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Review

Anthropogenic Pressures on Gorillas: A Case of Grauer's Gorillas in Maiko National Park, the Democratic Republic of Congo

Kahindo Tulizo Consolee [1], Xiaofeng Luan [1] and Li Cong [2,*]

[1] School of Ecology and Nature Conservation, Beijing Forestry University, Beijing 100083, China; tulizok@yahoo.com (K.T.C.); luanxiaofeng@bjfu.edu.cn (X.L.)
[2] School of Landscape and Architecture, Beijing Forestry University, Beijing 100083, China
* Correspondence: lisacong@bjfu.edu.cn

Abstract: Anthropogenic activities put biodiversity under pressure, adversely affecting the forest ecosystem and wildlife habitats. Habitat disturbance and modification are among the main threats to animal populations in tropical forests. In the Democratic Republic of Congo (DRC), Grauer's gorillas (*Gorilla beringei graueri*) are continuously threatened through forest encroachment for agricultural expansion, human settlements, new refugee camps, illegal logging, and mining across the country. Moreover, poaching and bushmeat trafficking continuously threaten gorillas' existence. These drivers increase the proximity of humans and the risk of disease transmission. The emerging and existing zoonotic diseases, including Ebola, are continuously impacting gorillas' lives. All of these pressures combined are disrupting natural behavior patterns and are leading to the decline in the Grauer's gorillas' population. Therefore, this review scrutinizes findings on the anthropogenic pressures on the habitats and survival of Grauer's gorillas. Also, it is important to engage with people for the shared conservation role and ecotourism to support the conservation of forest biodiversity and Grauer's gorillas' habitats, particularly for the Maiko National Park in the DRC.

Keywords: habitat degradation; Grauer's gorillas; zoonotic diseases; deforestation; agriculture; national park; Democratic Republic of Congo

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1. Introduction

Establishing a harmonious relationship among humans, nature and wildlife is an important goal of national park establishment and conservation initiatives. Human activities continuously put biodiversity under pressure, adversely affecting the balance of forest ecosystems and wildlife habitats. At the same time, anthropogenic activities increase the chances for human-wildlife interaction [1,2]. Anthropogenic pressure involves human activities such as farming, overgrazing, mining, bush burning, hunting, poaching, and timber harvest that impact the environment [3]. Habitat disturbance and modification are among the main threats to the wildlife population in tropical forests [4,5]. In addition, habitat pressures may lead to changes in species ecology and behavior. For instance, it was predicted that more than 90% of African great ape habitats will experience moderate to high impacts by 2030 as a result of anthropogenic actions [6]. As a consequence, the lowland eastern gorilla (*Gorilla beringei graueri* syn. Grauer's gorillas) remains one of the most critically endangered gorilla subspecies [7,8].

The Grauer's gorillas are distinct in their current population size, trends, and distribution range. In the early 1990s, Maiko Grauer's gorillas population numbered barely 250 individuals [9]. Worse still, field studies on Grauer's gorillas have predicted up to a 90% population drop in the last two decades due to anthropogenic pressures and habitat degradation [10]. Gorillas within the Democratic Republic of Congo (DRC) are continuously threatened in times of peace and war. New roads have been opened across the forests;

forests are cleared for agriculture and livestock; new refugee camps, human settlements, illegal logging, and mines are established; poaching, bushmeat trafficking, and disease epidemics put pressure on gorillas' habitat and existence. Collectively, diseases and poaching contribute to about 90% of gorilla deaths in some areas in Africa [11]. Over the last 25 years, diseases and poaching have contributed to more than a 60% decline in Grauer's gorillas population [12,13]. The Grauer's gorillas are sensitive to hunting pressure even at low levels because they have an extremely low reproductive rate, with females giving first birth at a mean age of 9.99 years and continuing to reproduce at an interbirth interval mean of 4.09 years [14]. At the same time, half of the protected habitats have been severely affected by Ebola epidemics [15].

Since the 1990s, gorillas have been and are still severely affected by human activities in the DRC. Over the years, the conservation of forests and Grauer's gorillas has been carried out in a context of violence and economic fragility due to continued political instability and civil war. This also complicates the development of studies and conservation initiatives. As a result, gorillas are constantly poached, and their habitats are cleared [16]. In the DRC, agriculture is mainly subsistence, and forests are continuously encroached and cleared to access fertile agricultural land. Also, most households rely on firewood and charcoal as their main energy source for heating and cooking [17]. Unsustainably, local people cut forest trees for charcoal and firewood, and the protected areas are often their immediate source of trees [18,19]. Furthermore, climate change events, including extreme weather, droughts, floods, increasing global temperatures, and wildfires, negatively impact Grauer's gorillas and their habitats.

Indeed, more information is required to link and create awareness of the effects of anthropogenic activities on gorillas and their habitats. Therefore, this review presents the effect of the anthropogenic pressures on the survival and habitats of Grauer's gorillas that may contribute to improved awareness to support the conservation of forest biodiversity and Grauer's gorillas' habitats, particularly in the vicinity of the Maiko National Park (MNP) in the DRC.

2. A Global Perspective of Anthropogenic Pressure on Deforestation and Habitat Loss

The pressure on the forests is the result of wealth and poverty in the neighboring community and region [20,21]. The anthropogenic pressures on the forest and wildlife habitats result in environmental degradation, expansion of agricultural production areas, overgrazing, deforestation, destruction of the ecosystems, water shortage, and contamination of water sources, which are exacerbated by climate change. This is because the local and indigenous population around the forest depends on subsistence agriculture, wild animal products, honey and timber, and traditional medicine sources for their livelihoods and economy [22–24]. At the same time, the growing urban population requires more resources to sustain living standards. Most resources utilized in urban settings, including meat, palm oil, coffee, soybeans, and chocolate, are produced from large plantations on the edge of the encroached and cleared forest [25]. Therefore, forests are under pressure from several perspectives.

