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REVIEW

Climate Change and Biodiversity in West Africa Sahel: A Review

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ARTICLE INFO

Article history
Received: 15 August 2022
Received in revised form: 10 September 2022
Accepted: 19 September 2022
Published: 29 September 2022

Keywords:
Climate change
Biodiversity education
Ecosystems
Biodiversity finance
West Africa Sahel

ABSTRACT

Climate change has many effects on biodiversity. Few studies have focused on the consequences of climate change on biodiversity in West Africa Sahel which is one of the most sensitive regions to climate change. Thus, this study examined the different effects of climate change on biodiversity in West Africa Sahel to guide climate policies. The authors used Google Scholar, Mendeley, ResearchGate, Science-direct, and selected websites of institutions in West Africa and the Sahel for the literature review, with selected keywords in French and English via Boolean operators from 2000 to 2022. The results identified many manifestations of climate change such as drought, lightning, floods, high winds, heavy rains, diseases, extreme heat, and conflicts that affect living things in terrestrial and aquatic ecosystems in these regions. For example, 15,000 animals died in Niger and 26,000 in Mali due to flood-related events. In Burkina, 41 people died, 112 injured, and 12,378 households were left homeless in 13 regions. In Senegal, water stress in the basin is increasingly close to 5,800 m^3 per person per year. Demographic pressure and planned irrigation projects along Niger and Senegal Rivers have resulted in a significant 25%-60% decline in flows over the past 30 years, causing increasingly severe low flows, frequent interruptions in water flows, drying up of reservoirs and reduced water supply to cities. Rainwater harvesting, afforestation, soil fertility regeneration practices and crop diversification are some biodiversity restoration activities limiting climate change effects in the Sahelian countries of West Africa. These practices have contributed to strengthening the resilience of ecosystems in most of communities. However, priority should be given to policies that raise communities' awareness on the importance of biodiversity conservation and take sustainable and innovative measures to deal with the consequences of floods, droughts, and heat waves, which are the most severe.

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DOI: https://doi.org/10.30564/re.v4i3.4961

1. Introduction

Climate change is currently one of the most critical global issues threatening the development and economies of Southern Hemisphere, especially African countries. Generally, climate change refers to any change in climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to the natural variability of climate observed over comparable time periods [1]. Biodiversity represents the variety of all living organisms on earth, including their genetic diversity, species diversity, and the diversity of marine, terrestrial, and aquatic ecosystems, as well as the evolutionary and ecological processes associated with them. Because of it, human life is possible on earth [2]. Biodiversity conservation provides substantial benefits to meet immediate human needs, such as clean, consistent water flows, protection from floods and storms, and a stable climate. The loss of biodiversity is dangerous and its consequences are immediate: decrease in rainfall, low soil productivity, lack of forest or wildlife, a decrease in aquatic resources, etc. [3]. About 40% of the world's economy and 80% of the livelihoods of the poor are based on biological resources. Nature and its component species also remain the primary source of daily livelihood for millions of people. This is especially true for struggling communities in developing countries, which often turn to high-biodiversity ecosystems as a source of food, fuel, medicines, and other products made from natural materials for their use and as sources of income [4]. Human-induced climate change is currently one of the most challenging pressures on biodiversity in the 21st century. The rate of present-day warming could be fast enough to push ecosystems towards thresholds beyond which they destabilize and further changes become difficult to predict [5]. According to the Intergovernmental Panel on Climate Change, climate change in sub-Saharan Africa will result in a reduction in rainfall, and a rise in temperature and sea level. They would affect natural and socio-economic ecosystems. Impacts are expected on agriculture, industry, forestry, water resources, and coastal. The Sahel is one of the regions of the world most vulnerable to the above-mentioned effects, due to poverty and the high dependence of populations on natural resources, the fragility of ecosystems, the precariousness of infrastructures, and limited scientific and technological capacities [6].

The Sahelian climate is characterized by a long dry season (seven to nine months) followed by a rainy season that begins in June and ends in September. This last season is linked to the process of transferring oceanic moisture toward the continent (the West African monsoon) [7]. Different researchers or scientists have predicted the effects of climate change on biodiversity predicting more negative effects of climate change on biodiversity than positive. The purpose of this study is to document the consequences of climate change on biodiversity in West Africa Sahel. Specifically, this involved identifying general climate change impacts on biodiversity in West Africa Sahel, presenting and discussing the major climate change consequences on aquatic and terrestrial ecosystems, agricultural yields, livestock, forests, and protected areas, and assessing key solutions to these major climate change impacts in West African Sahel.

