

Research Article

Major Anthropogenic Interactions Determining the Conservation Status of Endemic Mammals of Eastern Africa

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Africa, as a continent of diversity, harbors many cosmopolitan and endemic mammals, 17 of the world's 20 orders of terrestrial mammals. The Horn of Africa alone harbors nearly 220 mammalian species, including many threatened species. Mammals, particularly endemics ones, are threatened by anthropogenic challenges impacting their abundance, the number of reproductive individuals, and geographic ranges. Human population, in Eastern Africa, has been growing fast, and political and civil unrest aggravate human impacts on the environment. In particular, this study focused on identifying factors that are influencing the conservation status of endemic mammals of Eastern Africa using a multinomial logistic regression model. Agricultural expansion and deforestation threatened vulnerable (AOR: 2.650, $p < 0.05$) and critically endangered species (AOR: 4.763, $p < 0.05$) more than any other factors. Habitat loss persists as a major factor when critically endangered species (AOR: 3.520, $p < 0.05$) are compared to near threatened species. Collectively, threatened species are mainly impacted by habitat loss (AOR: 2.678, $p < 0.05$), agricultural expansion, and deforestation (AOR: 2.376, $p < 0.05$). In the next 50 years, threats to biodiversity are likely to grow as human populations increase. There is no a generalized global model to measure the intensity of agricultural expansion, habitat loss, hunting, and human settlement in the protected areas. Attempts should be made to develop conservation strategies that aim to articulate an array of several conservation threats together across space and time.

1. Introduction

Africa as a continent of environmental diversity enables it to harbor many species of mammals, including endemic mammals [1, 2]. The altitudinal range sea level is over 5000 m, [3] and the diversity of vegetation includes deserts, rainforests, woodlands, bushlands, shrublands, grasslands, alpine heathlands and grasslands, and swamps [1, 2]. Out of the world's 20 orders of terrestrial mammals, 17 live in Africa, which is more than any other continents' mammalian order composition [2, 4]. The region is particularly noted for the impressive array of large herbivores that occur in big numbers on the savannas of Central, Eastern, and Southern Africa [5]. All regions of the continent have a distinctive character of mammalian endemism, but the mountains of Eastern

Africa (EA) are exceptionally rich in endemic mammals [6, 7].

We are living in an era of unprecedented loss of biodiversity [8]. Mammals, despite their importance, are threatened by anthropogenic changes perhaps more than any other class of organisms [9]. Throughout the continent, extensive areas of forest that harbor several mammals have been destroyed, and much of the forest that remains is degraded and fragmented. Fast human populations growth in the regions of Eastern Africa [10] has dramatically and greatly impacted the biodiversity in recent decades through wildlife habitat degradation, fragmentation and loss, exploitation of natural resources, agricultural expansion, pollution, and urban expansion [11, 12]. As a result, the abundance, the number of reproductively mature individuals, and geographic ranges of many species of mammals

have declined [13], including endemics [14, 15]. Hence, it seems appropriate that our knowledge of each species and the factors affecting their conservation status are recorded now because the next few decades will see even more human-induced changes. The most optimistic projections forecast the decline and loss of several thousand species over the next few decades [16]. Therefore, we believe that immediate concern should be given to endemic mammals of Eastern Africa where the human population has been growing fast and political and civil unrest aggravated as compared to other regions of Africa. In particular, this study focused to identify factors that are affecting the conservation status of endemic mammals of EA.

2. Materials and Methods

2.1. Study Area. The study region is within 12.5 N to 12.5 S and 25 E to 42.5 E, representing the whole of Eastern Africa (Djibouti, DR Congo, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Uganda, and some parts of Tanzania) including the Horn (Figure 1).

2.2. Data Source and Type. A list of all endemic mammalian species of all sizes in EA, their conservation status, and cause of threatened status was developed from data gathered by assessing books, guides for mammals, scientific journal articles, reviews, theses, PhD dissertations, short communications, and global and regional reports published from 1877 to 2020 EC. These were identified from searches on the science databases Web of Science, Science Direct, Scopus, and Google Scholar. Some old references were gotten through personal communication and cross-references. Search terms including “endemic,” “mammals,” “threats,” “conservation,” “Eastern Africa,” “Djibouti,” “DR Congo,” “Eritrea,” “Ethiopia,” “Kenya,” “Sudan,” “South Sudan,” “Uganda,” and “Tanzania” with some phrases such as “population status” and “conservation threats” were used in an initial screening that took place from January to June 2021.