Interestingly, while local people need wood for heating in a traditional sustainable manner, the middle class and wealthier people in the urban cities need and utilize more resources in terms of timber, charcoal, and food, to mention a few. The growing human population in the regions of global rain forests in the DRC, Madagascar, Indonesia, and Brazil (the Amazon) has resulted in increased demand for natural resources, food, and non-food commodities, and the market pressure from industries, which significantly drives deforestation and habitat loss [22–24]. The anthropogenic pressures faced by each of these four countries include agricultural activities and farm expansion, illegal logging, mining, hunting, poaching, and local and international trade demands for food and non-food commodities such as tropical timber [26,27]. Evidently, illegal mining for precious gems or rare metals is widespread across the Amazon in Brazil, Indonesia, Madagascar, and the DRC forests [27]. Mining significantly contributes to habitat destruction, fragmentation,

deforestation, and pollution of surface and groundwater. At the same time, it stimulates human migration, illegal logging and settlements in the forest, poaching, and construction of access roads, as well as railways clearing the forest [22,28]. Not only are roads and railways constructed to facilitate human connectivity, but they also facilitate poaching, cause habitat fragmentation, promote pollution, and alter forest microclimate near the roads or railways [19,23,27]. For instance, roadkill of various animal species was reported along the road in the Amazon forests region of Ecuador [29]. Mining and access roads may affect wildlife habitats, behavior, demography, and population dynamics.

Globally, agriculture remains a principal anthropogenic threat to deforestation and primate habitats. Forests are encroached and cleared for establishing large plantations, livestock farming, and ranching, which leads to deforestation and consequential habitat loss. The plantations only partially respond to demands at the cost of degrading natural forests, so as agriculture-driven deforestation [22,23]. In addition, establishing and managing the plantation requires opening new networks of roads in the forest, providing access to services, and workers burning the last trees to grow. For instance, in the Amazon forest, the shrubland is cleared at the expense of agricultural expansion, converted to pasture, and subsequently to soybean crop production or oil palm plantation [30,31]. In Indonesia, oil palm and timber plantations contribute about 40% of overall drivers for deforestation and wildlife habitat losses [32]. The deforestation rate is worsening in Madagascar, with almost 80% of its natural forest being lost largely due to the conversion of forest to agricultural land, the production of charcoal, and illegal logging of precious tropical trees [33]. Therefore, deforestation and habitat loss call for global attention and collective effort to mitigate the causes and sustainable use of forest resources.

3. Democratic Republic of Congo Unique Forest

The DRC is home to vast tropical forests that boast incredible ecological diversity. It constitutes two-thirds of the entire forest massif of the Congo Basin and forms the second-largest tropical forest in the world after the Amazon forests. The Congo Basin is the home to the world's second-largest rainforest, with approximately 240 million hectares of dense forest, and accounts for about 18% of the total tropical forest [34]. The Congo Basin forest houses about 400 species of mammals, more than 1000 bird species, and more than 10,000 plant species, including 3000 that are endemic to the region [35]. The DRC forest serves as a critical habitat for a wealth of fauna species, notably, Grauer's gorillas, the endangered eastern chimpanzee (*Pan troglodytes schweinfurthii*), and the endemic and endangered bonobo (*P. pansiscus*) [36,37]. The persistence of the DRC forest mass, and consequently its function of carbon sink and sequestration, could continuously be challenged by anthropogenic pressure and economic development if not managed sustainably [38,39]. The MNP is a priority site for conserving gorillas (Grauer's gorillas), biodiversity, and endemism in the DRC [40,41].

The MNP covers an area of 10,885 km^2 extending between Kisangani lowland forest in the eastern DRC and Bukavu bordering Rwanda (Figure 1). The park is located at 0°24′ S, 27°–28°30′ E, and at the elevation of 605 to 1033 m above sea level. Predominantly, it is covered with the lowland tropical forest, a succession of hills, valleys, and mountains. The MNP's endemic animals include the Grauer's gorillas, the Okapi, elephants, the Congo peacock, and Peafowl among several others. Also, the park contains aquatic life residing in the Oso and Lindi rivers. The MNP forest cover is rich in fauna, forest essences, and animal species that are regularly exploitable, making it the main source of food, traditional medicines, and income to sustain livelihoods across neighboring communities.

Several factors contributing to anthropogenic forest cover loss and degradation are mostly outside the rural setting complex [42]. They include increased population pressure and the scarcity of land, socio-economic factors including conflicts, wars, poaching, and new virgin arable land in the forests claimed by farmers. Agricultural and pastoral activities, overgrazing, poaching, and uncontrolled bushfires threaten to extinguish the biological diversity of forests and some of the protected areas in the MNP and the DRC [43,44].

The cutting of trees for firewood, charcoal production, and artisanal timber adds further stress on the gorillas' habitat, threatening the isolated Grauer's gorillas population in MNP [36]. Although natural and human factors influence anthropogenic pressures, they are exacerbated by a long period of regional socio-political crises and wars [45,46]. As a result of armed conflicts in the DRC, there has been enormous human displacements for decades, which aggravates the human-gorilla conflicts around the MNP.