2. Materials and Methods

2.1 Study Area

The West African Sahel is a semi-arid region located in the South of the Sahara Desert. This strip covers about 5000 km and is composed mostly of grasses, shrubs and small thorny trees. The West African Sahel includes Mauritania, Senegal, Mali, Niger, and the northern parts of Burkina Faso and Nigeria [8] (Figure 1).

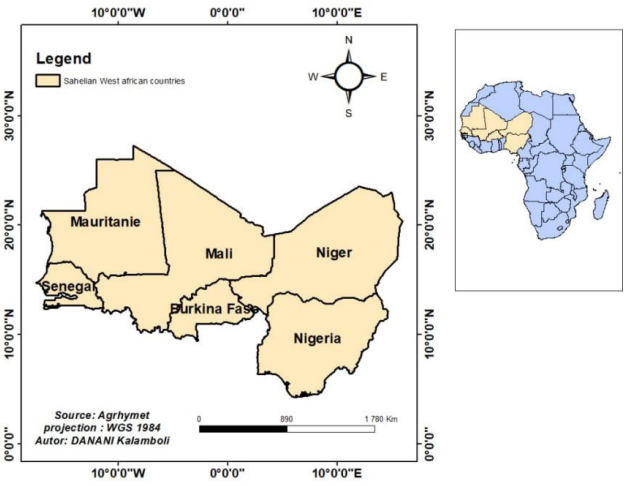

Figure 1. Sahelian countries of West Africa

2.2 Data Collection Methods and Analysis

This study used only secondary data. Journal articles published on Google Scholar, ScienceDirect, and ResearchGate, reports, books, and authorized web pages were critically reviewed. We had prepared syntheses after reviewing these articles to document the effects of climate change on biodiversity in Sahelian countries of West Africa. The first step was to identify key concepts of the topic to help us in our literature, including biodiversity, climate change, ecosystems, drought, floods, conflicts, climate-related diseases, heat waves, plants, crops, livestock,

land, soil fertility, mangroves, water resources, forests and protected areas, and climate change adaptation and mitigation. To get more recent data, our research on climate change and biodiversity was filtered over the period 2000 to 2022. Indeed, it is in the 21st century that environmentalists became more concerned about climate change and have focused their research on its impact on biodiversity degradation. This was also a period of international biodiversity engagement and critical manifestations of climate change in West Africa [9]. It is also the period where climatic phenomena have most affected the Sahel [10]. The Millennium Agenda, the Paris Agreement, and the United Nations Agenda were introduced within this timeline. The First United Nations Decade on Ecosystem Restoration was also implemented within the same period (2011-2020) to achieve healthy ecosystems that play a key role in achieving the Sustainable Development Goals by 2030 [11]. Some of the keywords were first used in French and then translated into English, in order to obtain a maximum of documents on the subject. Reading the abstract and conclusion ensured that each document provided new information.

3. Results and Discussion

In both Europe and Africa, climate change is already affecting biodiversity, ecosystems, and the services provided by nature to human populations. This is manifested in various ways, including shifts in species ranges, changes in the phenology of organisms, with earlier flowering and maturation in many plants, and altered migration and breeding periods in some animals, which can create a temporal shift between the life cycle of species and the peak abundance of their food resources [12]. Climate change is becoming a major threat to biological diversity [13]. Arid, semi-arid, and dry sub-humid lands, as well as African savannas, are particularly vulnerable. Due to disruptions in rainfall patterns and rising temperatures, thousands of plant and animal species are threatened. By 2080, 20% of coastal wetlands will be lost due to sea-level rise, and the risk of species extinction will concern 20% to 30% of species [6]. Many species will be unable to adapt quickly enough to the new conditions or find new habitats in areas where they can survive. Climate change, coupled with changes in land use and the spread of exotic or non-native species, will likely restrict the ability of some species to migrate and accelerate species loss [14]. Climate change is threatening several components of biodiversity in various ranges and if sustainable measures are not taken soon the risk of enhancing species, animals, and ecosystems extinction will be high.

3.1 Effects of Climate Change on Food Systems

In Africa, about 60% of the population resides in rural areas and depends directly or indirectly on agriculture and renewable natural resources (including forest products and services) for their livelihoods, resilience, income, employment, food, feed, energy, and well-being, yet it is the food and agriculture sector that is already most affected by climate change. Globally, it is estimated that between 2006 and 2016. Agriculture (crops, livestock, fisheries, aquaculture, and forestry) absorbed more than 26 percent of all damage and losses caused by extreme climate events and up to 80% of drought [15].

