead to irreversible shifts of the structure of ecosystems and their services. In recent years, climate prediction models have portended continued warming and more frequent extreme weather events across the region. Such weather-related disturbances such as El Niño will place a premium on biodiversity and biodiversity-based ecosystem services that people rely on.

**Conclusion:** As biodiversity underlies all goods and services provided by ecosystems that are crucial for human survival and well-being, this paper synthesizes and discusses observed and anticipated impacts of climate change on biodiversity and biodiversity-based ecosystem service provision and livelihoods, and what strategies might be employed to decrease current and future risks on the well-being of human in Africa.

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## Review

### Background

Climate change is a major global threat that has already had an observed impact on biodiversity and natural ecosystems. Over the last century, the global average temperatures have risen by 0.7°C and are predicted to continue rising. The Intergovernmental Panel on Climate Change (IPCC) predicts that temperatures are expected to rise by 1.1–6.4°C by the end of the twenty-first century relative to the 1980–1999 baseline (IPCC 2013). Global average precipitations have increased by 2% in the last 100 years and are likely to increase in future (IPCC 2013). Africa is a highly vulnerable continent in the world to climate change. Overall, the continent has warmed 0.7°C over the twentieth century and warming across Africa is expected to continue with an increase ranging from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario) (Hulme et al. 2001; IPCC 2001). Precipitation patterns in Africa are also more variable; however, historical records indicate that there has been an increase in rainfall over the last century in east and central Africa (Hulme et al. 2001; Intergovernmental Panel on Climate Change (IPCC

2001). In addition to the changes in climate and weather, climate change in Africa is also linked to changes in the frequency and intensity of extreme events such as episodes of El Niño–Southern Oscillation (ENSO), that is, El Niño and La Niña (Korcha and Sorteberg 2013; Midgley and Bond 2015). As climate change is expected to increase over the next century, it is expected to become one of the major drivers for the loss of African biodiversity (Sala et al. 2000; Bellard et al. 2012; Midgley and Bond 2015). Thus, it is important to understand the link between biodiversity, ecosystem services, and climate change.

Africa is immensely rich in biodiversity and contains an estimate of one-fifth of all known species of mammals, birds, and plants, as well as one-sixth of herpers (Siegfried 1989). The continent's species compose the world's most diverse and biologically important ecosystems such as savannahs, tropical forests, coral reef, marine and freshwater habitats, wetlands, and montane ecosystems. These regionally important ecosystems provide benefits that many African communities obtain, collectively known as ecosystem services (MA 2005). The African ecosystem supplies multiple ecosystem services required to meet human needs and sustain livelihoods including

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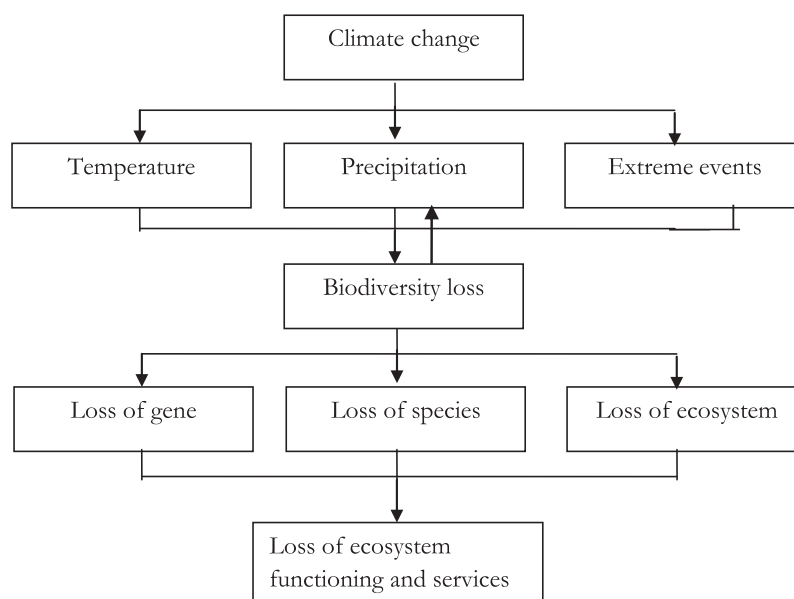
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provisioning (e.g., feed, fuel-wood, food, timber), regulating (e.g., disease and climate regulation), supporting (e.g., soil formation, nutrient retention), and cultural (e.g., recreation, ecotourism) services (Millennium Ecosystem Assessment (MA) 2005, Wangai, Burkhard, and Muller 2016). However, these biodiversity, ecosystem, and ecosystem services are threatened due to climate change.