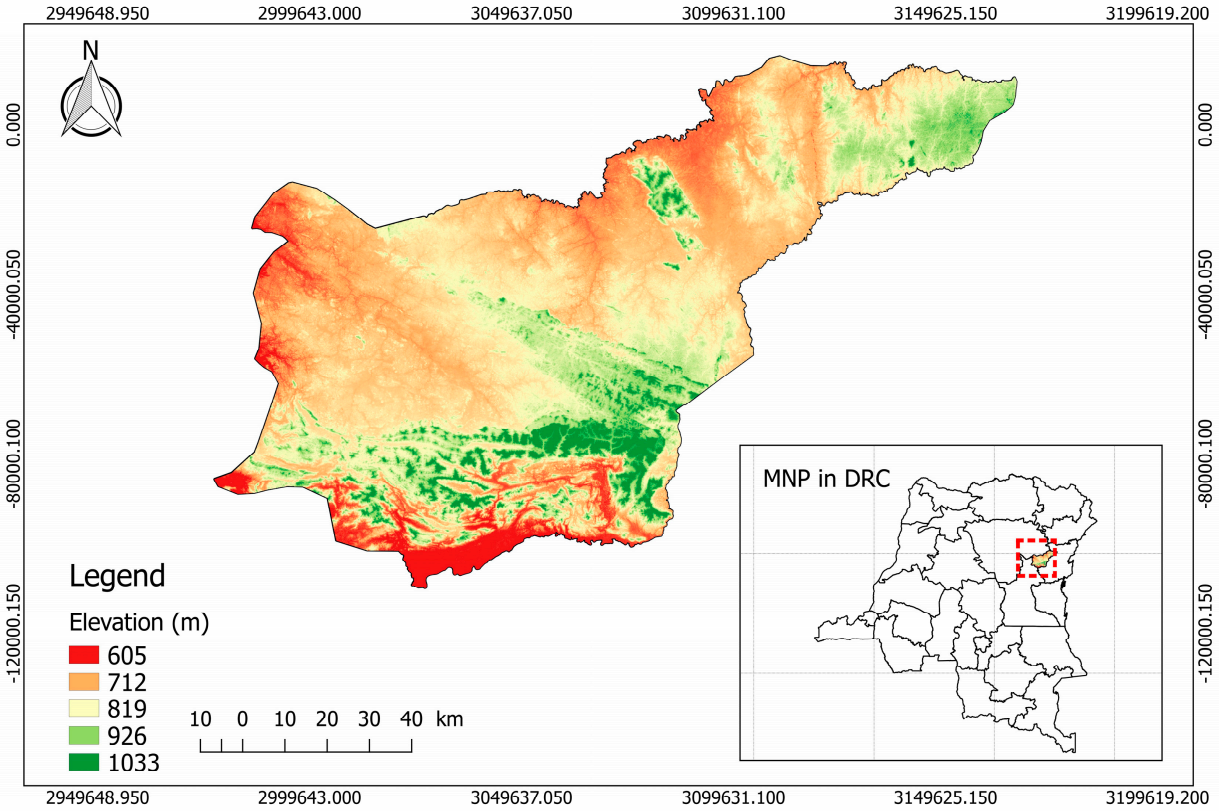

Figure 1. Maiko National Park map.

4. Human Population Growth Pressures on the Grauer's Gorillas

In the DRC, it was shown that forests shrunk by 32%, particularly in the mountainous forest [27,47]. Rural people depend heavily on forest resources for their survival and livelihood, especially with firewood and charcoal being used as the major energy source, greatly reducing and clearing forest resources [48,49]. The DRC is recognized as one of the world's most imperiled ecosystems and a global priority for conservation. Human population growth is concentrated in cities and towns along the forest lowlands, posing conservation challenges. Indeed, various species are already extinct or on the IUCN red list of extinction [36,50]. Unless urgent actions are taken, Grauer's gorillas may become extinct in the next decades, as illustrated in Figure 2. Moreover, studies have revealed that increased human population growth needs more land to live on, more buildings, and more services (hospitals, schools, supermarkets), and industries to sustain life [51]. As a consequence, forests are cleared for agricultural land, and expansion of some roadways among several projects. Population growth creates increasing concern about the effects of expanding towns and cities, which adversely impacts natural resources, forests, and forest products to meet development needs.

Despite their significance, Grauer's gorillas are likely more threatened by anthropogenic activities than any other class of primates [52]. For instance, the large tracts of forest home to the gorillas have been destroyed throughout the DRC, and the remaining forests are fragmented [36]. In recent decades, the country's rapid human population growth has significantly impacted biodiversity through the destruction and fragmentation

of gorilla habitats, overuse of natural resources, agriculture expansion, pollution, and urbanization [53,54]. Large-bodied, slow-breeding mammals like gorillas are more likely to disappear in severely disturbed areas than smaller and faster-reproducing species. For the Grauer's gorillas, survival prospects worsen, adult-adult playful interactions are reduced, and their sexual behaviors or affinity are affected by increasing human disturbances [55,56]. Because of that, the Grauer's gorilla population, numbers of sexually mature individuals, and geographic ranges have decreased [57]. In addition, it was predicted that thousands of species that support the ecology and survival of the Grauer's gorillas would disappear during the next few decades as influenced by increased disturbance from human activities [58]. Indeed, the population of Grauer's gorillas in the MNP is not spared. Given the severity of threats to the remaining population of Grauer's gorillas, our knowledge of the variables affecting their conservation status must be recorded and effective communication tools must be employed to strengthen conservation efforts among all stakeholders.