First, 879 scientific publications were identified from different databases and with different combinations of the search terms and phrases. Second, duplicated entries, indices, and retracted publications were removed and the titles and abstracts of the remaining 671 publications were screened. The publications that did not include at least one case of endemic species of mammals of EA were rejected, which resulted in 443 publications. Third, we read through the full texts of 443 publications to examine whether they were eligible to provide the necessary data and other 94 publications were excluded. Finally, 349 publications (Supplementary Materials) were selected as secondary data sources using a basic criterion of having information about geographical locations, endemism status, conservation threats, population status, and classification of endemic mammals of EA.

Based on the IUCN red list category format (<http://www.iucnredlist.org>), the conservation status of species was ranked into six categories (CR, critically endangered; EN,

endangered; VU, vulnerable; NT, near threatened; LC, least concern; DD, data deficient). The species' name is given using binomial nomenclature including authorship.

Our main goal is to expose current conservation threats that all endemic mammals of EA face to other researchers, conservationists, and concerned government bodies to take appropriate measures before the time is already late. Among all the threats identified, the most determinant ones are identified using the appropriate statistical tests as major threats to the endemic fauna of the region.

2.2.1. Variables of the Study. The dependent variable in this study was the conservation status of the endemic mammals (IUCN), which is dichotomous as least concern, near threatened, critically endangered, endangered, vulnerable, and data deficient. We form another dependent variable, “threatened,” by combining critically endangered, endangered, and vulnerable status to identify the cumulative determinant factors that distinguish threatened species from the rest of the other categories. The explanatory variables used in this study were agricultural expansion and deforestation, political and civil unrest, data deficient, disease, habitat loss, habitat fragmentation, hunting, hybridization, limited distribution, no threat, and finally, human settlement and infrastructure.

2.3. Data Analysis. A multinomial logistic regression model was fitted to the response and was used to identify the determinant threats that affect the conservation status of endemic species of mammals of the Eastern Africa region. Multinomial logistic regression is used where the response variable is composed of more than two levels or categories (IUCN categories). It does not assume linearity between the independent and dependent variables. However, it requires that observations be independent and that the independent variables be linearly related to the logit of the dependent [17]. While selecting explanatory variables, we only assume that conservation status of mammals is a direct effect or predicted output of those variables. In other cases, the explanatory variables might be covariates or effect of certain variables such as human population. An essential feature of the multinomial logit model is that it estimates $k-1$ models, where k is the number of levels of the outcome variable. Let π_j denote the multinomial probability of an observation falling in the j^{th} category; to find the relationship between this probability and the p explanatory variables, $x_1, x_2, x_3, \dots, x_k$ of the multinomial logistic regression model then is [18]

$$\text{Logit}[P(Y = 1)] = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \dots + \beta_k x_k, \quad (1)$$

and the alternative formula, directly specifying $\pi(x)$, is

$$\pi(x) = \frac{\exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k)}{1 + \exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k)}. \quad (2)$$

The multinomial logistic regression procedure reports that the Pearson chi-square test and deviance, along with