The Sahel is one of the most livestock-intensive regions in Africa. Numerous environmental constraints (lack of water, grazing, low productivity of rangelands, fires, etc.) linked to climatic phenomena threaten the productivity of the sector and the traditional migration routes of the herds. Indeed, the Sahelian populations live from the breeding of large and small ruminants, which contribute a lot to meet households needs (meat, milk production, prestige, customary, dowry, salary, trade, education, etc.). This sector contributes 10%-15% of GDP in Burkina Faso, Mali, and Niger, and an even larger share in Mauritania, where 50% of the population is pastoral. High temperatures reduce feed intake, lead to energy deficits, and reduce livestock productivity (fertility, body condition, and longevity), and milk production while drought can reduce calving rates from 60% to 70% to 25% to 30%. Warmer temperatures are vectors of loss of traditional pasture and water sources, altering the migration patterns of pastoralists. Erratic rainfall increases droughts and floods which reduce feed and milk production, meat quality and animal fertility, increase mortality and morbidity and consequently reduce livestock productivity. Another issue that araises from this is an increased competition and conflicts for water and land resources [16]. Droughts and floods, droughts and floods have had major impacts on all agricultural populations from Mauritania to Chad. These phenomena have also deteriorated the natural resources vital to the survival of agro-pastoralists who, through their activities, support the economy in much of the region. Under the combined effect of these disasters, agricultural land has lost its fertility, reducing forage capacity and the availability of water sources for grazing and cultivation [17]. According to projections by the Intergovernmental Panel on Climate Change [6], if current trends continue, harvests could drop by 50% by 2020 and 90% by 2100 in some regions, especially on small farms.

Climate change is also increasingly impacting biodiversity through significant losses in the Niger Delta region

of Nigeria. Ferns are part of the biodiversity often affected by floods. The stay of the plants in water kills the vegetation. Additionally, it kills wild species that are further used as bush meat or moved to other areas. Declining plant biodiversity poses a serious threat to indigenous people who use plants (medicine, timber). Impacts on water resources from soil erosion, sedimentation, silting and flooding also lead to biodiversity loss. Long-term soil erosion leads to loss of natural vegetation, reduced soil fertility, loss of arable land, and indirectly affects water and sediment quality [18]. In Niger, where the Sahara Desert covers much of the territory, rising temperatures and extreme rainfall are increasing pressure on water resources and crops, and are increasingly leading to loss of farmland and reduced grazing. This increases the food insecure population each year [19]. In Mauritania, the effects of climate change have already begun to be felt. The temperature rises, droughts, and increased heavy rainfall are accentuating the continuing trend of degradation of agricultural forests and pastoral ecosystems. This has negative consequences on the food security of rural populations and increases the potential for conflict between different groups exploiting natural resources [20]. As the overall West African Sahel is experiencing severe droughts, short rains or floods and heatwaves which are having drastic consequences on the agricultural calendars, plant growing, and food security, sustainable measures should be taken. For example, sustainable intensification of agricultural production can limit the area used for agriculture and limit the rate of deforestation, leaving more area available for biodiversity conservation [21]. Other agricultural practices, such as integrated pest management, regeneration of soil fertility, and protection of the habitat surrounding fields, can promote synergies between agriculture and biodiversity and reduce impacts [22].

3.2 Effects of Climate Change on Ecosystems

Climate change and biodiversity loss are the two major ecological crisis of this century and a considerable threat to the functioning of ecosystems. Biodiversity loss is a particularly serious threat to the functioning of ecosystems, which depend on the presence of multiple species to sustain themselves. Most of Africa's terrestrial ecosystems have already suffered significant biodiversity loss over the past 30 years, with negative impacts on ecosystem services, and this trend is expected to continue. Indeed, due to increasing population pressure, the main factors affecting biodiversity in Africa, including climatic phenomena, deforestation, agriculture, poaching, illegal fishing, and timber exploitation industries, are constantly intensifying. Rising temperatures, decreasing rainfall, longer dry seasons and the resulting increase in fire risk are likely to become major drivers of ecosystem change. Direct impacts include physiological stress, mortality, range change, and changes in ecosystem composition and functionality [23].