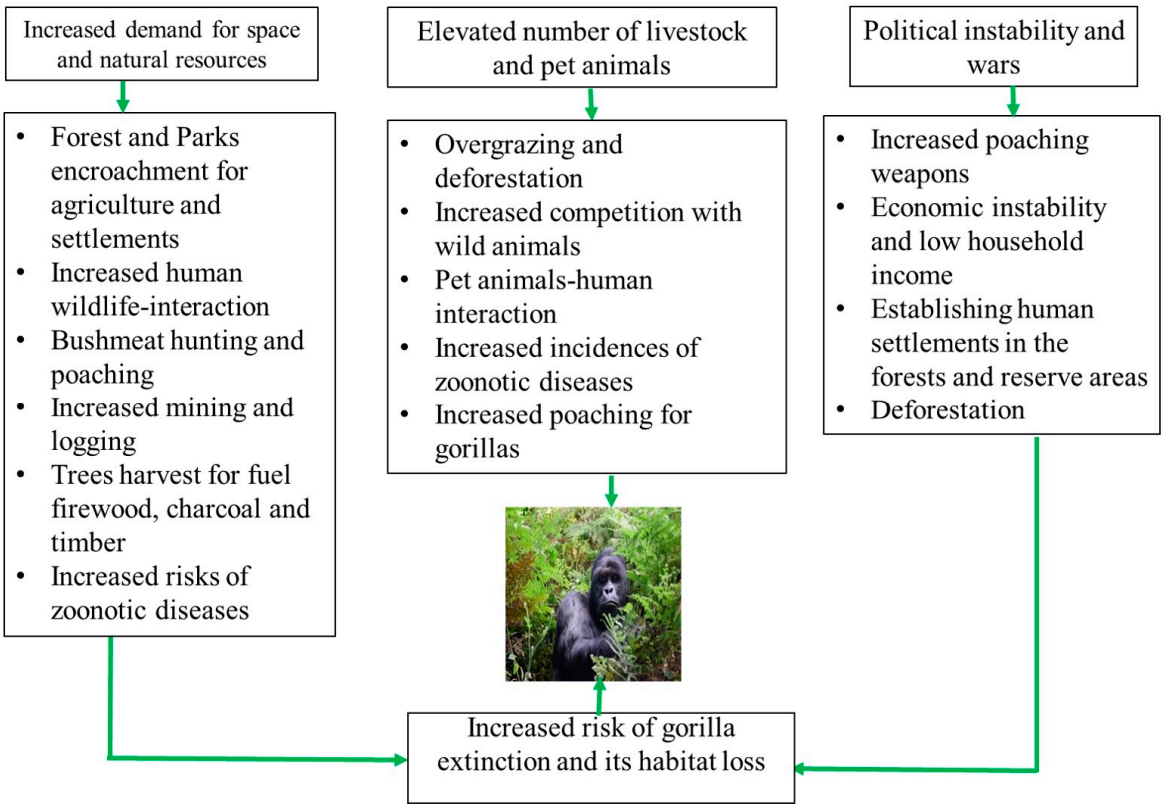

Figure 2. Schematic representation of the effects of anthropogenic activities on natural resources, forests, and gorillas habitats in the Democratic Republic of Congo.

Studies have shown that community attitude towards conservation depends on the efforts of both the surrounding communities and managers of the protected and conserved area. For instance, DRC has nine national parks; the most informed population hardly knows almost three protected areas [59]. It has been shown that most people display little or no interest in protected areas and forest landscapes [60]. This might be due to constant political instability, incidences of war, and the presence of armed groups. Also, the local population believes that the park promotes the looting of their natural resources, cultural wealth, and traditional knowledge [61,62]. With this in mind, not only demographic pressure but also abusive and irrational use of forest resources and gorillas' habitats increase pressure on the vulnerable Grauer's gorillas' population, further increasing deforestation pressure, poaching, and bushmeat trade activities, which worsen human-gorilla conflicts.

4.1. Deforestation Pressure on Gorillas

The Congo Basin is home to more than 20 million people whose livelihoods directly depend on forest resources [63]. The Congo Basin forests participate in global carbon storage and provide people and animals with what they need to survive. The rainforests, savanna, mountains, and active volcanoes of the Congo Basin provide food, water, and shelter to the unique fauna and humans that have coexisted for millennia. However, the forests are subjected to deforestation threats caused by myriad events.

The main causes of deforestation and Grauer's gorillas' habitat loss are the acquisition of forest land for subsistence agriculture and commercial plantation, overgrazing, illegal mining, the establishment of access roads, and the harvesting of trees for timber, charcoal, and firewood (Figure 3A,B). The facilitation of access roads to the forest not only increases the fragmentation of forests but also promotes commercial hunting, easy access by local communities, the establishment of refugee settlements, and the devastating incidences of fires, particularly during bush clearing and charcoal making. Although previously inaccessible areas were used for the hiding of poachers whose activities supported the lucrative bushmeat trade while seriously threatening wildlife, gorillas, and local communities [64,65]. Collectively, the pressures on the forest as well as on gorillas' habitat are contributed by both wealth and poverty in the region. Notably, a huge number of local people depend on low-productivity subsistence agriculture and collecting firewood or cutting trees for fuel. The urban middle-class population requires more resources produced on the edge of the forest, including meat, palm oil, coffee, soybeans, chocolate, timber, and fuel (charcoal), to mention a few. While forestry and plantations partially respond to these demands, they degrade natural forests, facilitate the opening of new networks of roads to the forest, and provide easy access by the farmers who clear and burn the last trees to grow [25,66]. These deforestation pressures are projected to increase over the next 20 to 30 years as a result of human demographic pressure, virtually nonexistent social development, unemployment, low incomes, and a lack of affordable alternative energy sources [67]. With more than 90% of the households in the DRC engaged in agriculture and the present population growing by 2–3% per year, the demand for cultivable land is increasing; the same goes for forestry processing and their products [68]. In addition, cutting down trees and clearing forests releases large amounts of greenhouse gases into the atmosphere, exacerbating global warming and climate change events [69]. Consequently, deforestation accounts for 18 to 25% of total anthropogenic greenhouse gas emissions globally [70].

Figure 3. *Cont.*

Figure 3. Anthropogenic pressure to gorillas and gorillas' habitat. (**A**) Illegal mining site in the park. (**B**) Forest encroachment and deforestation. (**C**) Spent remains of gun bullet cartridges.

4.2. Poaching

In the DRC, the survival of the Grauer's gorillas has been significantly impacted by civil wars and armed conflicts, which facilitate poaching and habitat loss [71,72]. Although hunting, killing, capturing, and consuming gorillas is illegal, the growing human population, widespread artisanal mining in remote areas, the destabilizing impacts of armed groups, and a general scarcity of domestic protein have created a high demand for bushmeat contributing to the high rate of poaching for gorillas [73,74]. Armed rebels residing in the forests increase the extent and intensity of poaching Grauer's gorillas [36]. For instance, twelve rangers, a driver, and four civilians lost their lives while on conservation roles following a rebel/armed group attack on 24 April 2020, within the forest range of lowland eastern gorillas (Grauer's gorillas) in the DRC [75]. It was not an isolated case; the number of employees who have died while on duty because of civil wars, rebel groups, and poachers in the last three decades is over 200, which account for about 10% of rangers within the protected forest in the DRC [76]. Also, tourism activities were halted over security concerns, and as a result, poaching was exacerbated.