Climate change is both a cause and an effect of biodiversity and ecosystem change in Africa (Thomas et al. 2004). Along with anthropogenic stressors, the multiple components of climate change are anticipated to be the main drivers of biodiversity at all levels (Parmesan 2006). Loss of biodiversity due to climate change have directly or indirectly changed the pattern and dynamics of energy flow and material circulation (Zhong and Wang 2017), which greatly impacts the African ecosystem and ecosystem service. For instance, the capacity of ecosystems to provide climate regulation service depends on the diversity of species they currently support (Bellard et al. 2012). Climate change is also a consequence of the way in which biological resources are converted into useful goods and services, and especially of the way in which grasslands and forests are converted into croplands (Lambin and Meyfroidt 2011). The production of biological resources for foods, fuels and fibers, and the conversion of forests and grasslands for agriculture both directly affect emissions of several greenhouse gases (GHGs) (Hector and Bagchi 2007, 2007; Burnham and Ma 2015). Changes in stocks of biomass can also influence the amount of carbon sequestered (Hector and Bagchi 2007). It follows that options for the mitigation of climate change include the management of both GHG emissions from productive processes and carbon sequestration, while

options for adaptation to climate change include the management of biodiversity for ecosystem resilience (Eric, Lambina, and Patrick 2011; Banin et al. 2014; Araos, Berrang-Ford, and Ford et al. 2016). As African climate continues to change, there seems a consequence for biodiversity loss. These resulting effects bring changes on the range and distribution pattern of ecosystem and ecosystem services upon which human populations depend (Figure 1). However, there is limited understanding of the impact of climate change on multiple component of African biodiversity, and their functional or interactive role in ecosystem integrity and stability, how the system will respond to biodiversity loss induced by climate change, and ultimately affect the societal benefits they support. Thus, this comprehensive synthesis considers the connection between climate, biodiversity, and biodiversity-based ecosystem services in Africa. Here, I used information gleaned from different studies and databases to show the status and identify biodiversity and biodiversity-based ecosystem services that have been and will continue to be affected by climate change and their impending impact on human well-being in Africa. The impact of climate change on the well-being of human is described in terms the change in ecosystem services caused by climate-induced change in biodiversity. In this review, the categories of ecosystem services are those applied in the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment (MA) 2005).

This paper is a technical review of the impact of the multiple components of climate change on biodiversity and associated ecosystem service provision and value. This review is an input into the national



**Figure 1.** Link between climate change and its impacts on biodiversity and ecosystem services, and the impact of biodiversity loss on climate change.

development policies and poverty reduction strategies of the African government to take the country in to the status of “middle income” by 2025 in the Second Growth and Transformation Plan (GTP II), which aims to promote more sustainable farming practices and enhanced conservation of indigenous biodiversity resources as well as livelihood development from natural resources. Moreover, the review will contribute to the building of climate-resilient Green Economy, which focuses on adaptation to climate change and mitigation of GHGs emissions, reducing GHG emissions through enhancing productivity of the crop and livestock subsectors that improve food security and income of farmers and pastoralists, protecting and rehabilitating forests for their economic and ecosystem services. The aim of this paper is not only to provide an encyclopedic treatment of the documented and expected impacts of climate change on biodiversity and biodiversity-based ecosystem service provision in Africa but also to extract highlights regarding selected ecosystem services. In particular, this review focuses on services that are (1) key to a broad swath of African society and to the nation’s economy; (2) if altered, could significantly affect the well-being peoples in Africa; and (3) not sufficiently addressed in the literature so far, so that, conclusions about their sensitivity to climate change can be drawn. I conclude the review with a discussion on how the Government of African and other stakeholders can prioritize ecosystem services based climate change adaptations, allocate resources and time, and highlight many of the perspectives in which Africans have experienced and expect to experience and notice climate change. Given the high values of these vulnerable biodiversity and biodiversity-based ecosystem services, it is needed to examine regarding the interlinkages between biodiversity conservation and ecosystem services. Therefore, I also highlight some potential policies and strategies useful for conservation and enhancement of biodiversity-based ecosystem service flows under the changing climate.

### Biodiversity loss

Globally, biodiversity is being lost and increasingly threatened through a range of anthropogenic actions (Jetz, Wilcove, and Dobson 2007; Bellard et al. 2012; Fardila et al. 2017; Barlow et al. 2018). The Convention of Biological Diversity (CBD) defines “biodiversity loss” as “the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional and national levels” (CBD COP VII/30). Fossil records showed that it took on average one million years before an individual vertebrate species became extinct (Lawton and May 1995). Hence, no more than one

out of one million species should go extinct. However, the current observed extinction rate is 2.6 vertebrate species per 10,000 per year (Pimm and Raven 2006; Whiteside and Ward 2011).

The most important notable drivers behind the current loss of biodiversity are habitat modification, overexploitation, climate change, invasive alien species, and chains of extinction, known collectively as the evil five biodiversity threats (Brook, Sodhi, and Bradshaw 2008; Guo, Desmet, and Powrie 2017; Sonwa et al. 2017). As mentioned in the IPCC (2013) report, global warming and precipitation is expected to increase, the changing climate is predicted to be one of the worst drivers for the loss of all level of biodiversity over the next 50–100 years, and further exaggerated the effects of earlier threats on biodiversity loss. However, only few studies have directly quantified climate-induced biodiversity extinctions. Even if it is difficult to disentangle the impacts of climate change from other anthropogenic stressors for a range of species, consequently, predictions may provide insights into the multiple components of climate change and their relative distribution threats to global biodiversity (IUCN 2014; Trull, Böhm, and Carr 2018). Predictions of climate-induced extinction rates are uncertain and expert opinions differ on the extent of loss due to the great deal of uncertainty regarding the number of species that exist on earth (He and Hubbell 2011; Mora et al. 2011). For instance, Monzón et al. (2011) found that 19 species have been extinct due to climate change. The International Union for Conservation of Nature Red List of Threatened Species predicted that 4161 species are being threatened by climate change, 33% are at the risk from climate change-induced habitat shifts and alteration, 29% are due to temperature extremes, and 28% are due to drought (IUCN 2016).