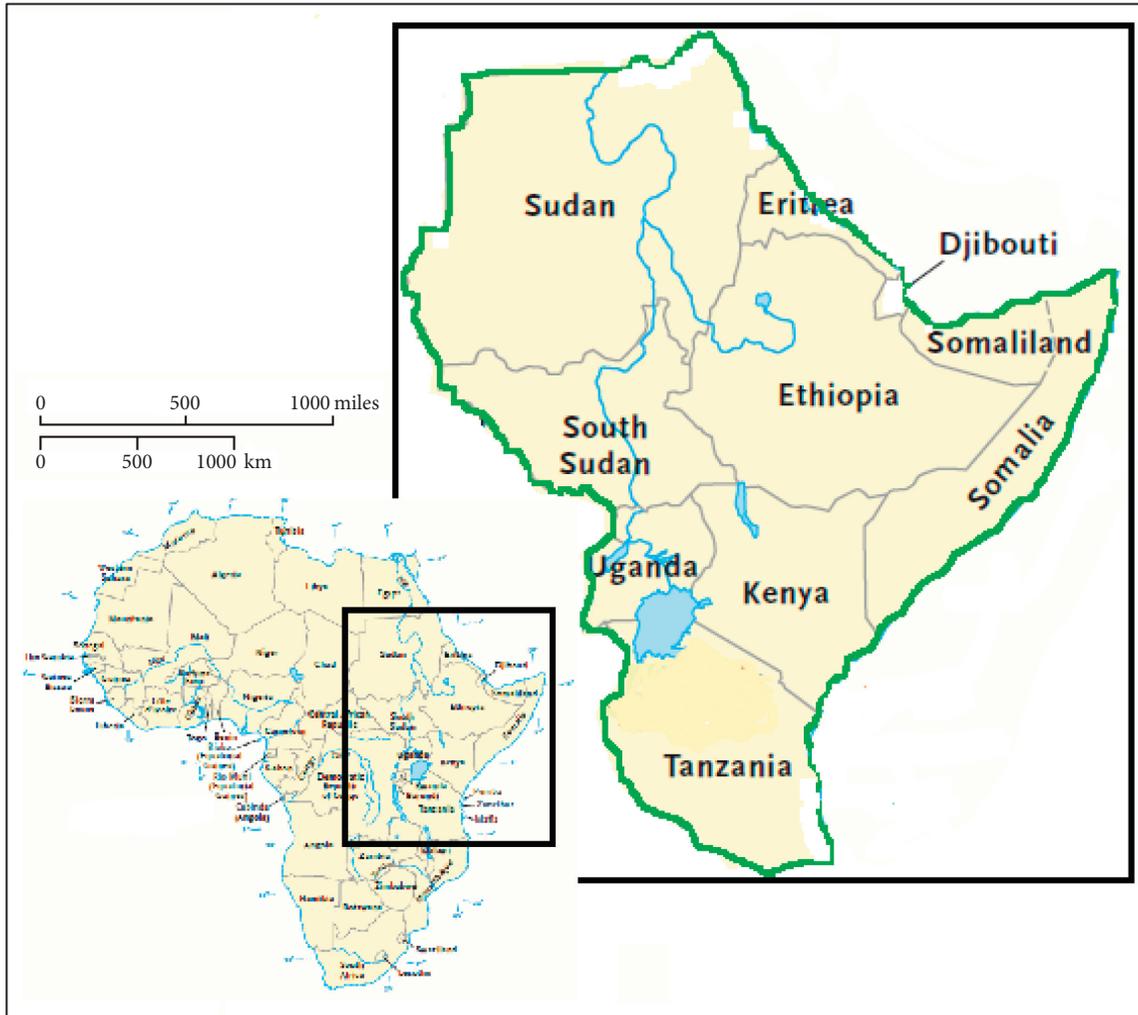


FIGURE 1: A geographical map for countries of Eastern Africa included in the present study.

their degrees of freedom, are used to test the goodness of fit of the models. If the null is true and the significance value is greater than the 0.05 significance level, the model adequately fits the data. The null is that the effect (independent variable) does not influence IUCN class of mammals in Eastern Africa.

Least concern and data deficient category is taken as a reference to compare the effect of each conservation threat on the threatened species relative to least concern and data deficient mammals. The least concern species are not a focus of conservation because there are large number of individuals in the wild and their habitat is at least moderately stable. Therefore, impacts of conservation threats on threatened mammals can be analyzed by comparing them to unthreatened mammals (least concern). The data deficient species are those without sufficient information on their status, however, with apparent conservation threats. We use this category as a reference to analyze whether they are close to threatened groups or least concern groups. Adjusted Odds Ratio (AOR) was tested to analyze how conservation threats (such as agricultural expansion and deforestation, habitat loss, habitat fragmentation, habitat loss, hunting,

hybridization, and limited distribution) affect the status of threatened mammals as compared the reference category. As the association of a particular threat and a current conservation status is determined as compared to the reference category, the other predictors are held constant. An odds ratio greater than 1 indicates that the conservation threat is more likely by the given value to affect the conservation status (IUCN class of mammals in Eastern Africa). The analyses were performed with Microsoft Excel and Windows-based SPSS 26.0 (SPSS, Chicago, USA).