At the same time, illegal miners have settled in the forest in search of valuable minerals such as gold, diamonds, and cobalt, contributing to deforestation and clearing the habitat of most wildlife [77]. They rely on bushmeat for their protein supplies, endangering the existence of Grauer's gorillas. Even fish, which were originally abundant in the river across the MNP, particularly the Oso and Lindi rivers to supplement for protein are scarce due to water pollution brought on by mining activities. Illegal miners working in the Grauer's gorillas' habitats admit to poaching gorillas, valuing them as relatively easy to hunt with

guns and providing large quantities of meat [44]. While the adults are killed for meat, the infant gorillas are captured. Attempts might be made to trade these orphan infants for exotic pets or zoo businesses in the black market [78–80]. For instance, on the 11th of September 2020, arrests were made following the seizure of more than 25 apes trafficked from the DRC to Zimbabwe [76]. These pressures have led to a decline in the population of these critically endangered Grauer's gorillas and disrupted their natural behavior patterns.

Moreover, increased human-gorilla interaction habituates gorillas to human presence, such that gorillas lose their fear to humans, attacking people working in the farm fields or collecting firewood near the forest or the protected park reserves. At the same time, the gorillas expose themselves to the risks of capture or killing by the poachers [1,2]. Overall, poaching remains a threat to gorillas' existence in the DRC.

4.3. Bushmeat Trade

In the DRC, subsistence hunting of bushmeat is one of the main threats to Grauer's gorillas' survival. Hunting for bushmeat is generally a cultural norm, and bushmeat is nutritionally important to the DRC community [81,82]. The community eats a lot of bushmeat, which also provides for their income. Different snares and guns are used to capture and kill gorillas. Also, spent remains of gun cartridges are frequently found in the park (Figure 3C). The impact of poaching for bushmeat is worsening and spreading rapidly following increasing accessibility, even in the most remote areas, because of emerging markets for bushmeat in the urban areas [82,83]. In the MNP, it is estimated that about 5% of the Grauer's gorillas population is killed each year by poachers for bushmeat [84]. This level of harvesting is unsustainable for an animal with a slow reproductive rate, such as the gorilla [85]. Female Grauer's gorillas are capable of giving first birth at around 10 years of age and have an infant on average every four years [86]. During her lifetime, a female gorilla can have up to eight offspring with 75% survival to maturity. This makes gorillas more vulnerable to anthropogenic pressures.

4.4. Other Form of Direct Threats to Grauer's Gorillas

In the past, gorillas were killed for their heads, hands, and feet, which were sold to collectors for traditional use [83]. This usage probably arose from the interest shown by expatriates in gorilla remains sold in traditional medicine stalls [87]. Also, gorillas were sold to zoos, researchers, and people who wanted them as pets. These practices have continued until recently, either as a side product of the bushmeat trade or a capture for pet businesses [78–80]. The abduction of young gorillas usually involves the loss of at least two adult gorillas as members of a group fight to the death to protect their infants. A mortality rate of 80% has been observed in confiscated infant gorillas as they are very sensitive to post-traumatic stress and poor nutrition [87]. These losses have multiplier effects as each infant gorilla that survives when it reaches a zoo or sanctuary represents a loss of 15 gorillas to the population (5 × 2 adults, four dead gorilla infants, and one alive) [88].

Climate Change

Climate influences ecological systems and characteristics, human settlement, health, and economies, which impacts biodiversity. Climate change involves long-term alteration of temperatures and weather patterns in a place. It includes increased global temperatures and warming, extreme floods and drought events, as well as increased frequency and intensity of wildfire incidences [89]. At the same time, anthropogenic activities contribute to climate change, thus causing concern for gorilla survival [90]. Changes that drive deforestation and vegetation shift may render unfavorable consequences and long-term variability of the gorilla habitat. Climate change is predicted to impact the DRC forests, including the MNP and montane forests, which are key habitats for gorillas [91,92]. Almost all montane forests in the eastern highlands are now destroyed, and the land has been converted to agriculture, supporting some of the highest human population densities in

Africa's Great Lake region [93,94]. These actions subject gorillas, particularly the Grauer's gorillas, to travel long distances searching for food, altering their feeding preferences and variability within their native habitat [95]. Climate change continues to be a serious threat to Grauer's gorillas at present and in the future because Grauer's gorillas have a small population size, long generation time, low reproductive rate, and relatively low genetic variability, which limit their ability to adapt to a changing climate [37,96]. For instance, the increasing temperatures due to climate change have subjected gorillas to an increased rate of drinking water [95]. The study by Carvalho et al. [97], revealed temperature as the most explainable variable for Grauer's gorillas' range. Moreover, Grauer's gorillas were predicted to lose three-quarters of their range under climate change scenario and anthropogenic pressure by 2050 [97].

In and around the MNP and the DRC forests, climate change indicators were revealed to include rising temperatures, prolonged dry season, decreased precipitation, and strong seasonal moisture deficit, which negatively impacts gorillas' behavior and habitats [98,99]. Also, climate change affects the gorillas' habitat and lives through degraded natural vegetation due to decreased rainfall and prolonged dry periods. Therefore, climate-informed conservation initiatives for gorillas are suggested, which may include initiatives to improve people's livelihoods surrounding the forests and MNP to adapt to climate change and contain human population pressure, as described in previous sections.

5. Human-Gorilla Interaction and Zoonotic Diseases

Zoonotic diseases are a threat to wildlife animals and global public health systems. Zoonotic diseases are specifically a concern for wild apes, which have shown vulnerability to human pathogens and diseases [100,101]. The number of clinically relevant pathogens that affect wild great apes may also affect humans and vice versa [101]. At the same time, the threat of disease transmission between wildlife, domestic animals, nature, and people is predicted to increase following a continuing growth of the human population and subsequent land-use change, deforestation, hunting, bushmeat trade, and increased field research on apes among other driving opportunities for disease pullover [102,103].