3.2.1 Effects of Climate Events on West Africa Sahel Forests, Savannah, Protected Areas, and Mangroves

Drought episodes are becoming more frequent, making the area more fragile, with an increase in bush fires in the Sahel. In general, high temperatures significantly degrade soils and reduce the density of trees and shrubs. Severe and prolonged droughts increase the loss of ecosystem services and biodiversity. Increased frequency of extreme events lowers water levels, impacts aquatic wildlife and species, and reduces tourism potential [24]. Over the past ten years in West Africa, several extreme weather events have caused significant damage to infrastructure, populations, and biodiversity (Figures 2, 3 and 4). In Mali, bushfires, linked to a sharp increase in temperature and lack of water, are a threat to protected areas and the species present. For example, in the *Boucle du Baoulé* protected area, the vegetation has changed, and consequently the availability of food for herbivores. Thus, species such as the buffalo, hartebeest, or *cob defassa*, have become very vulnerable [25]. Concerning marine biodiversity, the rise in sea level leads to salt water intrusion in freshwater rivers. The resulting flooding of estuaries and mangroves disrupts the breeding grounds of fish, which are then forced to migrate to other freshwater bodies [26]. If nothing is done, this will manifest itself in a change in the composition of ecosystems, the disappearance of certain species, or the change in migration periods [6]. During the 20th century, West Africa lost 83.3% of its forests and this trend is continuing but slowing, with the annual deforestation rate falling from 1.1% between 1990 and 2000 to 0.35% from 2000 to 2010. The rate of endemism in forest vertebrates is approximately 20%. Within protected areas, 91% of amphibians, 50% of mammals, and 39% of birds are projected to be in areas with less favorable climates by 2100 [27]. Among the 437 amphibian species of West and Central Africa, 16 are endangered, 46 threatened, 32 vulnerable, 29 considered near-threatened, and the remaining 216 species in a state of concern. As for mammals, for a total of 663 species in the past, 14% are threatened with extinction and 69% in an alarming state [28].

20-30% of Africa's mangrove has been lost over the past 25 years. Nigeria was having the largest mangroves in Africa located in the Niger Delta, where they cover 0.8 million hectares and play a vital role in supporting the rich wildlife of the region [29]. Between 1980 and 2006, mangroves in West Africa declined by about 25% [24]. Similarly,

from 1975 to 2013, West African forest cover decreased by 37%. Animal species like cheetah, lion, giraffe, hyena, elephants, etc. that formerly enrich the forests are now disappearing due to illegal hunting, poaching and ivory trade. Outside of protected areas, they are difficult to find [16]. All these are due to several factors, in particular, urbanization, urban infrastructure development, quarrying, salt and sand exploitation, pollution caused by industries, industrial agrochemicals, oil, and gas exploitation, lack of appropriate legislation, and climate variability. In the western Atlantic coastline, mangroves extend from Mauritania to Senegal in the Saloum delta, South Casamance over Guinea Bissau and South Guinea. In the Gulf of Guinea, they extend from the coast of Liberia to that of Angola. Tidal waves, floods, and natural disasters in coastal areas in recent years are evidence of increased vulnerability mainly due to human pressure. Furthermore, climate change threatens to further degrade land, vegetation and water resources by increasing the incidence of droughts, desertification and floods, as well as by the predicted shortening of the rainy season. In Senegal, the mangroves of the Saloum Delta have lost most of their property: low density, decrease of diversity in some places, decrease of the air of distribution of the species, decrease of the fauna due to overexploitation, hydro-agricultural activities, drought and coastal erosion [24].

On another hand, it should also be noticed that apart from depreciating forests, protected areas and mangroves, drought and flood-related events are having severe consequences on human life, livestock and infrastructures. It has been demonstrated by Tarchiani *et al.* [30] that over the past decade, severe flooding has occurred in the regions of Ouagadougou and Bobo-Dioulasso in Burkina Faso (2009, 2020), Niamey in Niger (2010, 2012, 2017, 2019 and 2020) and Mopti and Bamako in Mali (in 2019). Specially in Niger, from 1998 to 2020, about 3,115,290 people and 7,100 localities were affected by floods with more than 225,000 houses destroyed; 205,000 hectares of crops and 46,540 Tropical Livestock Units lost; the most significant damages occurred between 2010-2020 [30]. The 2020 rainy season per example, was particularly intense compared to previous years and caused severe flooding in Niger. More than 78,600 households were affected throughout the country, 69 people lost their lives, nearly 26,500 houses collapsed, and at least 28,000 hectares of agricultural land were lost, as well as the loss of nearly 15,000 heads of livestock. In addition to production losses, there was significant damage to infrastructure and equipment in rice and market garden areas, including buried wells, motor pumps and destroyed irrigation networks. Approximately 4,000 hectares of hydro-agricultural facilities were damaged, putting future production at risk. Many granaries were also destroyed by the rains and flooding [31]. The same year, 49 cases of flooding were registered in Mali, with about 46,952 people affected, compared to 41,008 in the previous year and nine deaths compared to 24 in 2019 [32]. In Burkina Faso, 41 people died, 112 injured and 12,378 left homeless in the 13 regions affected [33]. Changes in temperature, rainfall, and the occurrence of floods, droughts and lightning all have also negative effects on forage production, plant species, water availability, animal health and livestock productivity (Figures 5, 6 and 7) [16].