3. Results

3.1. Identified Mammals and Their Classification. Through detailed assessment and review, we identified a total of 172 endemic mammal species that live only within a geographical range of EA. These mammals represent 11 orders, i.e., Rodentia (7 families), Cetartiodactyla (2 families), Chiroptera (7 families), Carnivora (3 families), Primates (4 families), Afrosoricida (1 family), Eulipotyphla (2 families), Perissodactyla (1 family), Macroscelidea (1 family), Lagomorpha (1 family), and Artiodactyla (2 families). The order

with most mammals is Rodentia with 77 species, followed by Eulipotyphla with 24 species, and Primates with 20 species. The most prominent families were Muridae with 67 species, Soricidae with 23 species, and Cercopithecidae with 15 species, cumulatively comprising 61% of all identified endemic mammals. Orders Pholidota, Sirenia, Proboscidea, and Tubulidentata were found to have no representative taxa of endemic species.

3.2. Conservation Status. Of the 172 species recorded, 9 (5.23%), 22 (12.8%), and 18 (10.46%) are of high conservation importance globally, categorized as critically endangered, endangered, vulnerable on the IUCN Red List, respectively. About 8 (4.65%) and 66 (38.37%) species are classified under the near threatened and least concern category, respectively. There is no enough conservation information about the 49 (28.49%) endemic mammals, categorized under data deficient. The Eastern African population comprises 31.15% of the total species of endemic mammals of the whole continent. A total of 239 (43.3%) endemic mammals of Africa are known to be threatened, of which 49 (28.5%) are from EA (Figure 2).

3.3. Conservation Threats. The results conclude that agricultural expansion ($n=34$), habitat loss ($n=13$), limited distribution ($n=30$), hunting ($n=26$), and deforestation ($n=24$) are the most prominent issues as high ranking threats in the study region. Almost all species face three or more conservation threats at a time except data deficient species. Last, threats that scored the lower frequency are climate change, urbanization, irrigation, noncommensal life form, drought, predation, and road construction within the protected area (Figure 3). Critically endangered species face thirteen major threats that increase the probability of extinction incidence. Habitat loss (71.4%), agricultural expansion (57.1%), and hunting (42.9%) are among those threats. They are also affected by diseases, limited distribution, and overgrazing (Figure 4).

3.4. Association and Determination of Factors Affecting the Conservation Status. The result showed a significant association between the conservation status of mammals and their abundance. Test of independences indicated that species rarity is an associated factor increasing chances of IUCN status and ultimately cause extinction (Pearson chi-square = 76.815, $p=0.0001$; likelihood ratio = 80.684, $p=0.000$). The two tests of the null hypothesis showed that the model adequately fitted the data (Pearson = 2.276, $p=0.810$; deviance = 3.069, $p=0.689$).

The odds of limited distribution for the near threatened and vulnerable species are about 2.346 and 3.263, respectively, more likely than the least concern category. Agricultural expansion and deforestation threatened the vulnerable (Adjusted Odds Ratio (AOR): 2.650) and critically endangered species (AOR: 4.763) more likely as compared to the least concern groups while keeping all other variables constant. The odds of hunting for vulnerable and

endangered species are about 3.910 and 5.463, respectively, more likely relative to the least concern category. And also, habitat loss was a determinant factor affecting the status of endangered (AOR: 2.242) and critically endangered species (AOR: 4.722). Habitat loss persists as a major factor when the critically endangered species (AOR: 3.520) are compared to the near threatened species (Table 1).

The goodness of fit tests showed that the model adequately fits the data (Pearson = 31.65, $p=0.87$; deviance = 37.12, $p=0.685$) which is estimated for threatened (collectively includes vulnerable, endangered, and critically endangered) and the near threatened species relative to least concern. The model was also fitted for the least concern and the data deficient categories relative to the threatened ones. Therefore, the odds of limited distribution for the near threatened and threatened species are about 7.128 and 2.718, respectively, more likely than the least concern category. Hunting had impacted the near threatened (AOR: 5.439) and threatened (AOR: 4.539) species as compared to the least concern species. Threatened species are mainly affected by habitat loss (AOR: 2.678), agricultural expansion, and deforestation (AOR: 2.376) (Table 2).