The current velocity and magnitude of climate change trends will likely exceed the abilities of a number of species to survive and adapt to new environmental conditions thus leading to increased extinction rates (Keith et al. 2008; Loarie et al. 2009; Bellard et al. 2012). From an ecological point of view, climate velocity described as the speed and direction in which a species would need to move to sustain its current climate conditions under climate change (Brito-Morales et al. 2018). This is specifically true in Africa because the current threat from habitat destruction, land use change or fragmentation, and rapid population growth interacts with climate change in a nonlinear way so that the negative impacts are higher than expected (Midgley et al. 2002; Sonwa et al. 2017; Barlow et al. 2018). This change will lead to a growing demand for natural resources, resulting in land use change and unsustainable use of species. In addition, these changes place great pressure on biodiversity and ecosystem

service provision. Biodiversity is vital for human well-being. However, its irreversible loss that entails the loss of ecosystem services and its multifunctions is one of the most important environmental threats that humanity faces in the country. Therefore, it is necessary to examine the interlinkages between climate change, biodiversity, and biodiversity-based ecosystem services as well as the threats posed to these components by climate change.

## Biodiversity and climate change: effects and responses

### *Effects of climate change on biodiversity*

Africa boasts remarkable biodiversity, including the many endemic and endangered mammals and plants. However, species abundance and diversity is in decline and the threats to species diversity are increasing. Climate change is one of the major threats to biodiversity and ecosystem services in the region (Lepetz et al. 2009; Guo, Desmet, and Powrie 2017; Sonwa et al. 2017; Matata and Adan 2018). The United Nations Framework Convention on Climate Change and the CBD recognize that climate change is one of the greatest threats to biodiversity. Recent studies also have shown the impacts of climate change on biodiversity in Africa. For instance, Midgley et al. (2002) studying the potential impact of climate change on plant diversity in the Cape Floristic Region in South Africa have shown that 11% of the species studied are at risk of extinction, and a reduction in the modeled range sizes of 42% of the species, with the projected climate-change scenario. A study published in *Nature* (Thomas et al. 2004) reveals that climate change could result in the extinction of more than a million terrestrial species in the next 50 years. Rare species, fragmented ecosystems, and areas already under pressure from pollution and deforestation are the most vulnerable. Fire is a major cause of biodiversity loss in Africa. As global warming increases, these fires are likely to get more intense and extensive and may result in significant ecosystem changes that would affect biodiversity through species loss or changes in species composition (Bellard et al. 2012; Foden et al. 2013; Akcakaya et al. 2014; Bland et al. 2015; Pacifici et al. 2015). Similarly, the broad conclusions of the review outputs showed that direct and indirect effects of climate change have posed potential major threats to biodiversity in Africa.

Direct effects include those arising from increased temperature and increased CO<sub>2</sub> levels associated with global climate change (Adler, Leiker, and Levine 2009; Andrew et al. 2010; Dawson et al. 2011). These direct effects result in several potentially major indirect effects, such as changes in hydrologic

cycles (evaporation and precipitation) and an increasing magnitude and extent of extreme weather events and frequent fires that destroy the ecosystem. These changes can affect biodiversity in many ways, including altering life cycles, by shifting habitat ranges and species distribution, changes in abundance, changes in migration patterns, and changes in the frequency and severity of pest and disease outbreaks.

One of the other important pathways by which climate change affects African biodiversity is by reducing the amount and availability of suitable habitats and by eliminating species that are vital for the species in question (Lovett, Midgely, and Barnard 2005; Hély et al. 2006; Doak and Morris 2010; Dawson et al. 2011). A loss of species from an ecosystem not only affects the species that is lost but also the interactions with other species as well as the general ecological functions, which are expected from these interactions. Despite growing awareness that biodiversity is one of the most vulnerable to climate change, Africa is one of the least studied region in terms of biodiversity dynamics and climate variability (Getahun and Shefine 2015; Sonwa et al. 2017; Matata and Adan 2018). Therefore, understanding how climate change affects African biodiversity is important, both for examining status or trends, responses, and identifying biodiversity that are sensitive to climate change system and to provide valuable insights to avoid or mitigate climate-induced effects.