Figure 2: Drought in the Sahel, Mediaterre (2020)

Figure 3. Bamako area under water after an episode of torrential rains during which more than 20 people lost their lives/AFP/Archives/Habibou Kouyate.

Figure 4. Bamako floods: Thousands were also made homeless as the Niger river burst its banks, destroying around a hundred houses, Denise Hammick, 2013.

Figure 5. A cattle carcass in northern Niger in May 2010. Drought-related famine episodes are recurrent in the country/ISSOUF SANOGO/AFP

As climate change is having considerable impacts on the local climate, increasing desertification, land degradation, and disrupting the endemism and adaptive capacities of species, ecosystems supported by human activities, are also having an important role in climate disruption. Deforestation, reduction of fallow land, population growth and urbanization combine to reduce the water absorption capacity of the soil. If no measures are taken to maintain the global warming below 2 °C, one animal species out of six is likely to disappear. The acceleration of extinction risks calls for the fastest possible action to respond to the urgency of climate action [34]. Although some governments in the region have adopted various policies for the conservation of biological diversity, the conservation of mangroves is not yet sufficiently addressed. Thus, maintaining the balance between the needs of coastal populations and the ecological potential of the remaining mangroves should generate renewed interest, both ecological and economic, at the national and international levels, to conserve Africa's mangroves through concerted efforts [29]. Though it is obvious that flood-related impacts are mainly due to climate variability we must also consider the fact that in West African Sahel Countries, we don't have proper urbanization plans. And that is also contributing a lot to increasing vulnerability. Policies must work to ensure that all cities have building codes and are enforced to reduce the loss of human and animal life. There is also a need to continue capacity building to improve people's resilience to drought and to educate people to diversify their agricultural practices and sources of income to address food security.

a b c

Figure 6. Baobabs and mango trees dried out by the 2020 floods in Niamey.

a b

Figure 7. Dromedaries killed by lightning in the urban commune of Maïné-Soroa in Niger in July 2021.

Source: Hamat Bachir, 2021.

3.2.2 Effects of Climate Events on West Africa Sahel Water Resources

In Sahelian countries of West Africa, the stresses facing aquatic ecosystems are mainly the reduction of water quantity and quality due to several changes in rainfall patterns, increased disaster risks, exposure to drought, flooding, strong winds, and heat waves. Indeed, fishing is the lifeblood of a large part of the Sahel's population. Apart from being a mean of subsistence for the populations, it is the main source of income for most of the riparians [16]. Over time, coastal erosion, due to the advance of the sea has become a threat to this activity. Not only has it become almost impossible to fish, the fisheries are no longer as fruitful as before, but also the surrounding dwellings are increasingly destroyed by the rising waters. All this can be explained as much by climatic variability as by the fishing activity itself, which very often destroys the aquatic fauna as a result of overexploitation of the waters and species. On the other hand, chemicals from mining, agricultural and hotel industries have also contributed to the reduction of many fish species. This situation contributes significantly to exacerbating the food crisis in the territory and to the increase in market prices. FAO [35] projected that by 2070-2099, 60% of West African freshwater fishes will become vulnerable to climate change and up to more than 80% in some areas such as eastern Mali. Among the 311 species identified as susceptible to this hazard by the end of the century, 62 are already threatened. Climate change could also cause fishing catches to drop by 21%, with a potential loss of half of the jobs generated by this activity, costing the local economy US$ 311 million per year by 2050 [35]. Another well-known consequence of climate variability is the drastic droughts and locust invasions of the 1970s, which have wreaked havoc in the Sahel, notably a significant reduction in the flow of the region's largest rivers and basins. The Senegal River basin, one of the largest rivers in West Africa, which originates in Fouta Djallon in Guinea, was not spared. Indeed, the Senegal River extends from the western Sahel to Mali, Mauritania and Senegal, with a basin of about 218,000 km^2 [36]. A modeling done by the same authors to measure the impact of climate change on the water resources of the Upper Senegal River Basin has shown that if current trends continue as they are, the waters of the river will be depleted to the risk of the river drying up by the end of the 21st century. Changes in river flow have been observed in and around the Senegal River basin. The water stress in the basin is about 5800 m^3 person-1 year [37]. In Mali, the effects of climate change are being felt. Lake Faguibine, located 80 km from Tombouctou, has been drying up for years. Around this lake, vast stretches of water and cultivable land have been replaced by sand dunes. For the neighboring villages, the consequences are dramatic: the withdrawal of water has caused the cessation of fishing, the fall of pastoral activities, and the exodus of the inhabitants [38]. The Niger basin covers an area of 1.5 million km^2 shared by nine countries. In recent decades, global warming and unsustainable forest management have led to a reduction in water flow (40%-60% per year), overflowing of water due to increased pressure on land, siltation, increased erosion and a reduction in the moment during which tributaries flow into the river [39]. In general, in Sahelian West Africa, streamflow is expected to decrease by 34% depending on the time horizon and location [37].