4. Discussion

A total of 136 endemic mammals with adequate data available are reported as threatened by about 33 conservation threats. The present assessment concluded that agricultural expansion, habitat loss, limited distribution, hunting, and deforestation are the most prominent issues threatening mammals in Eastern Africa. All endemic mammals under the IUCN conservation categories (CE, EN, and VU) are impacted by the above threats. Different publications also reported similar results that habitat alteration, habitat loss, hunting, and persecution have been a major obstruction to mammals' conservation [19]. Worldwide decline of biodiversity is reportedly associated with habitat loss and degradation that pose the most frequent direct threats to terrestrial mammals [20, 21], by decreasing the size of the area that a species can occupy, and therefore ultimately impacting their abundance [22]. Habitat loss also fragments ranges of several populations into small isolated patches. Globally, about 80% of all threatened terrestrial bird and mammal species are jeopardized by agricultural expansion and activities that drive lately habitat loss [19].

Mammals are also hunted for valued body parts that in turn pose a serious threat. Moreover, the consumption of bushmeat threatened many species and led to catastrophic declines of sub-Saharan mammals [23–26]. Because of the threats that they pose to humans and their livestock, large carnivores may also experience high mortality following human-wildlife conflict [27–29].

Near threatened mammals are also significantly impacted by agricultural expansion and hunting. Limited distribution was also a key factor determining their conservation status. Several studies concerning the fragmentation of geographical ranges among mammals, concluding that low habitat fragmentation correlates with larger range sizes, with a higher proportion of suitable habitat within

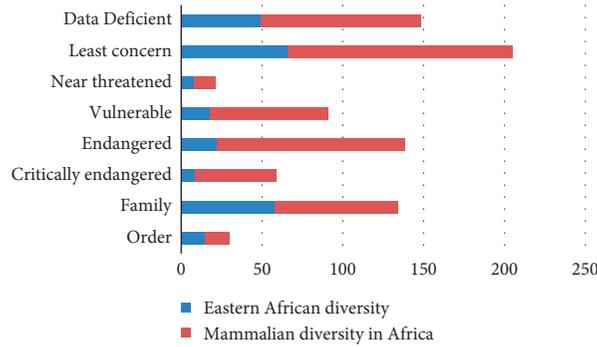


FIGURE 2: Comparison of proportion and conservation status of endemic mammals of EA to the whole African taxa.

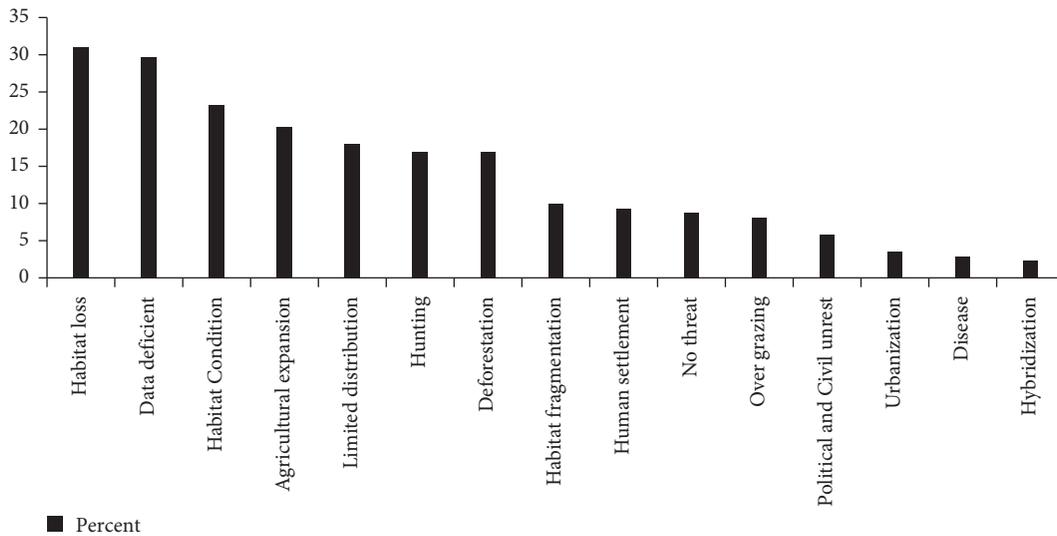


FIGURE 3: Ranked frequency of conservation threats that endemic mammals face across the regions of Eastern Africa.