### *Response of biodiversity to climate change*

#### *Shifts in species distribution*

The broad conclusion of literature results shows that many species have shifted their geographic ranges in response to rapid changes in temperature and precipitation regimes, generally poleward, toward higher elevations (Nye et al. 2010; Burrows, Schoeman, and Buckley et al. 2011; Chen et al. 2011; Doney, Ruckelshaus, and Duffy et al. 2012). Groffman et al. (2014) found that in terrestrial environments, plants and animals moved toward higher elevations at the rate of 0.011 km per decade and to higher latitudes at the rate of 16.9 km per decade. Climate change has resulted in dramatic shifts in the geographical distributions of east African species and ecosystems. The current rates of migration of species will have to be much higher than rates during postglacial periods in order for species to adapt to the changing climate (Malcolm et al. 2002; Hély et al. 2006; Doak and Morris 2010). Climate change is significantly altering Africa's species diversity. For example, the endemic Ethiopian wolf (*Canis simensis*) is struggling to adapt to the longer dry periods and shrinking availability of water and other resources. Ecological specialists are particularly vulnerable and react strongly to changing resources due to their relatively narrow dietary,



thermal, and habitat niche breadths (Altermatt 2010; Lawton et al. 2010; Montoya and Raffaelli 2010; Clavel, Julliard, and Devictor 2011) and association with relatively stable environments (Walther et al. 2002). In Ethiopia, the unique environments that support endangered and endemic species are more vulnerable to the impacts of climate change. For instance, studies showed that the reduction in the range of the rare and Africa's most endangered Ethiopian wolf (*C. simensis*) is likely to have an increased risk in local extinction as a result of climate change. Gottelli and Sillero-Zubiri (1992) recorded that *C. simensis* were distributed in Gojjam and northwestern Showa at 2500 m above sea level in the early twentieth century. Today, the distribution of the species shifts toward higher elevations and is known to occur above 3000 m above sea level, which extends up to 3700 m above sea level and is largely restricted to the highest peaks (Gottelli and Sillero-Zubiri 1992). Strategies for future designations of protected areas and conservation of ecological specialist species in Ethiopia need to be developed that include projections of future climate change and corresponding changes in the geographic range of plant and animal species to ensure adequate protection.

In fact, climate change has the potential to alter migratory routes (and timings) of species that use both seasonal wetlands (e.g., migratory birds) and track seasonal changes in vegetation (e.g., herbivores), which may also increase conflicts with humans, particularly in areas where rainfall is low (Thirgood et al. 2004). In Africa, wild animals that are unable to move or migrate are at risk. Solomon, Aklilu, and Eyualet (2014) found that land-use patterns in Ethiopia can also prevent animals from changing their migratory routes, for example, expansion of large-scale agriculture has been demonstrated to disrupt migratory journeys, leading to a population decline in large mammals.

### Demographic responses

Loss of natural habitats and shifting habitat ranges to more suitable ones as a result of climate change could have profound impacts on species population size (Erasmus et al. 2002; Walther 2010). *C. simensis* have already shifted its geographical range toward higher elevations in response to rapid changes in temperature and precipitation regimes. These shifts might likely bring about new assemblages of species (Williams and Jackson 2007), cause novel interspecific interactions, and in worst case, scenarios result in some extinction (Channel and Lomolino 2000; Butchart, Walpole, and Collen et al. 2010; Barnosky et al. 2011). Therefore, the shift in the distribution of *C. simensis* is a likely indicator of a rapid decline in its population size. Additionally, this relationship could be exacerbated if climate change restricts the range of a species to just a

few key sites and an extreme weather event occurs, thus driving up population decline and extinction of the species in the future. Species ranges will probably not shift in cohesive and intact units and are likely to become more fragmented as they shift in response to changing climate (Walther 2010; Barnosky et al. 2011). To be able to better conserve biodiversity in the future, it is imperative to understand how species and ecosystems are likely to change under varying climate change scenarios.

### Phenological shifts

Changes in phenology or the seasonal timing of life events have been observed in Africa in response to variations in temperature, precipitation, and photoperiod (Workie and Debella 2017). Phenological events include changes in leaf growth, flowering and blooming in plants, and shifts in the timing of spawning, reproduction, and migrations in animals (Doak and Morris 2010; Miller-Rushing et al. 2010; Dawson et al. 2011). Weather extremes can also affect biodiversity in more complex ways. For example, in African elephants (*Loxodonta africana*), breeding is year-round, but dominant males mate in the wet season and subordinate males breed in the dry season. Subsequently, a change in the intensity or duration of the rainy versus drought seasons could change relative breeding rates and, hence, genetic structures in these populations (Marcel, Visser, and Christiaan 2005). As food crop production is the main agricultural activity in Africa, lengthened growing seasons would also mean increments in costs of production of crops.

From a conservation point of view, the critical feature of multiple components of climate change is that it differentially affects the probability that species will be driven to population decline and extinction. It has been suggested that the risk of population decline and extinction is likely to increase for many species that are already vulnerable (Thomas et al. 2004), in part because of the time it takes for many species to adjust to climate change (Menendez et al. 2006). While the impact of climate change on extinction probabilities remains contentious, it is the effect that motivates the conservation community most strongly (Willis and Bhagwat 2009). Outside the conservation community, there is greater concern for the potential adverse impacts of climate change on biodiversity that most directly affects biodiversity based ecosystem service. Of particular concern are “tipping points” where ecosystem thresholds can lead to loss or irreversible shifts of ecosystems, their services and functioning to human society, and ending up in a global crisis.