3.3 Climate-related Diseases in West Africa Sahel

The Sahel is among the countries with the worst human health indices in the world. Climatic phenomena have worsened the situation by inducing new waves of diseases that affect both humans, animals and crops. When it comes to human life, children under five are the most vulnerable and affected by the spread of water-borne diseases caused by flood and elderly people are more sensitive to heat waves. Burkina Faso, Mali, Mauritania, Niger, and Chad have the highest under-five mortality rates, with most deaths due to pneumonia, diarrhea, and malaria. Malnutrition and lack of access to health care amplify the impact of these diseases and increase vulnerability to climate change impacts [16]. It should also be noted that with climate change, children are spending more time outdoors due to the heat, which exposes them to high temperatures and potentially to rodents, mosquitoes and ticks. They also need more water than adults, which makes them at higher risk of contact with waterborne pathogens. In addition, diarrheal diseases in children lead to dehydration much faster than in adults. Because children are smaller and have developed an immune system with little innate immunity or resistance, they are more likely to develop serious infections and complications during their recovery [40]. Rising temperatures and rainfall variability increase food and water insecurity, particularly during the dry season. Declining water availability concentrates users on limited water sources, facilitating contamination and transmission of endemic waterborne diseases such as cholera, diarrhea, and typhoid fever. West Africa has the highest malaria infection and mortality rates in the world, and this burden will continue in many parts of the region [16].

After agriculture, animal farming is the second most important activity that feeds the rural populations of the West African Sahel. Climate change affect livestock production and consequently food security through the spread

of diseases and low water availability, especially in dry regions like Sahel. The unpredictability of season reduces livestock productivity. In addition, the nutritional content of livestock products, which are one of the suppliers of global calories, proteins and essential micronutrients also subsequently depreciate [41]. According to Black P. et Nunn M. [42], Climate change is associated to the aggressiveness of many animal diseases such as viral zoonosis, equine diseases, hemorrhagic animal diseases, tick-borne diseases and anthrax. As a result, animal movements, trade, and changing climatic conditions led to 101 human cases of Rift Valley fever (RVF) including 28 deaths between 2nd August and 9th October, 2016, in Cintavaraden and Abalak (Tahoua region, Niger). Another RVF outbreak affecting cattle and small ruminants in Tansala was revealed on 19th September, 2016 [43].

Climate change negatively affects pastoral livestock systems through the drying up of water points, the reduction of available fodder, the decrease in milk and meat production, the increase in animal mortality, the reduction in the length and intensity of heat, fertility, and embryo survival [44]. Conversely, livestock production also influences climate change. Livestock is responsible for about 14.5% of global warming with cattle triggering almost 10% of that [15]. Feed production and manure contribute to CO_2, nitrous oxide (N_2O), and methane (CH_4) emissions, which are keys contributor to greenhouse emission. Land use change, feed production, animal production, manure, processing and transport also drive global warming. Animal production increases CH_4 emissions. Processing and transport of animal products and land use change contributes to the increase of CO_2 emissions [41]. To contribute to reducing the trends, it would be wise enough to combining crop production with livestock farming, which would make it possible to use animal waste as natural fertilizer and reduce the use of chemical fertilizers that impoverish the soil. Animal waste can also be used to produce bioenergy so that the methane will no more be release to the atmosphere.