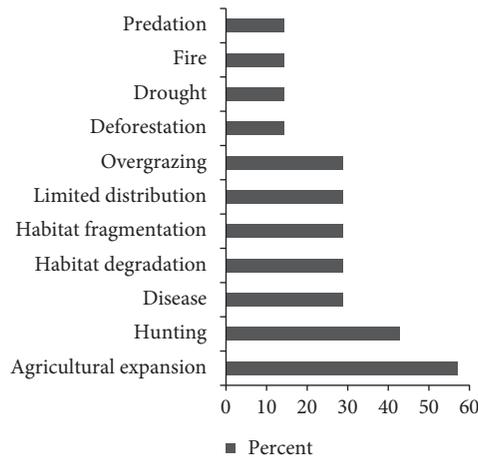


FIGURE 4: Ranked frequency of conservation threats that critically endangered (CR) endemic mammals face across the regions of Eastern Africa.

ranges, with higher spatial connectivity, and with lower species extinction risk. These studies suggest that threatened, restricted-range mammals may be more subjected to habitat loss and fragmentation than nonthreatened, large-ranged populations [30–35]. This result forecasts that many near

threatened mammals are likely to become threatened, inducing more burden to the current conservation efforts. This study’s results provide broad indications on the main causes of mammal decline in the region and can help provide clear focus for conservation strategies as to which pressures need

TABLE 1: Multinomial logistic model shows determinant factors of the conservation status of endemic mammals from the EA, taking least concern and then data deficient category as a reference.

Conservation status (IUCN)	Threats	Exp (β)	95% CI for exp (β) (LCI, UCI)	P value
Least concern (reference)				
Near threatened	Limited distribution	2.346	(2.125, 3.640)	$\leq 0.001^*$
	Agricultural expansion and deforestation	2.650	(1.142–6.149)	0.023*
Vulnerable	Hunting	3.910	(2.328, 6.245)	$\leq 0.001^*$
	Limited distribution	3.263	(2.315, 5.542)	$\leq 0.001^*$
Endangered	Habitat loss	2.242	(1.059, 4.745)	0.035*
	Hunting	5.463	(2.437, 7.245)	$\leq 0.001^*$
	Agricultural expansion and deforestation	4.763	(1.456, 5.585)	0.01*
Critically endangered	Habitat loss	4.722	(2.355, 5.301)	$\leq 0.001^*$
	Disease	2.560	(4.167, 6.256)	$\leq 0.001^*$
	Hunting	4.375	(2.191, 4.824)	0.011*
Near threatened (reference)				
Critically endangered	Habitat loss	3.520	(2.667, 5.846)	0.003*

*Significant at 0.05 alpha level. Exp (β), Adjusted Odds Ratio (AOR); CI for exp (β), confidence interval for the Adjusted Odds Ratio; LCI, low confidence interval; UCI, upper confidence interval).

TABLE 2: Multinomial logistic model shows determinant factors of the conservation status of endemic mammals from the EA, comparing all collectively threatened species, and near threatened species with the least concern species, and then comparing least concern and data deficient species with all threatened species to forecast future threats for unthreatened mammals.

Conservation status (IUCN)	Threats	Exp (β)	95% CI for exp (β) (LCI, UCI)	P value
Least concern (reference)				
Near threatened	Hunting	5.439	(1.249, 7.688)	0.024*
	Limited distribution	7.128	(5.348, 9.843)	$\leq 0.001^*$
	Agricultural expansion and deforestation	2.376	(1.287, 4.387)	0.006*
Threatened (vulnerable, endangered, and critically endangered)	Limited distribution	2.718	(2.064, 8.726)	0.004*
	Hunting	4.539	(3.798, 9.199)	$\leq 0.001^*$
	Habitat loss	2.678	(1.451, 4.940)	0.002*
Threatened (vulnerable, endangered, and critically endangered) (reference)				
	Agricultural expansion and deforestation	0.351	(0.194, 0.636)	$\leq 0.001^*$
Least concern	Hunting	0.171	(0.082, 0.355)	$\leq 0.001^*$
	Habitat loss	0.373	(0.202, 0.689)	$\leq 0.001^*$
	Agricultural expansion and deforestation	0.033	(0.008, 0.141)	$\leq 0.001^*$
Data deficient	Habitat loss	0.080	(0.027, 0.235)	$\leq 0.001^*$

*Significant at 0.05 alpha level. Exp (β), Adjusted Odds Ratio (AOR); CI for exp (β), confidence interval for the Adjusted Odds Ratio; LCI, lower confidence interval; UCI, upper confidence interval.

to be addressed in order to protect endemic mammals of the region.