### Climate change, biodiversity, and ecosystem services

Biodiversity is fundamental to ecosystem structure and function and underpins the broad spectrum of

goods and services that humans derive from natural ecosystems (Chapin et al. 2000; Walther et al. 2002; Millennium Ecosystem Assessment (MA) 2005; Naeem et al. 2009; Leadley et al. 2010; Mace, Gittleman, and Purvis 2003). At least 40% of the world's economy, and 80% of the economy of less-industrialized nations, is derived directly from biological resources as a function of ecosystem service (Travis 2003). Declines or loss of any aspect of biodiversity to the point that they no longer contribute to ecosystem servicing can have dramatic impacts on the importance of ecosystem services upon which people depend. The decline or loss might move toward its particular "tipping point," lead to loss or irreversible shifts of ecosystems, their services, and functioning to human society, ending up in a global crisis. However, there is limited understanding of the functional or interactive role biodiversity plays in a system. It is, therefore, vital to gain a better understanding of the linkages between biodiversity and ecosystem services, and how climate change threats to biodiversity will affect human well-being (Mace, Gittleman, and Purvis 2003).

Millennium Ecosystem Assessment has defined four types of ecosystem services (provisioning, regulating, cultural, and supporting) (Millennium Ecosystem Assessment (MA) 2005; Mace, Gittleman, and Purvis 2003). The Millennium Assessment's evaluation of biodiversity through the services it offers (Millennium Ecosystem Assessment (MA) 2005) is the approach that economists have traditionally taken to the problem (Perrings, Folke, and Mäler 1992). In this approach, biodiversity change is evaluated in terms of its implications for (a) as supporting (e.g., nutrient cycling, primary production), (b) regulating (e.g., climate and disease regulation), (c) cultural (e.g., spiritual values, recreation), and (d) provisioning (e.g., food, fuel, fiber, and fresh water) services (Millennium Ecosystem Assessment (MA) 2005). The approach recognizes that change in biodiversity is a source of both benefits and costs. At the global level, the MEA documented that over 60% of ecosystem services were deteriorating or already overused (Larigauderie and Cesario et al. 2009), and it has been worsened by the impact of increasing climate change. As biodiversity underlies all goods and services provided by ecosystems that are crucial for human survival and well-being, this paper presents the potential effects of climate change on biodiversity and associated ecosystem services and function on human society as classified by the Millennium Ecosystem Assessment:

- (1) Provisioning services (production of foods, i.e., crop and livestock production)
- (2) Regulating services particularly on disease and climate regulation

### **Agricultural production and food security**

The agriculture sector in Africa has a large impact on fostering economic growth, reducing poverty, and improving food and nutrition security. It also accounts for about 20–30% of gross domestic product (GDP), 55% of the total value of export, and 80% of total employment (FAO 2014; Palma et al. 2014). Agriculture is dominated by smallholders who contribute up to 90% of agricultural production in the region (Brown, Nuberg, and Llewellyn 2018). Africa depends heavily on rain-fed agriculture making rural livelihoods and food security highly vulnerable to climate variability such as shifts in growing season conditions (Intergovernmental Panel on Climate Change (IPCC) 2001, Corbeels et al. 2014). There is a strong link between climate, natural ecosystem, and African agriculture. Biodiversity and ecosystem services are at the heart of many solutions for sustainable increases in agricultural productivity in Africa that not only deliver better outcomes for food and nutrition security but also reduce climate externalities (Barrios et al. 2018; Bommarco, Vico, and Hallin 2018). Besides agricultural products, many peoples in Africa depend on food product from natural ecosystems. Moreover, these ecosystems are essential in provisioning important agricultural services like irrigation water, improving soil nutrients, and erosion control (Bommarco, Vico, and Hallin 2018; Georg, Requier, and Fijen 2018). Areas which sustain higher level of biodiversity generally are much more resilient to environmental change and increase agricultural production (Winfrey and Kremen 2009). On the other hand, the degradation of natural ecosystem reduces their capacity to store and regulate water availability, soil formation, and energy and nutrient flow (Bommarco, Vico, and Hallin 2018; Georg, Requier, and Fijen 2018). Consequently, this will also affect agricultural productivity, and this effect is enhanced if as a result of climate change.

In Africa, temperature has increased and precipitation in the region has varied in most areas; many countries are already being affected. For example, from 1996 to 2003, there has been a decline in rainfall by as much as 50–150 mm per season (March–May) and corresponding decline in long-cycle crops (e.g., slowly maturing varieties of sorghum and maize) across most of Africa (Funk et al. 2005). Long-cycle crops depend upon rain during this typically wet season and progressive moisture deficit results in low crop yields in the fall, thereby impacting the available food supply. Nelson et al. (2009) predicted that the net effects of climate change on agriculture in many developing countries would be negative (Nelson et al. 2009). Most African countries are the most at risk countries from climate change impacts (Evangelista et al. 2013). Gebreegziabher et al. (2011) also reported that low adaptive capacity, geographical location, and topography

make the region highly vulnerable to crop failure due to adverse impacts of climate change (Gebreegziabher et al. 2011). It is estimated that climate-induced drought reduced Africa's agricultural production by 21%, which led to a 9.7% fall in the GDP (World Bank 2006).