3.4 Climate-related Conflicts in West Africa Sahel

In the Sahel, conflicts usually revolve around natural resources. With climatic phenomena, these resources are becoming increasingly scarce. Populations are forced to share plots of land and insignificant resources. This contributes to increased pressure on resources and exacerbates tensions at the group, camp and community levels and disturbs the distribution of resources [45]. By disturbing the distribution of natural resources, Climate change causes conflicts among people. Since it is no longer raining enough and there are not enough resources, everyone is moving to areas where resources are more favorable, which creates tensions and pressure on resources. Increasingly, there are conflicts between herders and farmers. In fact, Farmer-herder conflicts are the most frequent climate-related conflicts in West Africa Sahel. These conflicts are either due to water scarcity or diminution of land use. As the herders seek water for their livestock, they encroach on the farmers' crops, resulting in conflicts. However, conflicts between farmers and herders started since the drought of 1970 in West Africa Sahel and resulted several times in a loss of life and livestock. On the other hand, forests and green areas are often occupied by terrorists, which limits access to the population. Instead of these areas serving as a resource for people to cope with food insecurity due to drought, they are increasingly becoming nests of insecurity. Many women are often attacked in the forests in search of fruit or firewood to feed their families. At the same time, we also have religious conflicts, especially jihadism, which is not due to climate change but also contributes biodiversity loss because the forests have become today the refuge of jihadists for whom forests have become military bases and feed on them without respite ansd controversy. Knowing that forests are supposed to be the nurturing fountain of the surrounding communities, in weak conditions, this function is no longer effective. Communities no longer take advantage of it and do not contribute to its regeneration. Burkina-Faso, Mali, and Niger are the most vulnerable areas affected by this phenomenon. According to the World Economic Forum [46], Sahelian countries have had unprecedented attacks in 2018. For many years now, Mali and Burkina Faso have been the sinks of this violence and the most affected, with huge losses of life and livestock. Marginalized pastoralists and youth are increasingly becoming the core soldiers in these conflicts. Due to their diminished livelihoods and social exclusion as a result of the food crisis, they are the most vulnerable to recruitment by bad faith individuals and have become easy targets. Indeed, all G5 Sahel countries recorded more than four times as many deaths in 2018 as in 2012, with 62% of all reported violent deaths concentrated in Mali. At least 5 million people were displaced across borders or inland in Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal, and about 24 million people were food insecure. Another eight million people received emergency assistance in the middle belt provinces of Nigeria and in the Lake Chad basin. Situations of precarious droughts, low rainfall, river and dam flooding, and livestock and crop losses have been ongoing since 2018 with different trends from one country to another. Faced with this crisis situation, the Permanent Inter-State Committee for Drought Control in the Sahel predicts "per-

sistent food insecurity" for the foreseeable future. Climate change is not only a factor that aggravates conflicts, but also a considerable cause of conflicts in the Sahel by causing food crises in most African Sahelian countries due to lack or irregularity of rainfall and prolonged drought [45]. The West African Sahel is not only vulnerable because of changes in climate trends or variability, but also because of economic, financial and political instability [47].

Between 2009 and 2016, approximately 30,000 people were killed in Boko Haram-related clashes and 2.4 million people were displaced in the Lake Chad basin region [48]. On August 9, 2020, six French humanitarians from the NGO Acted, their driver and their Nigerien guides, were killed by jihadists during a visit to the Kouré giraffe reserve located 60 km southeast of Niamey. Due to this unfortunate event, the reserve was closed by the government of Niger and the site placed in a "red zone" by the French partners. This led to the disruption of financial support for the reserve by this NGO, as well as support from other NGOs involved in community development projects [49]. Initially (1996) there were 50 giraffes in the reserve, but in 2019 the number was estimated at 664. In February 2022, the W-Arly-Pendjari Complex (Benin, Burkina Faso and Niger) experienced two deadly attacks on guard teams patrolling the W National Park in Benin [50].These situations contributed to making investors reluctant to the biodiversity finance mobilization initiative and reducing the interest of tourists.