Concerning mammalian population, several global assessments have been published within the past ten years that can contribute to a global mammal conservation strategy [22, 36–42]. According to these studies, between 21% and 36% of the mammals are reportedly threatened with extinction, due to human settlement and agricultural expansion (affecting 68% of mammal species), habitat loss (affecting 40%), and hunting (affecting 17%). In the present study, a multinomial logistic model also confirmed that the same threats are deeply affecting the conservation status of Eastern African mammals.

Several endemic mammals have been regarded as the potential umbrella for the conservation of many other native and widely distributed species, owing to their wide habitat

and spatial requirements [43]. Regions and conservation hotspots with high levels of endemism that are now experiencing habitat loss on a large scale will probably face increased extinction risks [44, 45]. Threats and extinction risks that are associated with human population density [46] and affecting the quality of habitat and the resources within the remaining patches of natural land that the species need in order to survive and reproduce [39] will grow worse. Between 2010 and 2060, the human population worldwide is projected to increase by 3.2 billion people [47, 48], and an increase of 1.7 billion people is expected to occur in sub-Saharan Africa. Population growth results in a growing demand for cropland and the destruction of habitat, fragmentation, and deforestation that are associated with it. This study shows that these will likely be the drivers of future extinction incidents. Escalating conservation action is

therefore crucial, not only by substantially increasing overall investment [49] but also by designing a strategic plan that such investment would be possible. This necessitates setting clear goals and priorities [50] and then making the best use of available data to maximize conservation impact with the limited available resources [51].

Several publications addressed the issue of mammalian conservation and its prioritization. Redford et al. [52] reviewed the criteria that have been used to value mammals. Many approaches propose that conserving mammals must be done from protected areas to matrix management, from preservation to sustainable use and from complete protection to triage, outlining the steps necessary to fill the gap between planning and action [53]. Mammal conservation strategy focuses on the requirements of species spatial data in terms of spatial coverage, bias, accuracy, scale, time relevance, reliability, biological significance, and availability [54]. This study suggests that the strategy focuses mainly on agricultural expansion, deforestation, and habitat loss. These threats will need to be addressed by conservation actions that, in addition to strengthening protected areas, also importantly include people. For instance, human-wildlife conflict management could help abate the pressure from hunting on predatory mammals. Matrix management and sustainable use can potentially address issues of fragmentation and help to create corridors between remaining patches of habitat.

5. Conclusions and Recommendations

Biodiversity is being eroded globally by human population growth which leads to agricultural expansion, habitat loss, and hunting. Biodiversity in the mammals of Eastern Africa is presently under threat from these same factors. In the next 50 years, threats to biodiversity are likely to grow as both human populations increase, and those threats to mammals are only measured in terms of the number of species affected, but no global model of the intensity of agricultural expansion, human settlement in the protected areas, hunting, and habitat loss exists. Attempts should be made to develop conservation strategies that aim to articulate an array of several conservation threats together across space and time. A lack of information on key factors driving pressures on mammal species has hampered the development of effective conservation strategies. This study has clearly highlighted key threats which can be included in conservation strategies for on and off-reserve conservation initiatives.

Conservation strategies can address specific threats with off-reserve conservation initiatives in order to reduce their impact on mammalian species. Conservation strategies that focus on protected areas and biodiversity hotspots to protect biodiversity from damaging human impacts should also be given full support. Eight ecological locations are classified as a biodiversity hotspot in Africa, and three of those are exclusive of EA that harbor a vast array of species. In addition to that, there are 43 protected areas in eastern [13]. It is crucial to document and monitor how effectively they are performing their role, particularly in relation to data deficient species that are of potential conservation concern. We

also recommend that a strategic approach is urgently needed to enhance the conservation value of data deficient assessments. Transparently prioritizing data deficient species for future study is likely to encourage additional stakeholders' participation, financial support, and protection for these regionally endemic species, thereby improving capacity to monitor changes in their population status, distribution, abundance, and ultimately set effective conservation priorities [55]. We believe that although all best efforts should be applied to reduce the risk of extinction by filling knowledge gaps of species distribution, status, threats, and conservation costs, data deficiency should not be used as an impediment that makes the existing global conservation progresses difficult [56].

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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