Crop yields show a strong correlation with climate change and with the duration of heat or cold waves and differ based on plant maturity stages during extreme weather events (Hoffmann 2013). Modified precipitation patterns will enhance water scarcity and associated drought stress for crops and alter irrigation water supplies. They also reduce the predictability for farmers' planning (OECD 2014). In an indirect way, a change in temperature and moisture levels may lead to a change in the absorption rate of fertilizers and other minerals, which determine yield output. In short, the rise in temperature along with reduction in rainfall reduces agricultural productivity if both are beyond the threshold that is suitable for crop production (Tirado and Cotter 2010). According to Ignaciuk and Mason-D'Croz (2014), climate change currently decreases the yield of maize, rice, wheat, potatoes, and vegetables and continues to reduce seriously in the future. Bezabih, DiFalco, and Mekonnen (2014) also pointed out that climate variability and change in Africa has a significant impact on different crop yield. Particularly, Bayrau, Assefa, and Hagos (2015) showed that change in climate will likely have an overall significant impact in reducing the productivity of sugarcane and cotton in Ethiopia. Increased variability (i.e., deviation from the mean) of crop production is also a major concern of farmers in Ethiopia. Interannual climate variability (e.g., ENSO) has huge impacts on Ethiopia's climate. Warm ENSO events also referred to as El Niño events produce abnormally high amounts of precipitation in parts of Africa and can result in flooding and decreased agricultural yields. The authors argue that in developing countries, climate change will induce yield declines for the most important crops. Similarly, in Africa, researchers correlated past El Niño and La Niña episodes and found that overall major cereal crop yields were decreased by 16% and 5.3% in Upper Awash Basin during El Niño and La Niña episodes, respectively (Abdisa, Dirba, and Muktar 2017, Sintayehu et al. 2017). Further south, in Zimbabwe, researchers correlated past El Niño events and warm sea surface temperatures in the eastern equatorial Pacific with more than 60% of the change between above and below average agricultural production of maize (Patt, Suarez and Gwata 2005).

Africa is home to Africa's largest livestock population and is the world's 10th largest producer of livestock and livestock products (MacDonald and Simon 2011), which make up about 10% of the country's foreign currency earnings (Pantuliano and Wekesa 2008). Frequent and extensive droughts in the country have a

considerable effect on Ethiopia's livestock because decreased rainfall shrinks available water resources and reduces the productivity of grassland and rangeland. The main causes of livestock deaths in Africa are shortages of water and food during drought (MacDonald and Simon 2011). Increased temperatures can affect the behavior and metabolism (internal body processes) of livestock, such as a reduced intake of food and a decline in productivity (Thornton et al. 2009). These impacts on livestock are already being felt in Ethiopia; in the past two decades in Borana zone, southern Ethiopia, there have been losses of livestock associated with drought. The number of animals per household declined on average "to three oxen from ten; to seven cows from 35; and to six goats, down from 33" (MacDonald and Simon 2011). According to the Afar National Regional State (ANRS) 2010 report, all pastoral regions in Ethiopia are highly prone to the adverse impacts of climate change, while the problem is more prevalent in the North Eastern lowlands of the country mainly Afar region. Afar pastoral communities mostly depend on rainfall during the main rainy season for availability of pasture and water resources. Hence, the decline in rainfall has resulted in severe livestock reduction. For instance, in La-Niño years 2008, cattle mortality increased by 12.4%, sheep 26.2%, and goats by 6.5% in Shinile pastoral communities (Ahmed et al. 2017, Sintayehu et al. 2017). Therefore, any substantial climate-change-induced disruption in African crop and livestock production would likely increase food prices and insecurity and worsen the standards of living. There are many opportunities for ecosystem-service-based adaptation in African agriculture, determining which strategies are feasible and most cost-effective is an important next step for researchers, economists, and policy makers.

### **Disease regulation**

The impacts of climate-induced biodiversity change on human, animal, and plant health are of concern because of the potentially high cost associated with both emerging zoonotic diseases and changes in the distribution of existing disease vectors. Many pathogens are maintained by multiple host species in natural systems (Woolhouse and Gowtage-Sequeria 2005), where the loss of a host species or biodiversity as a result of climate change in an area can influence disease risk and is expected to exacerbate the occurrence and intensity of future disease outbreaks and perhaps increase the spread of diseases in Africa. For instance, bovine tuberculosis (bTB) infection rate was positively associated with mammalian species evenness ( $J'$ ) loss. Loss of noncompetent or spillover mammalian species as a result of climate change might increase cattle herd movement and increase encounter rates among cattle. Such an "encounter



increase” (Keesing, Holt, and Ostfeld 2006) might lead to increased probabilities of bTB infection risks. Loss of other host species in the community that are less competent reservoirs for bTB, that is, transmitting the pathogen ineffectively, might increase the contact between bTB wildlife reservoir hosts and cattle. Such an “encounter increase” (Keesing, Holt, and Ostfeld 2006) might lead to increase probabilities of bTB infection risk.