The world is enduring a tragic example in the COVID-19 pandemic, which might have been caused by a virus believed to originate from wildlife hunted or consumed by people. Less appreciated is the fact that these same drivers lead to an increased risk of disease transmission from humans to wildlife [104,105]. This is particularly evident in great apes, human's closest relatives, which share susceptibility to most pathogens and diseases. Numerous examples of gorilla morbidity and mortality are likely caused by infection of human pathogens [106]. For instance, the population of gorillas that are frequently in contact with humans shows high vulnerability to respiratory infection and displays clinical signs like sneezing, coughing, running nose, and open-mouth breathing [107,108]. Gorillas are among the closest cousins of humans and share a 98.3% similarity in their genome [109]. Therefore, transmissible human-gorilla diseases are easily shared through the air, water, green vegetation, fruits, direct contact with animal or bushmeat, and/or oral routes. For instance, the deadly Ebola virus model of transmission is through direct contact with body fluids [105]. Bushmeat consumption accelerates human-gorilla interaction, thus facilitating transmission as well as infestation of high-mortality zoonotic diseases such as Ebola and respiratory diseases [110]. Interestingly, gorillas-human disease transmission not only contributes to the extinction of gorillas but also affects spiritual taboos and traditional beliefs connecting indigenous people to their nature. This has continuously resulted in devastating outbreaks of diseases both in human and gorillas around the DRC forests, particularly Ebola virus which emerges frequently.

The Maiko region's population relies on basic amenities like drinking water, which flows from natural springs and rivers in the forest [111]. Local people are forced to drink the river water and for other domestic uses because there are no well-established and well-protected water sources in the area. This condition explains why numerous water-borne diseases, including cholera, typhoid, bilharzia (*Schistosomiasis*), and amoebiasis,

are frequently reported in the community residing by the MNP and rivers shared with gorillas [112].

Ebola and Other Deadly Epidemics

Epidemics pose a potentially devastating threat to Grauer's gorillas. They are affected by many parasites and diseases, including Ebola, common cold virus, pneumonia, smallpox, chickenpox, tuberculosis, measles, rubella, and yellow fever [102]. This is not surprising, considering that respiratory infections are the primary cause of morbidity and mortality in gorillas in most settings [102,113]. Of note, viruses that are relatively benign in human can cause lethal outbreaks in ape populations, indicating poor host adaptation and a lack of resistance in apes [102]. Although not irrefutable, there is reasonable evidence that airborne virus transmission can occur between infected human and Grauer's gorillas. This is particularly true for adenoviruses and metapneumovirus [102].

As demonstrated during the COVID-19 global pandemic, low-income households are more vulnerable, leading to an increase in wildlife poaching, among which many flagship species, such as Grauer's gorillas are killed for consumption, to generate revenue, or for traditional medicinal practices [114]. With COVID-19, both government monitoring and the presence of people such as researchers or fieldworkers in remote areas used to buffers for poaching and other activities have declined in the forests [115]. Also, during and after the COVID-19 pandemic, the tourism industry once considered a means to safeguard wildlife, was enormously affected. However, the anthroponotic transmission events are generally not conclusive because studies detecting pathogens simultaneously in wild great ape and human population-sharing habitats are scarce, and there are limited molecular data at the genotype level, essential to ascertain the occurrence and directionality of zoonotic transmission events. Table 1 shows some selected pathogen lists infesting both human and gorillas.

Table 1. Some of the reported zoonotic diseases affecting both gorillas and human.

Pathogenic or Disease Agent	Affects Human	Affects Gorillas	References
Virus			
Ebola virus	Yes	Yes	[105]
Monkeypox	Yes	Plausible host	[116,117]
Human metapneumovirus (HMPV)	Yes	Yes	[118]
Severe Acute Respiratory Syndrome (SARS) *coronavirus*	Yes	Unknown	[119]
Bacteria			
Campylobacter spp.	Yes	Yes	[120]
Escherichia coli	Yes	Yes	[121]
Klebsiella pneumoniae	Yes	Yes	[122]
Salmonella spp.	Yes	Yes	[123]
Shigella spp.	Yes	Yes	[100]
Streptococcus pneumoniae	Yes	Yes	[122]
Treponema pallidum pertenue	Yes	Yes	[124]
Parasites (microeukaryote)			
Cryptosporidium spp.	Yes	Yes	[125]
Cryptosporidium meleagridis	Yes	Yes	[126]
Cryptosporidium muris	Yes	Yes	[126]
Cryptosporidium parvum	Yes	Yes	[127]
Giardia duodenalis	Yes	Yes	[128]
Plasmodium ovale walikeri	Yes	Yes	[129]
Parasites (*Helminths*)			

Table 1. *Cont.*

Pathogenic or Disease Agent	Affects Human	Affects Gorillas	References
Capillaria hepatica	Yes	Yes	[106]
Necator americanus	Yes	Yes	[130]
Parasites (*Arthropods*)			
Sarcoptes scabiei	Yes	Yes	[131]

Several Ebola outbreaks have killed a number of gorillas in the DRC. Ebola hemorrhagic fever, a fatal disease in humans, can kill about 80% of infected individuals. This virus has an even higher mortality rate, from 95% to 99%, in gorillas [132,133]. Evidently, it was estimated that the Ebola virus had killed a third of the gorilla population in the DRC, while the species continue to remain at risk [105]. Overall, the Ebola virus disease is a concern in the DRC, Uganda, and spans the borders of Rwanda's forest landscape, which is the home to one of the two species of the endangered lowland eastern gorilla [95]. This region has experienced frequent Ebola virus disease outbreaks, with 14 outbreaks occurring in the DRC since the virus was first reported in the country [105].