Other factors exacerbating pastoralist-farmer conflicts and armed conflicts include disregard of policies and demographic pressure that affects resource availability. Intra-community consultation mechanisms must be strengthened to ensure the survival of the populations and to reinforce the production of livestock feed, the creation of pastoral facilities, as well as climate-smart practices for farmers to enable them to make better use of their lands. Programs helping to build and strengthen people's resilience to overcome the crisis through the implementation of more sustainable and productive production systems in all seasons must also keep been taught in practical ways. There is also a need to incorporate biodiversity finance in communal, regional, and national budgets in the private and public sectors. Biodiversity education focusing on climate change need to be integrated into the curricula. Furthermore, the existing biodiversity law in West Africa Sahel needs to be revised in order to capture the different manifestations of climate change driven by lawless human activities. Added to that there is a need to conduct further studies on the effects of climate change on biodiversity in order to produce more biodiversity data as part of the biodiversity loss solutions.

3.5 Some Solutions for Sustainable Biodiversity Management in the West Africa Sahel

Tree planting, the creation of multipurpose village gardens, the use of trees in agriculture (forestry or agroforestry), the strengthening of the protection of natural reserves, land rehabilitation (soil and water conservation techniques), and agroecological practices [51] such as stabilization of sand dunes, creation of terraces on slopes, trees and shrubs as windbreaks, Zai, stones diguettes and the Great Green Wall initiative are some of the practices that have made it possible to regenerate the majority of species damaged by drought in the Sahelian countries of West Africa (Figures 8, 9 and 10). In addition, the populations themselves are developing local initiatives such as crops diversification, rainwater storage, mulching, branch deposits to wedge waterways, traditional dykes, diversification of sources of income, integration of livestock farming, the development of small-scale trade with agriculture as well as market gardening and beekeeping. All these practices have contributed to reducing the number of food insecure people and the level of environmental degradation. Thank to these practices, in southern Niger, almost six million hectares of land have been restored and provided more than 600,000 additional tons of food per year in 2009 [52]. In Burkina, about three million more people got food secured in 2018, six million hectares of land regreened and 200 additional trees planted [51].

Especially in Niger, multiple cropping systems, land restoration pratices, agroforestery and plantation of some trees of socio-economic and dietary importance as *Andropogon gayanus, Euphorbia balsamifera, Leptadenia hastata and Leptadenia pyrotechnica* are the common sustainable biodiversity management practices [53]. These techniques aim at improving water retention capacities and soil fertility. Crop diversification, as well as agroforestry practices, are also used. The use of organic garbage manure is a coping strategy widely used by farmers in northern Nigeria. This technique has proven to be very efficient in regenerating soil productivity and improving agricultural production. The "Rhumbu Storage System" (Figure 11) is another effective technology used by rural people to protect themselves from post-harvest losses due to pest infestation and drought. These are local granaries made from readily available resources such as pieces of wood, straw and vegetable twine [54]. In most countries, some plant species are also used as an effective means of piling and storing stalks of sorghum, maize, millet and woody plants. The same practices are used in Burkina, Mali, Senegal and Mauritania depending on yearly context.

Figure 8. Half-moon after a rain in a field in Burkina

Source: Livelihoods, 2017.

Figure 9. A woman practicing the Zaï technique

Source: CGIAR.

Figure 10. Plantation of native acacia trees along Adger-Doutchi Plateau in Niger

Source: Gray Tappan/USGS.

a b c

Figure 11. The Rhumbu Granary in Northern Nigeria

Source: Musa and Umar [54]

4. Conclusions

The effects of climate events on Sahelian ecosystems are more evident today than has ever been. The most affected sectors are agriculture due to land degradation, reduced crop productivity, livestock and water resources. The impacts on these sectors negatively affect the population since more than 80% of the population lives in rural areas [55]. Climate change and biodiversity are correlated. This interconnection can be seen in two ways. A rapid change in climate directly affects the species and ecosystem, thereby affecting biodiversity. On the other hand, deteriorations in biodiversity may result in further changes in climate. West Africa Sahel is experiencing unprecedented effects of climate change. Severe droughts, floods, heat waves, storm sands are some of the direct phenomena that affect terrestrial and aquatic ecosystems. They result in stress on natural resources, loss of animals, aquatic species, plants and exacerbate food insecurity, spread of diseases, and conflicts among people due to the scarcity of resources and land use. Climate change also includes changes in the distribution and endemism of species, and reproduction patterns of animals. Afforestation, farmer regenerated natural resources, ecosystems adaptive biodiversity management, water harvesting, crops diversification, multipurpose village gardens, intra-community conflicts resolutions, etc. are some of the solutions used by communities to cope with the situation and build resilience. Proactive management of biodiversity is a sustainable strategy to reduce the worsening effects of climate change in West Africa Sahel.

Conflict of Interest

There is no conflict of interest.

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