Invasive species have been shown to be highly adaptive to variable climatic conditions (Malcolm et al. 2002). Due to its climate-sensitive distribution of native flora and fauna, Africa may be particularly vulnerable to exotic and invasive species (i.e., *Prosopis juliflora*, *Lantana camara*) colonization. Land-use changes as a result of plant species invasions and associated changes in the composition of the host community have been described as one of the causal drivers in current emergence and re-emergence of infectious diseases. In semi-arid African Savana, bTB prevalence was positively associated with the invasion of *P. juliflora* (Sintayehu et al. 2018). Invasive species have the ability to change ecosystem processes (Ehrenfeld 2010) and decrease the abundance, structure, and diversity of native species (Blackburn et al. 2004; Gaertner et al. 2009). Similarly, invasion of *Prosopis* has been shown to suppress the growth of grasses and other herbaceous species and reduce species diversity (Getachew, Demissew, and Woldemariam 2012; El-Keblawy and Al-Rawai 2007; Haregeweyn et al. 2013). The influence of *Prosopis* on the palatable herbaceous species in highly invaded areas may contribute to the reduction in mammal species evenness, as abundance and distribution of mammal species is partly determined by the availability and quality of palatable plant species (Treydte et al. 2013; Young et al. 2013). Haregeweyn et al. (2013) also reported negative impacts of *Prosopis* invasion on biodiversity in Ethiopia, as the invasion of *Prosopis* reduced the densities of wild animal species, such as oryx (*Oryx gazelle*), zebra (*Equus grevyi*), dik-dik (*Madoqua saltiana*), and kob (*Kobus ellipsiprymnus*) in response to a reduction of palatable plant species (Haregeweyn et al. 2013).

Another way by which *Prosopis* may influence the prevalence of bTB is through livestock herd movement. Invasion of *Prosopis* species have been observed to suppress grass growth and reduce availability of herbaceous plant species (Brown and Archer 1989). The invasion by *Prosopis* reduces availability of palatable herbaceous species in Ethiopia (Mehari 2015). Several useful palatable plant species such as *Chrysopogon plumulosus*, *Cymbopogon schoenanthus*, *Cymbopogon pospischilii*, *Andropogon canaliculatus*, *Eragrostis cylindriflore*, and *Terapogon cenchriformis* are now on the verge of local extinction

in areas due to *Prosopis* invasion (Haregeweyn et al. 2013, Mehari 2015), which could increase the movement of cattle herd in search for pasture. This study also showed that high proportion of *Prosopis* cover increased the movement of livestock herd. The herd moved more and grazed in larger areas, hence the probability of contact with either infected domestic or infected wildlife hosts increased, amplifying the chances for bTB infection (Sintayehu et al. 2016). For the loss of biological diversity (i.e., native flora and fauna) and the homogenization of host communities due to invasion of invasive species in the changing climate, Africa may be particularly have the potential to increase the prevalence of and risk of exposure to zoonotic diseases.

It is known that climate variability and extreme weather events, such as high temperatures and intense rainfall events, are critical factors in initiating malaria epidemics, especially in the highlands of western Kenya, Uganda, Ethiopia, Tanzania, Rwanda, and Madagascar (Zhou et al. 2004). While other factors, such as topography and health preparedness, can influence the spread of malaria, scientists have found a correlation between rainfall and unusually high maximum temperatures and the number of malaria cases (Githeko and Ndegwa 2001; Zhou et al. 2004). This is due to the fact that the survival of mosquito vectors (*Anopheles* spp.) and the mosquito parasite that causes malaria (*Plasmodium falciparum*) are also effected by climate. Temperature affects the development rates of vectors and parasites while rainfall affects the availability of mosquito breeding sites (Zhou et al. 2004; Craig et al. 2004). Rift Valley Fever epidemics are also correlated to climate variability. Between 1950 and 1998, three quarters of the Rift Valley Fever outbreaks occurred during warm ENSO event periods (i.e., El Niño events). During El Niño, the East African highlands typically receive unusually high rainfall which is correlated with Rift Valley Fever outbreaks (Patz et al. 2005).

### Carbon sequestration

One of the key supporting services provided by forests is carbon removal from the atmosphere (carbon sequestration) and the long-term storage of this carbon in biomass, dead organic matter, and soil carbon pools. Of the global forest carbon stocks, an estimated 55% (471 Pg C) is stored in tropical forests, of which more than half is stored in biomass (Pan et al. 2011). The role of forests in sequestering carbon is evident when considering that 57% of the carbon emitted annually from global fossil fuel use and land-use change is absorbed by land and ocean sinks, cutting in half the rate of increase in atmospheric CO<sub>2</sub> concentrations over the past four decades (Le Quééré et al.



2009). Species can affect the long-term balance of carbon gains and losses in ecosystems through different components of the carbon cycle, including the magnitude, turnover, and longevity of carbon stocks in soils and vegetation (Díaz, Hector, and Wardle 2009; Murphy et al. 2008; Barantal et al. 2011; Maestre et al. 2012). Experiments with tree plantations of native and introduced species have often found significant and positive effects of species richness on different components of the carbon cycle, including productivity (Piotto 2008, Healy, Gotelli, and Potvin 2008), decomposition (Scherer-Lorenzen, Luis Bonilla, and Potvin 2007), soil respiration (Murphy et al. 2008), and plant mortality (Healy, Gotelli, and Potvin 2008). Similarly in Africa, there has been strong evidence that better managed biodiversity sequesters more carbon (Abebe et al. 2013). The current ecosystem conservation in Africa relies on afforestation and reforestation of the natural area, which increases the annual productivity. Increase in annual productivity directly indicates an increase in forest biomass and hence higher carbon sequestration potential. Studies have shown that, under similar conditions, tree plantations with two or more species may achieve higher levels of productivity than single-species plantations for a range of species combinations (Forrester et al. 2006, Kelty 2006; Piotto 2008). In Africa, a positive relationship between tree species richness and above-ground productivity has often been found (Sintayehu et al. 2018b). Moreover, Sintayehu et al. (2018) that in individual species may dominate processes; thus, functional groups are often particularly important in controlling specific processes (Sintayehu et al. 2018). Loss of biodiversity, linked to deforestation and forest degradation, could further diminish the ability of forests to effectively provide multiple ecosystem services, including carbon sequestration. Therefore, greater clarification of the importance of individual species effects and the role of functional groups for carbon storage is an important area for further research.