In addition, the first monkeypox virus (MPXV) a zoonotic disease transmission outbreak in human was reported in 1996–1997 in the DRC through respiratory droplets and direct contact with infected individuals [116,134]. In May 2022, the MPXV re-emerged in multiple countries, with no evidence of the epidemiological link between reported cases with humans and gorillas as incidental hosts, and about 250 confirmed human monkeypox cases have been reported globally [117].

6. Mitigation Strategies to Contain Human-Gorilla Interaction

Several factors may help ameliorate the impacts of growing anthropogenic pressures on Grauer's gorillas in and around the MNP, as presented in the subsequent subsections.

6.1. Improved Governance and Poverty Alleviation

Good governance would help reduce poverty, improve food security, and contribute sustainably to managing wildlife and forests. Improved governance and poverty reduction are correlated with the reduction of some conservation threats, such as the poaching of gorillas [53]. There is a need to improve nearby community livelihoods by ensuring local households constitute key beneficiaries of conservation interventions for the sustainability of the MNP. Strengthening the village-level engagements with ecology and conservation projects is also necessary. Imposing project ideas on the communities, however viable, may appear less participatory and not productive. Another important aspect that can improve the outcomes of the conservation benefit-sharing schemes is the development and implementation of robust monitoring and evaluation mechanism to ensure community engagement and support are regularly evaluated and communicated. Moreover, relevant stakeholders and beneficiaries should be involved in the development of the monitoring and evaluation framework to harmoniously maintain and safeguard biodiversity and indigenous knowledge to sustainably conserve the gorilla's habitats.

6.1.1. Improving the Economic Status of MNP and Benefit-Sharing Systems for Local People

Adequate political and economic support for conservation projects and initiatives is required to make funds available to improve park infrastructures, employment opportunities, and tangible benefit-sharing systems for local communities [22]. This forms a positive start towards establishing the park's operational and financial needs as well as complete management initiatives to engage local communities. The local communities should be engaged in taking responsibilities to ensure more effective management of Grauer's gorillas and their habitats. Thus, the MNP strategic plan can include actions to work in collaboration with the government to improve the infrastructures and services access to the community

and the region, which were previously suggested as the motivating factors for communities to value conservation initiatives [93,94]. The design of management plans and policies may guide the quality and effectiveness of benefit-sharing systems. For instance, there is a chance for economic empowerment to shift to an alternative source of cooking energy, such as gases or electricity, and to constantly shift the household's reliance on forest resources for firewood and charcoal. On the other hand, while engaging local communities, an inclusive approach is important, such that marginalized groups also benefit from the conservation initiatives [135]. Therefore, a strategic plan for the preserved MNP and forest may include initiatives to review and amend co-management agreements with local people. Possible amendments may include implementing management actions and identifying how benefits will be managed and shared, developing a feedback mechanism to monitor the distribution of financial funds to the neighboring villages, and developing an educational campaign to improve awareness of the impacts of deforestation and poaching in villages bordering the MNP reserves in collaboration with other stakeholders. Nevertheless, poverty alleviation around the MNP is fundamental and could help to reduce the exploitation of forest resources and Grauer's gorillas' habitats, improve agricultural productivity, and provide people with financial means to value biodiversity and their co-existence around the MNP.

6.1.2. Building Common Ground and Generating Shared Conservation Values and Vision

Safeguarding and valuing indigenous people's knowledge, land, languages, and culture have been suggested to represent the greatest chance to preserve forests and prevent the extinction of wild primates [136]. In addition, wildlife authorities need to re-assess their definition of the term "poaching", for instance, defining the differences between subsistence-based activities and large-scale consumptive use by working with researchers to assess the ecological impacts of harvesting activities before denouncing them as poaching. In another context, the participatory nature of the indigenous community allows informants to openly discuss issues that they deem important, resulting in the co-production of new knowledge for the conservation of Grauer's gorillas and the MNP, which emerged because of spiritual interaction with the environment and its resources [137]. The co-production of knowledge is a dynamic process. It is contingent upon validated and adapted information to changing circumstances to establish relationships among indigenous people as co-producers of relevant indigenous knowledge towards conservation and sustainable use of forest and environment resources [138]. In turn, habitat-specific taboos also demonstrate the development of indigenous people's conservation ethics for managing natural resources and safeguarding biodiversity [136]. These values can be aligned with Grauer's gorillas' conservation values and open avenues for common goals between indigenous communities and conservationists. Indeed, when indigenous communities observe that their values are realized and reflected through the governance framework, it builds trust, legitimacy, and the foundation for collective conservation efforts. Anthropologists may serve a similar role in building organizations for awareness creation to link local knowledge to achieve conservation goals for Grauer's gorillas. Formal incorporation of the species-specific taboo into government policies to curtail lethal control measures would serve a dual purpose, protecting Grauer's gorillas, and preserving local values and knowledge (Figure 4). Conservationists should engage with local people landowners, traditional authorities, and other community opinion leaders to identify the biodiversity value of respective sites and explore local interest in the established sites as formal conservation areas [36]. Overall, shared goals enable conservationists and local communities to redefine themselves as belonging to the same group for biodiversity conservation [139].