## Conclusion

African biodiversity currently faces insurmountable problems than in the past due to climate change. There are two major reasons for this: (1) Species habitats are smaller than in the past. Smaller habitats support smaller populations which constitute less genetic diversity and have less evolutionary potential. This evolutionary potential is critical for species' ability to adapt to the changing environmental conditions. (2) Species habitats are more fragmented than in the past. The fragmentation prevents individuals from being able to shift their distribution in response to climate-related impacts as easily as in the past. These are the two fates available to species

other than going extinct: adapt to climate change or migrate in response to climate change in order to track environmental conditions favorable for survival. The current rate of climate change is probably unprecedented and would present extreme challenges to the biota of the planet under normal circumstances. However, the combination of the magnitude of change, the extreme fragmentation of habitats, and the fact that there are 180 million people using a very large proportion of Africa's resources means that neither evolution nor migration will be sufficient to allow many species to cope with current rates of global climate change. Thus, the species might be lost, and their value to humans and their beauty will decrease.

Scenarios related to the impact of climate change on biodiversity are made up continuously, often predicting fast paced extinction of species, loss of natural habitats, and shifts in the distribution and abundance of species during the first decade of this twenty-first century. Pressures on biodiversity can shove ecosystems beyond what might be termed "safe functioning space." Once an ecosystem enters the peril zone, it is in danger of crossing a threshold which will tip it into an alternative state. Actions to increase the resilience of ecosystems, that is, by conserving biodiversity, are critical to prevent the "tipping point" being surpassed. Recent "tipping points" analyses indicate that rising atmospheric CO<sub>2</sub> concentrations could lead to major biodiversity transformations (Bellard et al. 2012). Especially in tropical regions, levels near or below the 2°C global warming, are defined as "dangerous" by the IPCC. The change eventually becomes self-perpetuating through what is known as a "positive feedback," for example, deforestation may reduce regional rainfall, leading to greater fire risk, further drying, and dieback of forest. As a result of lags in the socioeconomic, biological, and physical systems, these transformations will be irreversible over the next several centuries, creating great difficulties in ecological management. The broad conclusions of the review output showed that climate change have created potential threats to the loss of African biodiversity which basically fundamental for providing ecosystem services to which human well-being. These effects give upsurge to numerous potentially serious negative impacts on key ecosystem services, such as crop and livestock production, and disease and climate regulation as well as reduce human benefits.

In this context, "Climate Change" may be a familiar term by now, but further attention and action is urgently needed. Even a modest and slow warming of the climate will have complex consequences in terms of species numbers and distributions, thus potentially disrupting ecosystem services. This will be exponentially severe in highly diverse

ecosystems like tropical forests comprising highly specialized organisms. This causality is particularly relevant for developing countries where often the majority of local livelihoods depend on goods and services provided by ecosystems like tropical forests. Drivers of biodiversity loss have not yet been addressed significantly. Furthermore, there is paucity of research dealing with the interaction between different drivers of global change. So far, most studies only focus on particular ones (mostly either climate change or habitat loss) and the mentioned interactions are largely neglected in assessments under global change scenarios. Hence, it is necessary to consider those interactions among different drivers of environmental change in the future.

Biodiversity issues suffer from insufficient integration into broader policies, and stringent strategies and programs at international, national, and local levels are mostly far from being functional. Future initiatives must start to overcome the lack of connections between the relevant sectors. They must be able to adapt in an appropriate way toward increasing knowledge, raising public awareness and responsibility and thus toward changing conditions. The recent establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, which fittingly complements the existent structures like IPCC, is a step in the right direction for tackling the threat of climate change on biodiversity. The platform could be used to push out the frontiers of knowledge and performance in the area of biodiversity conservation and climate change for sustainable development and improved livelihoods of society.

In order to reduce losses in biodiversity, associated key biodiversity-based ecosystem services, and to produce a high quality of life in a way that does not damage the environment, the government of Africa and other stakeholders following urgent and important actions are needed to head in to mitigate climate change:

- Need to a move away from static targets of nature-based conservation to nature-human conservation approach
- Ensuring integrated climate change adaptation activities and developing policies across many sectors whilst avoiding conflicting targets
- Ensuring that any climate-induced biodiversity loss impacts are understood in terms of biodiversity-based ecosystem services losses in order to integrate into National Poverty Reduction and other National Strategies

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## Author contributions

SWD initiated the work, and writing and revising the manuscript.

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