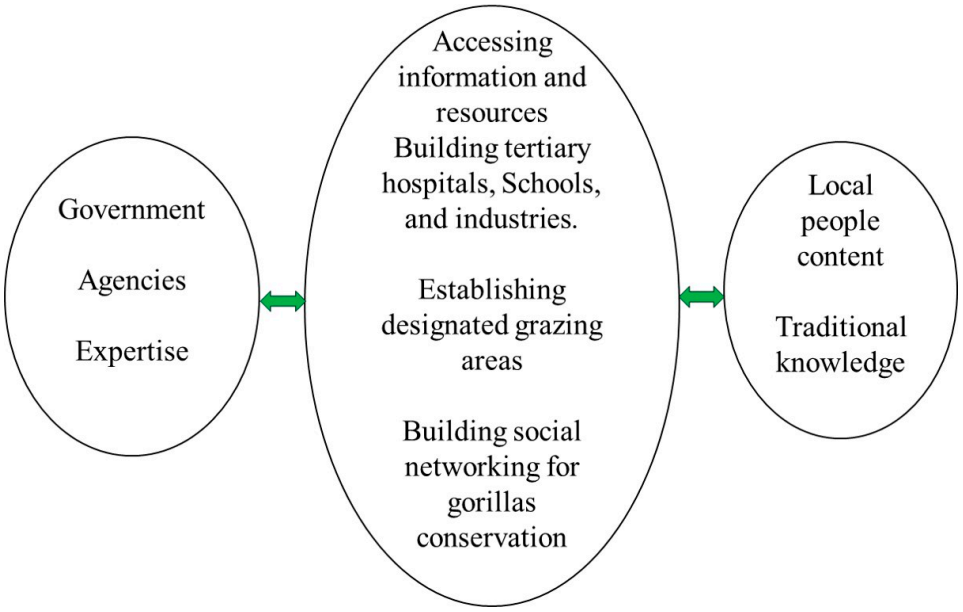

Figure 4. The role of bridging organizations and traditional knowledge in co-management of natural resources and forest conservation.

6.2. Gorillas and Their Habitats as Resources for Sustainable Development

Natural habitats and wildlife offer a wide range of global services that are far more valuable, both financial and non-financial, than the benefits of direct, destructive consumption of forest products [140]. However, forests continue to be destroyed due to the lack of conservation incentives for indigenous communities and local households. If the carbon sink market develops further, paying for ecosystem services in terms of fighting climate change seems like a promising forest conservation path not to be missed in the DRC for the MNP in particular and Grauer's gorillas conservation [141,142]. Also, planting and establishing new forests with natural vegetation rather than exotic trees to sustain gorillas' existence and maintain biodiversity can attract inclusiveness.

The degradation of nature could potentially be followed by a Green Anthropocene, a period where human influence remains pervasive but where people prioritize nature conservation and adopt adequate mechanisms to avoid consistent loss of biodiversity. Thus, achieving co-existence and improving prospects for ecological restoration. While we envisage a brighter future for biodiversity, the full consequences of human impacts on nature may take hundreds or even thousands of years to manifest. Attaining the Green Anthropocene will require extraordinary efforts to raise agricultural productivity and yields in the DRC and reduce forest encroachment and bush clearing. Such achievements may require great strides by the Congolese and the United Nations institutions, international cooperations, and targeted financial support for ecology and conservation projects, as reviewed by Reuter [143]. Thus, policy decisions undertaken now and in the next 20–50 years will determine what will be left in terms of Grauer's gorillas and the DRC forests for future generations.

6.3. Improving Communication between MNP and Local Communities

The first step in the process towards indigenous people and community participation is to improve communication between stakeholders. Co-management agreements involve sharing power and responsibility between the government and local people. Co-management agreements increase local people's sense of justice, equity, and empowerment [144]. Power-sharing is made more equitable through state legitimization and official agreement arrangements between government and resource users [144]. The public decision-making processes are guaranteed to reflect local values and cultural norms, and locals are given the authority to access and have an impact on management choices that

promote the survival of Grauer's gorillas and protect their habitats, selecting an impartial third party to enhance stakeholder engagement and communication [145,146]. A role for community engagement personnel should be made available to act as a contact for outside inquiries and to facilitate educational and awareness programs on behalf of the MNP. Over time, improved communication may lead to greater community involvement, decrease conflicts, and facilitate effective conservation management for Grauer's gorillas and their habitats, as reported by previous studies [2,143]. Therefore, sustaining the MNP forest, Grauer's gorillas, and the overall ecosystem while addressing local people's concerns is paramount.

6.4. Ecotourism

Ecotourism is a form of tourism inspired by the natural history of an area, including its indigenous people's knowledge and enjoying local culture in native settings while conserving the ecosystem [147]. It is central to socially capable tourism, self-improvement, and ecological sustainability and takes full accountability for its current and future economy while addressing the needs of tourists, the industry, the environment, and host communities. Moreover, the eco-tourist uses wildlife and natural resources sparingly and makes voluntary or financial contributions to the region they visit to directly support the locals' economic well-being and the site's protection and indigenous communities [148]. Ecotourism is one of the fastest-growing industries in the world and has been widely used to generate resources for conservation [149]. When well-thought, it can be one of the best ways to involve local people in conservation activities and to share with them the income directly related to the presence of gorillas. However, this sector remains largely underdeveloped in the Grauer's gorillas range states. For instance, the model of gorilla vision tourism in Rwanda and Uganda can be adapted for the MNP and the DRC to preserve Grauer's gorillas and their habitats in undeveloped native forms [150]. However, the potential for ecotourism may vary considerably across the range of gorilla habitats. In addition, other available ecotourism opportunities suggested to preserve gorillas and forests should be sought to preserve MNP Grauer's gorillas' habitats and their existence.

7. Conclusions

For the survival, vitality, and productivity of *gorilla beringei graueri* (Grauer's gorillas), the DRC tropical forests must be safeguarded from the cracks and encroachment by the modern man that extensively exploits them to the last tree. Rainforests are essential for storing water, preventing soil erosion, habitats of wild animals, particularly the gorillas, and a home of myriad biodiversity. The Congo Basin tropical forests are among the most effective living resources for carbon sink, which helps contain climate change events. However, anthropogenic activities, including agriculture, established plantations, human settlements, illegal logging, mining, poaching, bushmeat business, and forest harvesting for tropical timber, charcoal, and firewood, constantly affect the forest reserves and Grauer's gorillas' habitats, specifically in the Maiko National Park.

Bringing everything together, the difficulties of protecting the endangered Grauer's gorillas and the forests in Maiko National Park calls for global attention. Preserving the biodiversity of these forests and the natural and cultural assets is important to maintain the ecosystem and Grauer's gorillas' existence. Lastly, more studies on Grauer's gorillas zoonotic diseases are suggested to prevent and contain associated pandemics, such as the case of Ebola viruses.

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